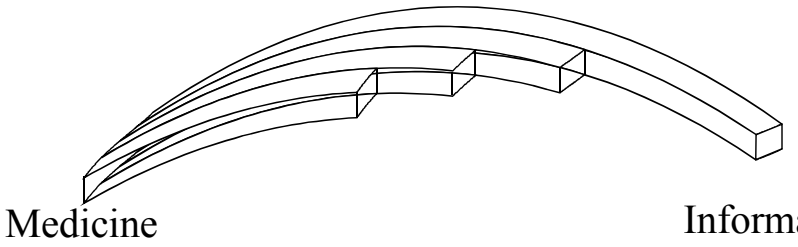
Dental Decision Making

EKKEHARD FINKEISSEN

DENTAL DECISION MAKING

A FOUNDATION FOR KNOWLEDGE-BASED SECOND OPINIONS AND DENTAL INFORMATICS

Dr. Ekkehard Finkeissen
Institute of Medical Biometry and Informatics
Department of Medical Informatics
University of Heidelberg



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PREFACE

A new scientific theory is, by experience, initially awarded much attention. Later, however, in routine use, it may not receive enough. Strong emphasis must, therefore, be placed on thoroughly planning the treatment planning methodology itself.

This applies both for human and machine-supported treatment planning. A comprehensive and conclusive model is necessary to solve the underlying problems involved. A model helps to point out unsolved problems during its development phase. Then, after reaching an acknowledged maturity, it enters general practice. During this course, theses serve to establish the truth of the model, even if they do not always directly serve truth itself.

The complexity of dental decision making has increased immensely due to the increased application of modern technologies during the last century. Among others, medical, biomechanical, technical, economical and information technology aspects are involved and must be given consideration. Additionally, dental medicine holds a special place in the medical field due to its manifold prosthetic constructions and technical aids.

Therefore, a systematic approach to describing relationships and conclusions, is needed, which is able to take different scientific positions into account equally. It has to be emphasized that the aspects of dental decision making are put into the foreground and informational models are seen as a consequence. For that reason, informaticists might be surprised that informational “foundations” of Dental Informatics are put into the last chapter.

Interactions between the sub-disciplines of the dental domain are described based on system and decision theory in order to derive at a normative sequence of decision making. An attempt to describe dental medicine in its detailed entirety would go far beyond the scope of this work. Selectively, therefore, an analytical approach serves to describe the underlying structures and procedures related to dental decision-making and Dental Informatics.

June, 2003 Ekkehard Finkeissen

Content Summary

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1 PROBLEM DESCRIPTION, GOALS AND METHODOLOGY

1.1 SUBJECT AND MOTIVATION

Despite the vast number of textbooks written to cover the various dental sub-disciplines, the dental treatment planning process has not yet been described comprehensively. To date, it can not be shown whether or not decision making processes are being followed strictly, because the knowledge in current literature is primarily presented as case collections[1]. An optimal use of the current knowledge is, therefore, limited to those experts able to keep an overview of the multitude of case collections available.

Since structural knowledge is more basic than detailed knowledge, it is of greater importance. Structural knowledge guides the user through the reasoning process involved in treatment planning[2]. It should be possible to obtain the required detailed knowledge during treatment based on the structural knowledge of the basic procedures captured during the treatment planning process.

[1] Partially structured approaches exist in dental medicine that have not yet, however, been combined systematically. Also, they would not cover dental treatment planning completely.

[2] A glossary has been included at the end of this document to prevent misunderstandings due to terminology usage. It serves logical understanding by clearly bringing out the relationships existing between the structures. A tooth, for example, is made up of a dental crown (or simply “crown”) and an abutment. Crowns and abutments can be natural or artificial. Therefore, crown replacement, for example, includes all prosthetic possibilities available to restore a dental crown. The terms were defined in such a way that certain treatment planning rules could be applied to natural and artificial structures. Nomenclatures, such as SNOMED, were deliberately not used to avoid discussions that do not have an underlying influence on the actual analysis.

However, detailed knowledge alone is not enough to draw conclusions about the structure of comprehensive treatment planning.

The dental sub-disciplines are often seen and discussed separately both in practice and education.[3] This leads to individual, discontiguous case collections, as well as to processing anamneses, diagnosing, and treatment planning for each discipline. A need to develop a comprehensive view of decision structures in dental medicine exists, which combines all of the sub-disciplines into an overall methodology. The work presented here does not claim to have better answers to all of the details of an actual treatment scenario than a well-trained dentist. Far from this, the presented analysis serves to point out relationships that can be systematized to better integrate detailed research and, therefore, provide patients a better quality dentition in the long run.

1.2 PROBLEM DESCRIPTION

"Code writing is not the problem
understanding the problem is the problem" [1]

The way the behavioral, social, and natural sciences see medicine must be comparable [2]. The views of, for example, a physicist, chemist, or biologist on the one hand, and the methodological practice of the “soft sciences” on the other, must be seen as positive complements of one another [3]. Although causal modeling always also includes faulty or incoherent causal concepts [2], it has the considerable advantage that its models are criticizable in the scientific sense. They do not necessarily represent general truths; however, they deliver the largest area for attack for finding errors. Therefore, they provide opportunity for systematic procedures, which can be used to further develop the domain. [4].

[3] Examples: conservative dental medicine, periodontics, dental surgery, implantology, orthodontics, oral surgery, prosthetics.

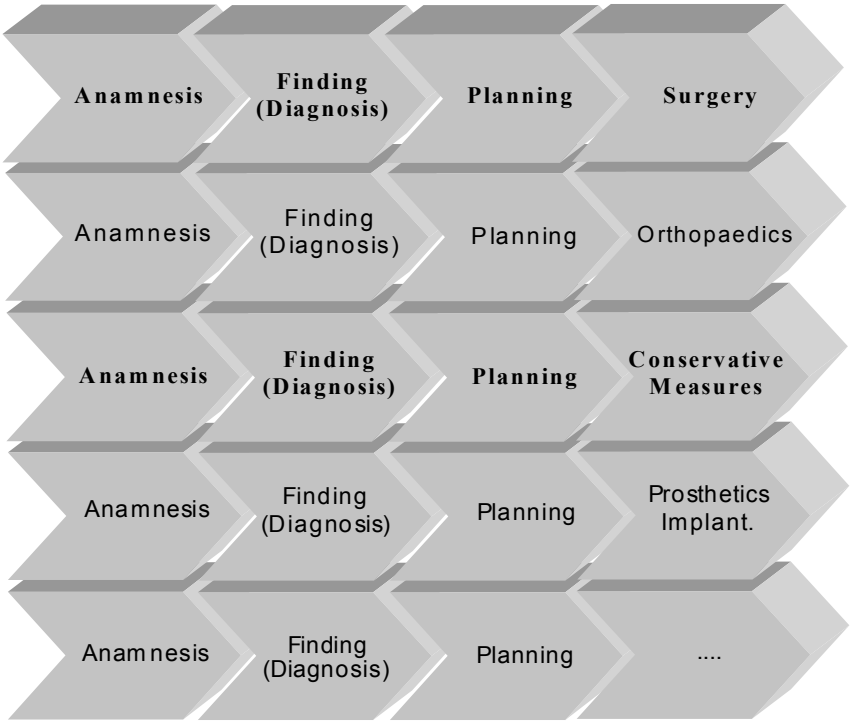

Figure 1: Strongly simplified representation of how treatment is currently initiated. A number of dental sub-disciplines are involved, and a multitude of relationships exist between them.

Currently, dentists are often guided through the dental treatment planning by experience-based comparisons to known cases. The groundwork for this individualistic mode of treatment is set during the dental studies period. During this time, the dental student learns to plan and conduct dental treatment under the guidance and supervision of a field expert. Atlases (e.g. [5-13]) and checklists for standard dental treatment (e.g. [14]) expand treatment knowledge based on tables, graphs, photos and sketches. Overall, this process aims at providing the dental student with a comprehensive volume of detailed knowledge, which covers the most frequent cases. Although dental study programs also place value on finding new and individual solutions, comprehensive treatment planning can not yet be spoken of today, since targeted treatment planning is not based on a strict overall methodology.

The treatment quality strongly depends on the experience of the dentist responsible for planning the treatment. This, from a quality management perspective, can be seen as a flaw. In accordance to Donabedian, therefore, focus should be placed on how structural, process and outcome quality can be attained during dental treatment [15]. Advantages of such a focus are not given only for

patients desiring comprehensive consultation, but also, by the fact that quality and cost efficiency can be derived them. This form of patient orientation is already being called for by many [16,17].

Dental experts responsible for conducting appraisals, for example, are demanding that dental work be based on acknowledged criteria. A need for a uniform methodology that allows case comparisons is evident [18].

The intent is not to restrict practicing dentists in their work. The full spectrum of dentally meaningful solutions remains open to them. Much more, dentists will be able to better protect themselves legally by consequently using an acknowledged treatment planning methodology. Structuring and standardizing decision making paths can help eliminate error sources through self-control by the practicing dentists and, thereby, help reduce treatment errors.

For this purpose, uniform reasoning, founded in scientific knowledge and sound models, is required (compare [4]). A neutral approach, capable of adequately representing the manifold aspects of treatment planning, must be taken toward developing a model for the dental treatment planning process.

Generally, treatment planning includes documenting the anamneses, current diagnoses, expected treatment results, concrete treatment alternatives, the means required for treatment, and the respective risk analyses. Since all measures must be coordinated, a strict formulation of their relationships is required, in an algorithmic form, to avoid inconsistencies. However, a comprehensive foundation for a strict derivation of the treatment plan does not yet exist. In addition, in an overall context, a detailed scientific foundation is not possible for planning all of the decisions required by patients, dentists, legal and health insurance agencies.

Yet, all of the currently available partial methodologies are lacking an overall concept of how information could be evaluated in view of the overall treatment plan. This conceptual deficit goes hand in hand with the constant increase in learning capacity requirements. Even if dentists possess a comprehensive, detailed dental knowledge, realization of the patient treatment is not automatically guaranteed. This applies especially in cases of complex treatment planning. Such cases require a clear definition of the treatment goals and, if necessary, a goal-oriented improvement of the dental structures – the teeth and their surrounding structures. This complexity is difficult to master by an

individual dentist. As a result, possible alternative treatment approaches are not being considered in everyday practice [19]. Also, the question of which measures could be left out to avoid iatrogenic damage is not always followed through consequently.

Socially active voices have suggested establishing information centers within dental board facilities for the purpose of obtaining second opinions. This would serve to improve treatment quality, despite the immense amounts of effort required. For instance, the patient would have to make a second dental appointment, which could be more expensive to the patient in terms of lost wages than the actual cost of the second opinion. In this case, a conceivable answer would be to offer dentists the opportunity of obtaining a second opinion via video conferencing. However, several general problems still surround second opinions:

Summary 1: General problems surrounding second opinions

1. The treating dentist may not necessarily notice that a second opinion is indicated for a case, since he either does not see the risk involved in the intended treatment, or he does not realize that an interesting treatment alternative is available.
2. It is not always clear which specialist is suited to give a second opinion in a certain case.
3. Even if such an expert has been found, it can not be sure that the expert is available at the required time.
4. Often, manual diagnostics are required that can not be delegated (e.g. palpation of the jaw joint or masticatory muscles).
5. The cost effort is immense.

In addition to the difficulties encountered by the dentists in their detailed search to oversee, conceive, and specify possible solutions, further difficulties arise when viewing the situation from the patient perspective. For instance, the transparency of each individual solution must be given, with all arising consequences, such as conservation of oral structures, function, aesthetics, and price among others.

It is difficult for patients to realistically judge the situation, because they lack the long-term dentition care experience required. Patients would, for instance, need to understand the effects of an offensive preventive strategy, including regular training in oral hygiene, establishment of a hygienic environment, as well as professional dental scaling. Also, the necessary degree of invasiveness of restorative treatment and its long-term effects are not always clear to neither the dentist nor the patient.

Identical pre-operative cases often receive fully different treatment recommendations. For example, a tooth has previously received endodontic treatment and now holds an older, expanded filling with quality deficits. These deficits do not, however, cause grave functional or aesthetic loss. The treatment recommendations in such a case may be:

- *Leave the restoration, no corrective action (possibly, however, initiate improvement of preventive treatment and the establishment of regular progress controls/monitoring).*
- *Leave the restoration, take corrective action (e.g. polish surface, remove projecting edges, correct marginal fractures with adhesive plastic filling material.)*
- *Partially replace the restoration by filling the visible cavity with plastic metallic or non-metallic material.*
- *Completely replace the restoration with plastic or metallic filling material (amalgam) following prior endodontic revision.*
- *Completely replace the restoration with plastic tooth-colored adhesive material (composite filling).*
- *Completely replace the restoration with a metallic inlay/onlay.*
- *Completely replace the restoration with a tooth-colored ceramic or composite inlay/onlay.*
- *Completely replace the restoration with a metal crown (partial or complete crown with pin construction, if necessary).*
- *Completely replace the restoration with a synthetic or ceramic veneer crown.*
- *Completely replace the restoration with a tooth-colored ceramic or composite crown (partial or complete crown).*
- *Extract tooth and leave gap.*

- *Extract tooth and minimize the gap by correcting the form of the adjacent teeth.*
- *Extract tooth and construct bridge (using diverse materials and combinations).*
- *Extract tooth and implant crown (using diverse materials and combinations).*

Each of the suggested treatments is an option. Selecting minimally invasive treatment measures – such as those that leave the restorations – increases the chance of conserving dentition health more than selecting strongly invasive treatment measures. A "neutral entity" should lay down the basis upon which selections are made, due to credibility [20]. The goal must be that practicing dentists base their treatment selections primarily on medically supported reasoning. Especially in light of quality management, the dentist should, ideally, receive a selection of consequently founded medical treatment options from which he can select the one best suited for an individual patient. For this purpose, a neutral entity is required to present impartial options to both the patient and dentist, based on current scientific knowledge and facts[21].

Decision structures in form of case-based decision trees have already been developed for some areas of dental medicine [22]. Checklists for dental students [14,23] also contain a selection of solutions for certain problem areas. These solutions, however, are not bound to a comprehensive, strict concept and, therefore, remain scattered.

To date, computer-based dental treatment planning has been limited to certain aspects of dental medicine. [24-30]. Although programs are available for designing dental prostheses, they are limited primarily to graphical tools that alarm the user of serious planning errors by using constraints [31-35].

Such systems offer solutions for certain problem areas without taking the overall dental problem area into consideration. It is not plausibly in which relationship the found solution stands in comparison to other patient-specific issues.

Dental medicine, therefore, lacks a decision making methodology that takes a synoptic view of the overall problem (compare synoptic dentistry [21],). Such a comprehensive methodology would not contribute to dental treatment directly. Rather, it would provide a solid basis for informing patients and providing legal security.

1.3 VISION AND OBJECTIVES

In the following, a dental decision model will be presented from which individual treatment decisions, guidelines, text books, multimedia documents, etc. can be derived. A part of the methodology will be specified in detail to show its benefits for daily use. The possibility of machine support will then be discussed.

A vision has been defined in order to keep the sub-goals in mind. Although it surely will never be realized in its idealized form, its formulation offers sufficient surface for critical argumentation and offers a stepping stone for a systematic analysis. As seen from this abstract view, new possibilities are opened which are organized and, in part, tested within the scope of this research work.

Definition 1: Vision of the overall system

The system takes over the entire patient treatment planning. It diagnoses and makes all necessary treatment decisions. It can handle all devices and takes care of all administrative tasks. It serves as a general and treatment-specific information medium. The system optimizes the communication between the participants and the devices required for treatment. It possesses the necessary knowledge and answers in a form suited to the purpose. Treatment planning is conducted in an objectively measurable way, whereby the patients' wishes are taken into consideration.

The term 'system' in Definition 1 does not refer to a computer system for overall dental treatment. In addition to the devices, it also includes dentists and their patients. This approach does not degrade people to machines. Rather, its purpose is to obtain a comprehensive view of the relationships involved, even though not all problems and questions can be formulated mathematically or logically. For this reason, the dentist, the patient, the dental assistants and other specialists and technicians must be included in the treatment process.

The following objectives serve to guide the way through further analysis:

Definition 2: Objectives

1. Description of the requirements placed on treatment goal criteria.

2. Description of the requirements placed on treatment alternatives.
3. Description of the medical requirements placed on the problem solving concepts of a treatment.
4. Description of the requirements placed on finding practical results.
5. Description of the requirements placed on treatment selection.
6. Description of the development of a problem solving algorithm.

An important goal is to show the limitations of a systematized second opinion. The relationship between the generalized decision methodology and an individual decision must be clarified, as well as in which situations the practicing dentist may disregard the methodology.

The effort of individual planning should be reduced to a minimum. Hereby, customizing the delivered information plays an important role in quickly gaining benefits from the methodology.

Delivering a comprehensive model for dental medicine in its entirety would go far beyond the scope of this research work. Therefore, focus is placed on describing the various decision levels from which further refinement can take place. The foundation of this work is not grounded solely on new knowledge, nor is its sole purpose to generate it. Rather, part of the available knowledge is to be structured in such a way that dental experts can identify with it, and can obtain a structured formulation of the relationships found in their daily practice work. For this reason, the inner model of this approach concentrates on a mechanical concept, and does not include the psychological issues surrounding the participants. This concept is not intended to limit the view to possible treatment alternatives, but rather to allow their initially rational and emotionless selection. This creates a space in which the dentist and the patient can then realize a rationally chosen preferred treatment.

To meet today's information processing demands, the discovered relationships are represented as an algorithm to allow the sequential processing of the particular problem area. The arising possibilities and problems will then be discussed at the end of this research work.

The quality of the overall methodology should generally meet the following requirements:

Definition 3: Solution requirements (compare [36])

- Functionality
- Objectivity
- Reliability

The economical aspects of dental decision making will be excluded from the inner model as explained below in detail.

1.4 SUMMARY OF THE INVESTIGATED PROBLEM AREAS

The questions investigated during the course of this research work are defined as follows:

Definition 4: Investigated problem areas

1. What are the tasks and goals of dental medicine?
2. Which dental treatment measures must be planned?
3. Which parts of the planning process can be structured?
4. How does the basic structure of a planning methodology look?
5. How can treatment planning be conducted with a minimal amount of effort?
6. Which part of the planning process can be implemented in software?

1.5 METHODOLOGY

According to Walther, quality must be generated where the decisions are made [19]. By partitioning the specialized knowledge, a better overview of the relationships involved should be achieved. The description of the relationships and their dependencies will offer a roadmap of the dental tasks involved. Upon this basis, fine-tuning can take place without overlooking the interactions with neighboring areas.

The developed overall model has been organized in accordance to decision theory and information technology methodologies to achieve a neutral and scientific representation. Beside a clear presentation of the secured knowledge, it is hoped that modeling the decision process will make knowledge gaps more apparent, and, thereby, point out future research requirements.

The methodology allows the formulation of knowledge, the identification of automatable components and the development of a preliminary knowledge based system. The foundation here for is a schema that depicts the basic processes involved in dental treatment planning and treatment.

This methodology centers around the thought that the dentist and patient are brought into a position in which they are able to make a professional treatment choice, as long as all of the necessary information is presented to them. Complete treatment planning is required for evaluating a proposed solution, because the advantages and disadvantages of a treatment can only be fully understood depending on the details of their specifications.

This work takes a goal-oriented treatment planning approach to guarantee that the developed treatment alternatives meet the determined goal criteria. The process of developing planning guidelines takes place backwards for reasons of practicality – beginning from the end of treatment back to the beginning. This complies with the view that each treatment step is a preparatory measure conducted to achieve a designated treatment goal. The actual treatment process for each treatment alternative can then be specified, including the material and scheduling requirements. The individual treatment alternatives should be based on the strictest generation methods possible to offer a neutral groundwork for dental decision making.

A targeted approach for dealing with the status of incomplete information is necessary to fulfill the general framework requirements of diagnosing. Since a dentist can not exactly comprehend a patient's situation, a methodology must, to a certain degree, be able to deal with the lacking information. The methodology should, for example, be able to deliver sensible results even when only a rough description of the situation is available. More so, a targeted request for the missing information should take place. Therefore, intermediate goals are defined for each planning step, the practicality of which is tested during treatment planning. In this sense, a step-wise backward planning can be spoken of, because the necessary requirements are planned and examined starting out from a desired overall goal.

Machine-based decision making and treatment can be only thought of after a solely medical formulation of the involved relationships. Which parts of a treatment can be automated well, poorly, or not all must be described. The

following steps allow a comprehensive approach to describing the processes involved:

Summary 2: Steps necessary for a comprehensive approach

1. Systematic structuring of dental knowledge.
2. Development of a targeted planning process. Dental treatment planning must take place in a backward order to dental treatment to meet the goal-orientation requirements. A goal-oriented planning process begins with the targeted state set for a functional and aesthetic dentition. The respective planning and treatment steps are seen as the required preparatory measures to meet the target state. Within this context, the developed methodology should generally be inclined toward dental conservation measures.

The model, primarily formulated in the language of dental medicine, serves as the basis for a design model, from which automated algorithms can be derived for some domain areas. This approach should allow for an open discourse, without hiding behind non-dental formalisms.

The derivation of dental meta-planning can not be proven formally, because a comprehensive, formal concept does not exist for the dental domain. Therefore, it does not make sense to formally describe the derivation of the structure of dental decision making itself. For, if the modeling process did stand in a formal relationship to the actual formal model, it would, in turn, be a part of the formal model itself. Hence, it must differ from the model and can be seen as a creative act of modeling.

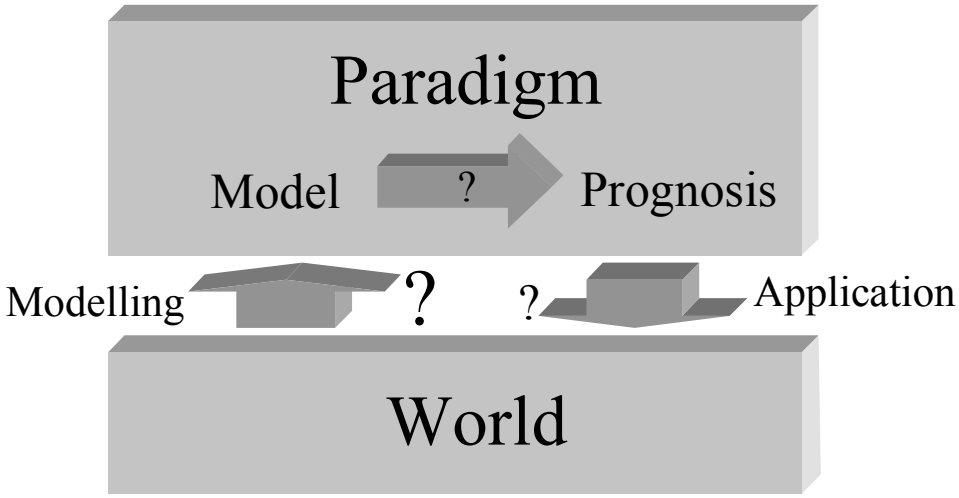

Figure 2: Modeling deals with representing a part of the world within a formal model. It, therefore, must be different from the actual model.

According to Simon, a decision process generally follows the steps: (a) define the problem, (b) generate treatment alternatives, and (c) make treatment decision (compare [37]). These steps fundamentally influence the design of this work:

Approach 1: Design steps

General dental:

1. Define the goal criteria of dental medicine.

Derived patient-specific :

2. Derive goal criteria for a specific patient.
3. Derive patient-specific treatment alternatives.
4. Derive treatment process for a specific treatment alternative.
5. Derive advantages and disadvantages of a specific treatment alternative.

Patient-specific results:

6. Select best-suited treatment alternative.

Technical goals:

7. Describe possibilities for automatic treatment planning.

Here, a strict separation between dental and financial aspects is necessary to avoid problems that have arisen in the medical area: the merging of these aspects, e.g. in ICD-10, can lead to an inadequate structuring of the domain knowledge and might result in difficulties during inference processes. Unfortunately, respective problems will mostly be blamed on informatitions, if

they are not able to build successful decision-support systems. In fact, this kind of problems arise from the underlying medical point of view and would make a change in the point of view of the domain experts necessary. Respective mistakes should be avoided in dentistry, especially as the dental domain does not emphasize the concept of a diagnosis, yet.

Diagnoses do appear in the following descriptions, however, they are deliberately kept out of the focal point. This is due to the nature of the definition of diagnoses, which is still imprecise and lacking in formality. In addition, solitude diagnoses neither adequately allow for the chaining of decision layers, nor the construction of complex constellations regarding geometry, mechanics, or microbiology. Rather, they have to be included into a comprehensive decision model to make inferences possible. From a current point of view, a diagnosis involves reducing complex cases to individual, generally independent, diseases. This stands in direct conflict to the set goals, especially the goal of presenting the *relationships* between individual dental problem areas.

A *static view* was chosen for analyzing the relationships of the stomatognathic system. Static, in this case, refers to the instantaneous nature of the planning. In other words, the patient does not change during the planning process. This represents a first approximation of the relationships as seen from the view of a discrete transformation between treatment situations, at respective instances in time. It is assumed, that the *dynamic aspects* of dental medicine can be brought into the methodology without requiring fundamental changes, since the actual structure of the decision process is defined less by dental medicine itself than by general decision theory, as will be shown in Chapter 2.4.

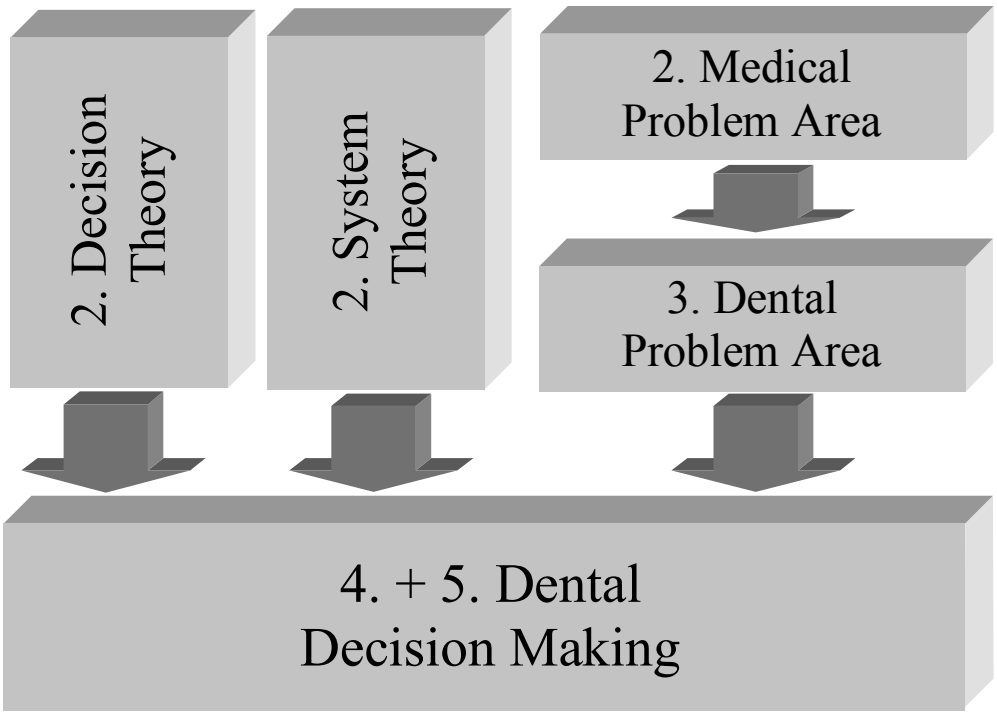

Figure 3: Approach of this work. System theory, decision theory, as well as medical and dental goals all flow into the decision methodology, and form its foundation. The numbers refers to the chapters of this work in which the respective topics are treated.

Definition 5: Quality benchmarks of this work

- The quality of the work presented here is measured by how well it helps the researching dentist to structure dental problem areas. Because the approach has not yet reached the stage of a routine system, its success should be measured by how well research questions can be derived from it.[4]
- The quality is measured by how well the realization of the methodology on a computer system is being prepared and, at least in parts, is proven. This should offer an improved foundation for discussion to further develop the methodology. An evaluation will to demonstrate the practical relevance of the approach.

[4] Medical vocabulary was deliberately used in most parts of this research work. This serves to enable and stimulate discussion primarily between (dental) specialists.

It is to be pointed out that certain topic areas may reappear at various locations of this work. This is due to the fact that several aspects of dental medicine are very complex and, in part, possess circular interactions that can only be presented linearly for the sake of clarity. At times, therefore, the impression may arise that the relationships have been strongly simplified. The true complexity becomes apparent at a different location, when the larger picture is shown. For this reason, we recommend the reader to initially gain a structural overview of this research work before beginning with its details.

2 GENERAL FOUNDATIONS

Dental medicine serves the purpose of solving problems patients have regarding the stomatognathic system, and to help prevent such problems in the future.

Sometimes, measures become necessary to improve the often unsatisfactory patient conditions in this regard. Treatment planning is unavoidable in order to know what must be done before realizing a treatment. It should follow objective criteria to allow an estimation of its quality[5].

This, in turn, calls for an objective decision structure. A comprehensive decision methodology is not yet available for dental medicine. The existing structure fragments and case studies can, however, be used to develop a coherent model that meets the required framework criteria.

To state the relationships in a scientific manner and introduce quality measures, a uniform methodology is required that, in principle, is independent of human emotions, ignorance, and forgetfulness. Puppe [38], advises a representation outside of the human mind in form of an expert system. This structure should be free of redundancies to allow the unique assignment of responsibilities.

Haux states that one of the main research areas of medical informatics is the creation of foundations for the understandable documentation of medical knowledge, and for knowledge-based decision support within medicine, whereby “the informed patient” holds a key position [36]. Since this directly confronts one with the underlying problem of the decision process, it is beneficial to make use of decision theory approaches [39].

Knowledge acquisition is of underlying importance in modeling these relationships. The possibilities and requirements of knowledge acquisition carry over to the model that is to be developed. Therefore, they also carry over to the

[5] Compare.: Quality of structure, process and outcome [15]; Quality assurance through recording the results [21].

decision process itself. A quick overview of dental, informatics, medical informatics, and economical aspects involved is given in the following sections.

2.1 MEDICAL AND DENTAL ASPECTS (MEDICINE)

In the following, dental medicine is seen as a medical domain. An analysis must, therefore, begin with the basics of medicine.

Based on the Hippocratic Oath, the Genfer (Ärzte-)Gelöbnis /Genevan (Physicians) Oath states that the utmost goal of medical treatment is the conservation and restoration of a patient's health. No differences should be made based on creed, nationality, race, party affiliation, or social position.

Because these statements are also part of the Code of Conduct for German Physicians (Musterberufsordnung deutscher Ärzte), an ideal methodology for the decision making process should be formulated uniformly, free of mental limitations and prejudices. In addition, an optimal treatment must be guaranteed to reach these goals. The following 10 points taken directly from the constitution of the World Health Organization, the WHO, describe the just mentioned aspects in more detail [40]:

The State Parties to this Constitution declare, in conformity with the Charter of the United Nations, that the following principles are basic to the happiness, harmonious relations and security of all peoples:

- *Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity.*
- *The enjoyment of the highest attainable standard of health is one of the fundamental rights of every human being without distinction of race, political belief, economic or social condition.*
- *The health of all peoples is fundamental to the attainment of peace and security and is dependent upon the fullest co-operation of individuals and States.*
- *The achievement of any State in the promotion and protection of health is of value to all.*
- *Unequal development in different countries in the promotion of health and control of disease, especially communicable disease, is a common danger.*

- *Healthy development of the child is of basic importance; the ability to live harmoniously in a changing total environment is essential to such development.*
- *The extension to all peoples of the benefits of medical, psychological and related knowledge is essential to the fullest attainment of health.*
- *Informed opinion and active co-operation on the part of the public are of the utmost importance in the improvement of the health of the people.*
- *Governments have a responsibility for the health of their peoples which can be fulfilled only by the provision of adequate health and social measures.*

Comprehensive sub-goals are required to implement these goals. As a result, costs accrue that increase with the scope of the treatment[6]. Therefore, it must be clarified how a credible concept for neutral decision making processes could look. This concept must find a balance between the highly set goals and a justifiable effort.

A meaningful approach to this seems to be to disregard the costs during the actual treatment planning process. In other words, conduct treatment planning based solely on medical criteria [41]. The expected costs and efforts can then be calculated after planning the possible treatment alternatives. This approach allows the presentation of the available qualitative and quantitative alternatives, followed by a neutral selection of an appropriate solution during the patient-dentist consultation[7]. This procedure secures an unbiased approach to treatment selection while meeting the requirement of limited effort.

The treatment planning methodology should cater to the treating physician as well as to the patient to ensure transparency and common understanding, as well as an optimal treatment selection [41].

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[6] An optimal treatment does not necessarily mean maximizing the cost of treatment. Yet, sadly, a tendency to select the most profitable treatment measures – for reasons of amortization – exists in part within the medical (and dental) field. Sometimes, however, an EEG can be as meaningful as an expensive CT examination.

[7] According to decision theory, the mutual quantification of treatment quality and costs is an individual factor and is difficult to generalize. Winning the lottery, for instance, strongly shifts this relationship, but it can not be integrated into a scientific decision model.

The necessity to find alternative medical decision structures does not stem from automated decision support. More so, it follows the demand for objectivity and communicability as such. Exactly these demands are why machines were invented (compare [41,42]).

Modeling dental decision structures

The information used to design the planning methodology described here stems from several different sources. As far as credit can explicitly be given any one source, this has been done in the reference section. It would be extremely difficult, however, to trace all of the relationships described here to a concrete source. The necessary structural knowledge required to develop the planning methodology can not be found in most text books or guidelines, since these sources treat actual planning problems in individual cases, not general planning structures as a whole. However, the form and content of the available media shall be described briefly.

The underlying structural knowledge used was taken from general economic and informatics theories. Hereby, extensively used and tried scientific foundations underlie the development of the dental treatment planning methodology. In other words, knowledge acquisition was performed by taking structured knowledge from other domains and fitting them into the terminology of the dental domain. Naturally, this also included testing whether the used hypothesis actually fit into the structure of the dental domain. Actual cases were used for this purpose. Therefore, the following is not a validation in the positivistic sense, but rather represents the non-existence of mistakes within a randomly selected set of sample cases.

The approach was tested in each stage of its development by using theoretical and actual cases to cover a broad spectrum of practically relevant cases. The discrepancies between actual and abstract cases on the one hand, and the system solution on the other, allowed drawing conclusions upon which necessary system adjustments were made.

The domain-specific structure and detailed knowledge approaches were laid and fortified during the educational study period of the dentists and physicians. Discussions made clear that physicians and dentists constantly compared current

cases with case collections stored in their minds. Rarely, did they use literature to find structures for solving common problems.

Summarizing case types can also be seen as an act of modeling. Although no concrete rules were set, a pre-structuring based on simple rules of thumb is, however, unavoidable to ensure a good cross-section of the vast amounts of cases within a justifiable amount of effort. In this way, rare cases could also be integrated, which might not have received consideration otherwise. Of course, no guarantee can be made in terms of completeness, since each new problem solution also represent a new, individual aspect.

Knowledge acquisition using biometry

Biometry is concerned with validating medical knowledge. It offers methods to support decision making during the treatment selection process.

Biometrical problems of interest [43,44]

- Validate medical facts.
- Develop and use measurement methods.
- Develop and use evaluation methods.
- Develop and use testing methods.

As described in Chapter 5, decision making processes are not made up solely of logically understandable decisions. Hazy criteria are also allowed, and necessary, during the evaluation of the generated treatment alternatives. An available biometric study can be integrated into the decision methodology, as long as it offers a scientific solution to an area of the overall problem area. Especially in regard to prognoses, biometrical methods represent important evaluation aids for individual treatment alternatives.

Knowledge representation in text books, journals and on electronic media

Comprehensive descriptions of problematic cases and problem-type solution approaches can be found in the available literature[8]. However, this type of

[8] A detailed description of the available literature can not be presented within the scope of this research work. However, an index of standard German dental text books is

fragmented knowledge can not assure a stringent argumentation for treatment planning.

During the initial planning phase, it became clear that the available text books argument on the basis of concrete cases, on a problem-oriented level. A similar situation exists within scientific journals and on electronic media. Most of the sources found were case-oriented. A process-oriented analysis was rarely conducted. If so, it took place only for certain, concrete problem areas. Therefore, a comprehensive description of decision structures and processes is still missing.

Guidelines and procedures

Guidelines have not yet reached the status of being a comprehensive planning aid. Rather, they provide practical support to dentists during treatment of individual cases. Their formulation centers around individual cases, which is not rated a scientific approach in the sense of comprehensive treatment planning. According to the work community of scientific medical specialty associations [45], the use of guidelines should provide answers to the following questions: (compare [46,47]):

Definition 6: Quality criteria for current guidelines [45]

- What is necessary?
- What is effective in individual cases?
- What is dispensable?
- What is obsolete?
- Which cases must be treated as in-patient cases?
- Which cases can be treated as out-patient cases?

The AWMF supports uniform, yet comprehensive, guidelines (checklists). On various group levels, work is currently being conducted to design mid and long-term guideline solutions. Three such group levels are:

presented in the appendix to provide some insight into the vast amounts of books available.

Definition 7: Path of guideline design [45]

1. Nominal group process: An expert group selects between 15 – 20 experts that then meet and design new, or improve current, guidelines during a two-day conference.
2. Consensus conference: The guideline is verified on the next higher level and the result is granted a higher priority of relevance.
3. Delphi conference: The guideline and open questions are sent to further field experts (approx. 50 – 100). The results are integrated and the guidelines then finalized.

The approach chosen here differs considerably from previous guidelines in that a fragmented view of the overall problem of dental medicine is avoided. More so, a comprehensive approach is to be found that integrates all sub-domains of dental medicine.

Directives differ from guidelines mainly in that they lay down a more stringent set of rules for a particular institution. They are legally binding for the respective institution and draw sanctions upon that institution in case they are not followed.

Current approaches for developing guidelines do not replace the need for a comprehensive decision structure from the medical perspective. Guidelines offer well-founded reasoning for handling specific situations, or a limited topic area. In some cases, medical, financial, and political aspects are intermingled to emphasize preference for socially financed treatment alternatives. As brought out above, a separate analysis of the medical alternatives and their funding is necessary from a scientific point of view. Therefore, to prevent biased action, guidelines are not used for knowledge acquisition here. In Chapter 6.3.3.2 possibilities of deriving guidelines from the inner decision model are shown.

Evidence-Based Dentistry (EBD)

Evidence-based dentistry (EBD) must be mentioned in connection with a decision foundation [48]. The purpose of EBD, in analogy to Evidence-based medicine (EBM), is to replace less well-founded knowledge with founded knowledge regarding the use of therapeutic and diagnostic measures in practice. Since EBD is still in its beginning stages, it can not yet be finally described

which methodic or scientific evidence stages should realistically be preferred [49]. Correspondingly, EBD can not yet be used as the basis for a decision methodology.

As is known, EBD (controlled studies, meta-analyses) belongs to the current state of the art for obtaining the higher quality evidence needed to formulate guidelines. However, previously conducted studies often use comparably isolated measures, while implicitly referring to an overall model of dental processes in which their results have a founded basis. Such an overall model has not, however, been presented explicitly. Should EBD not take on a considerably different development than EBM, it can be expected that only a number of well-founded individual treatment decisions will arise from it, not, however, an overall treatment planning methodology.

2.2 GENERAL KNOWLEDGE PROCESSING METHODS (INFORMATICS)

Although the primary goal of the presented methodology is not to develop software for decision support, a scientifically developed methodology should be well-understood in its basic structure, and, therefore, its instructions should be presented in an algorithmic form (compare Chapter 2.3).

For the analysis then, knowledge acquisition methods should be used that meet these requirements. Informatics, as the science of information processing, offers a wide range of approaches for this purpose. According to Breuker et al. [50], the process of modeling knowledge can be described as a circulatory process made up of analysis, design, modeling and maintenance (compare Figure 4).

To avoid abstracting the problem too far away from dental medicine, the emphasis of this research is placed on the analysis of dental relationships and decision structures. The medical relationships of these methods flow into the analysis without requiring further specific mention.

The design and implementation of automated decision support will be discussed briefly in Chapter 6.2.2.4. Maintenance of the decision methodology will be discussed in Chapter 6 based on the evaluation of the prototype. This allows a more detailed discussion of the decision structure.

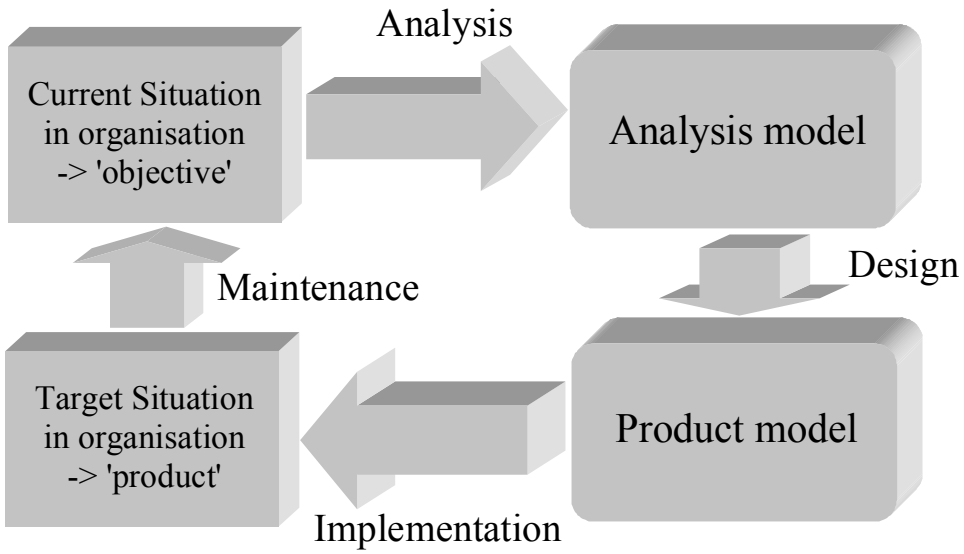

Figure 4: Process of modeling knowledge [50]**. In this representation, the process of modeling knowledge follows a circular path. This path, can, in principle, never end due to constant adjustments to the requirements and the given facts.**

This research focuses on the first part of the paradigms suggested in KADS (Knowledge Acquisition, Documentation, Structuring [51,52]). Whereby, the experiences of practicing physicians, actual patient data, and specialty literature serve as the basis for the development of a conceptual model. It, in turn, serves as the abstract foundation for the development of a design model (compare Figure 5).

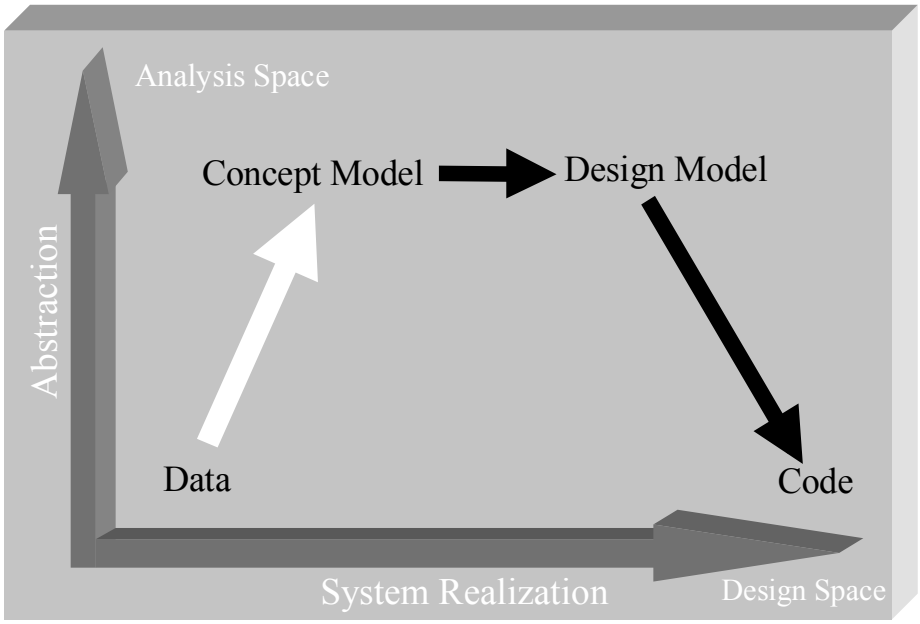

Figure 5: The planning and realization of knowledge-based systems[52]. This research emphasizes conceptual modeling, which is the first step toward system realization. The design model and the coding are described by example only in order to stay within the boundaries of the work.

Dental experts are, by all means, in the position to solve complex problems within their domain. The exact formulation of the dependencies and their derivations, however, still pose difficulties. This applies especially to the attempt to develop a comprehensive approach for larger domains. Especially, differentiating between procedures and dependencies, and the interactions between both of these views, is often underestimated. This often leads to gaps in the argumentation [53,54]. Procedural[9] and declarative[10] relationships should be represented with their corresponding interactions to gain a structural understanding of dental decision processes.

Within artificial intelligence (AI), the design phase of a decision process is generally separated from the spatial and timely order of a system (configuration or planning compare [53]). For the sake of clarity, both of these aspects of dental problem solving have been treated separately in this methodology.

According to Newell, the underlying decision structure should not be represented using formalisms (rule schemas or frames), because knowledge

[9] procedere (lat.) = to proceed

[10] declarare (lat.) = to declare, to describe

exists independent of its representation [55]. Therefore, common medical formulation has consciously been used to stimulate and allow for a purely medical discussion.

Upon answering the underlying questions, information-technical modeling of individual aspects can begin using problem solving agents. Chapter 6 will discuss details of how the general approach can be represented technically using an object-oriented analysis method (compare [56,57]). The area of dental prosthetics has been selected to serve as an example for such an analysis. The common Unified Modeling Language notation (UML, compare [58]) was used to model the relationships involved.

2.3 INFORMATICS SOLUTIONS IN MEDICINE (MEDICAL INFORMATICS)

According to Victor, it is beyond dispute that theory development in medicine is helpful and necessary [59]. At first glance, it may seem over-dimensioned to say that a separate field is necessary for this purpose, namely the field of medical information processing, or "medical informatics". However, the medical field has always employed itself with collecting data, running error controls, interpreting data and drawing conclusions upon that data (compare [60]). Therefore, the need for the medical informatics discipline will now be explained.

Due to the rapid development of scientific research, the amount of medical knowledge has increased explosively[11]. From this knowledge gain, new medical specialty areas have arisen. Logic[12] was used to form a uniform basis for representing the knowledge. Such uniform representation makes diagnostics and treatment planning possible (compare [42]).

Intense communication between the medical domains has become more essential than in most other fields. Many sciences are touched by the field of

[11] In 1999, the National Library of Medicine referenced 5,330,000 books and other documents, including 412,000 articles (all databases) and 3,300 journals (for the Medicus Index) [61].

[12] In this research, the use of formal logic has been declined, since logic can only be used within a closed model (compare [62]). Because this work centers around deriving a model for dental decision structures, formal argumentation does not make sense.

medical informatics. Beside (dental) medicine, the fields of information technology, electrical metrology, psychology, economics and other fields collide.

Although this research focuses on the area of dental medicine, other outlying aspects must be taken into consideration. The major task of medical informatics is to united these aspects into one overall information concept. To provide the necessary support in dealing with this complexity, medical informatics is forced to deal with a broad spectrum of information (compare [63]).

In other words, medical informatics deals with the systematic processing of data, information, and knowledge in the medical field and health care in general [64]. It is the science of utilizing systematized analytical tools to develop procedures and algorithms for management, process control, decision processing and the scientific analysis of medical knowledge [65]. Medical informatics holds the theoretical and practical aspects of information processing based on knowledge and experience that have derived from medical procedures and health care provision [66].

In summarizing all of these definitions, one of the main tasks of medical informatics can be seen as the task of formulating algorithms for decision making processes. Therefore, in its fixed position within the medical field, medical informatics serves as a connection to information technology.

2.4 BUSINESS ANALYSIS METHODS (ECONOMICS)

The underlying types of descriptions used in this research work stem from economic decision theory[13]. System theory [39,67] requires that all scientific argumentation must begin with a suitable research approach to serve as a frame of reference. The system described here contains many elements between which relationships and certain characteristics exist. Ulrich understood such an approach as: „[...] the possible starting point for a scientific approach that can not be traced back any further" [68]. Breaking down an objective approach is either not possible, because the "underlying" structures are unknown, or it does

[13] Due to its general nature it can be counted to philosophy, but it was developed within the field of economics.

not make sense, because the "underlying" structures are irrelevant for understanding the goal.

Therefore, selecting a suitable system that allows the comprehensive description of its processes also applies for dental medicine. It is important that not only the oral hygiene, but also the overall patient condition is taken into consideration. This means, the patient's personal expectations and situation must be considered in the treatment planning process.

With help of system analyses, the dental domain is broken down into its elementary parts, making individual patient treatment planning possible. The decomposition allows the creation of a general model of the relationships true to all human beings. Characteristics of the individual dentitions then result in further specifications of the general model (compare "A system of systems concept" [69]).

Definition 8: System
A system is a set of objects, including the relationships between the objects and their attributes [70].

The individual parts of an overall "super-system", are known as sub-systems. Sub-systems that can not be broken down any further by the analysis are known as system elements. "Relationships" exist between system elements and can be defined as mutual dependencies (compare [68,69]). The hierarchy of system terminology is shown in the following (compare [71]):

System levels	System term
Next higher system level	Super-system, Hyper-system
Current system level	System
Next lower system level	Subsystem, Hypo-system
Lowest system level still of interest for a certain context	Element
Vicinity of the system	System environment

The quality concept plays an important role during treatment planning (compare [72]): It describes the freedom of errors for a particular solution or a process. Higher quality means reducing error rates, rework, rejects, drop outs, customer dissatisfaction, inspections and tests, and negative effects on cost efforts, as well as an increase in general benefits and capacities. It is generally expected that higher quality should cost as little as possible. Since, however, an absolute measure for quality is not available, it does not make sense to try and increase quality without a targeted goal. Therefore, it is also a task of treatment planning to define the necessary goals beforehand.

Definition 9: Basic tasks of planning [73]

The basic planning tasks are

a) Determining quality goals, and the
b) Development of the processes required to reach the determined quality goals.

It is necessary to plan the planning phase (meta-planning) in order to formulate the general process model (compare roadmap to quality planning in [72]). A decision becomes necessary as soon as the results of the 'ex-ante design' of the treatment alternatives of the meta-planning become available for use. A decision, in this context, is the selection of a treatment alternative from a number of available alternatives that can not all be realized at one time [74]. During treatment planning, decisions are aimed into the future. A court decision, in contrast, is directed into the past. According to Wittmann, through goal-orientation, intellectual decision making receives the nature of a conscious, action-oriented evaluation [74]. Decision theory states that a decision is made up of the following:

Definition 10: Decision theory [75,76]

Factual decision components:

- Situations (= environmental conditions)
- Possible alternatives (= actions)
- Results (consequences) of the actions

Evaluation components:

- Goal criteria
- Selecting a suitable treatment alternative
- Making use of the alternative

An idea exists within reference literature that a decision process is made up of clearly defined phases, each requiring various degrees of thinking and action. From the vast sources available, let the following summarize this phase theory:

Definition 11: Phase theory of decision making [77]

1. Identify the problem
2. Search for information
3. Collect treatment alternatives
4. Evaluate the collected treatment alternatives
5. Select a treatment alternative
6. Realize the selected treatment alternative

This research assumes that decision making in dental medicine is a closed process that can be described and modeled within itself.

3 TARGETED DENTAL TREATMENT GOALS

Now that the general goals and the foundation required for this research have been described, the goals of dental treatment will be defined As decision and phase theory show (compare Chapter 2.4), goal criteria must be defined from which actual treatment alternatives can then be generated.

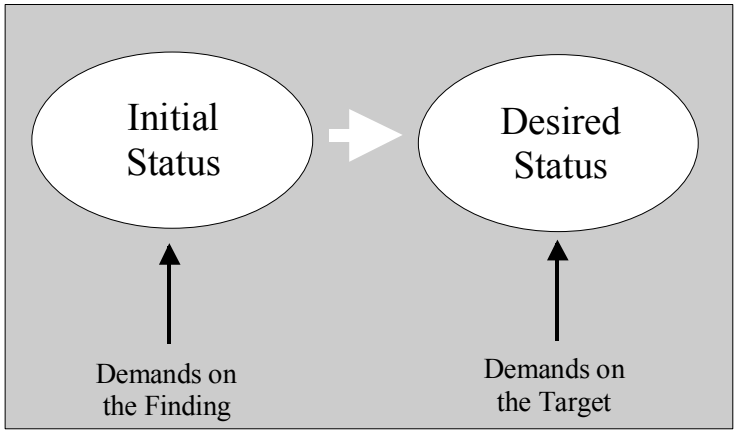

Figure 6: Dental goals. As decision and phase theory show, goal criteria must be defined for the overall problem area. All of the solutions generated throughout the planning process must meet the defined goal criteria and lead to their fulfillment.

As was explained in Chapter 2.4, decision theory states that defining general dental goal criteria is of basic importance. From these, in combined use with the specific patient status, it must be possible to obtain patient-specific goal criteria. The treatment alternatives must, in turn, meet the requirements set by the patient-specific goal criteria[14].

[14] It may seem surprising that treatment alternatives must be generated first in order to generate the treatment procedure plan. Taking a closer look, however, it would not be stringent planning, but rather a search mechanism, if the process took place the other way around. It can not be said whether a generated alternative actually meets the goal criteria until after the treatment procedure planning has been completed.

The quality of dental treatment planning currently depends strongly on the degree of education and personal experience of the treating dentist, as well as on the extent of the examinations required in the case. As a consequence, this complexity is difficult to master by an individual dentist in everyday practice, and a broad spectrum of treatment approaches are frequently not being considered [19]**.** As in any form of planning, treatment selection in dental planning should be based on well-founded decisions. Therefore, a goal-oriented approach to planning of dental treatment planning (meta-planning) is needed (compare [76]). A series of questions pertaining to dental treatment planning result based on phase theory (compare Definition 11 in Chapter 2.4)

Summary 3: Questions surrounding dental treatment planning

1. What is the dental problem at hand?
2. What information is required to derive patient-specific goal criteria?
3. Which treatment alternatives can fulfill the patient-specific goal criteria? How does the corresponding treatment look?
4. How can treatment alternatives and their treatment plans be evaluated?
5. Who makes the final selection among the generated treatment alternatives and their corresponding evaluations?
6. How must the treatment be realized?

To secure the consistent distribution of the responsibilities of the medical specialties, the general dental goals targeted should be based on the general medical goal criteria (compare Chapter 2.1). From these, patient-specific goal criteria should be specified, from which treatment alternatives are then generated. The criteria for an actual treatment, or its procedure, in turn, result from the generated alternatives.

The following reflections focus on planning. A stringent realization of the treatment should be possible according to the treatment plan, if comprehensive planning took place. In the sense of idealized planning, no questions should left open following the planning phase. There upon, it must be clear how the selected treatment is to be realized, and its execution by a specialist must be possible without causing any further problems. Complete planning covers all respective

forms of creative and ingenious processes [76]. Therefore, in the following, treatment is reduced to a solely intellectual planning process.

However, the possibility that unexpected questions, demanding answer, may occur during treatment can not be eliminated. These questions must be included in the planning phase, even if they could be answered prior to beginning treatment. Chapter 4.1.4.4 will discuss the procedures for such a situation. Until then, for the sake of simplicity, it will be assumed that planning is complete prior to beginning treatment.

At this time, it is again pointed out that practicing dentists may expect that certain topics, discussed in later chapters, be discussed in this chapter. If so, please refer to the table of contents or the glossary.

3.1 DENTAL PROBLEM AREAS

Before going further into the overall goals of dental medicine, the respective problem areas must be covered in more closely. This is necessary to be able to derive concrete sub-goals from abstract detail.

Solutions are offered for problems arising in the areas of dental functionality and aesthetics while taking preventive preservation into account[15]. Due to research within its specialty areas, dental medicine has seen a great deal of refinement during the past century. Therefore, it is necessary to analyze the overall relationships involved. Sub-disciplines should be bundled and directed toward an overall goal. The sub-goals defined from the analysis are subordinate to the overall goal, and even more so, should result from a strict formulation. The exemplary formulation of an overall goal and the derived sub-goals will be presented briefly.

[15] As mentioned in Chapter 2.1, a funding issue comes into play here. It generally counteracts functional and aesthetic improvements. The consequences of this problem should be kept out of medical planning, even if they play an important role in selecting a suitable treatment. Integration of the financial aspect will be discussed later.

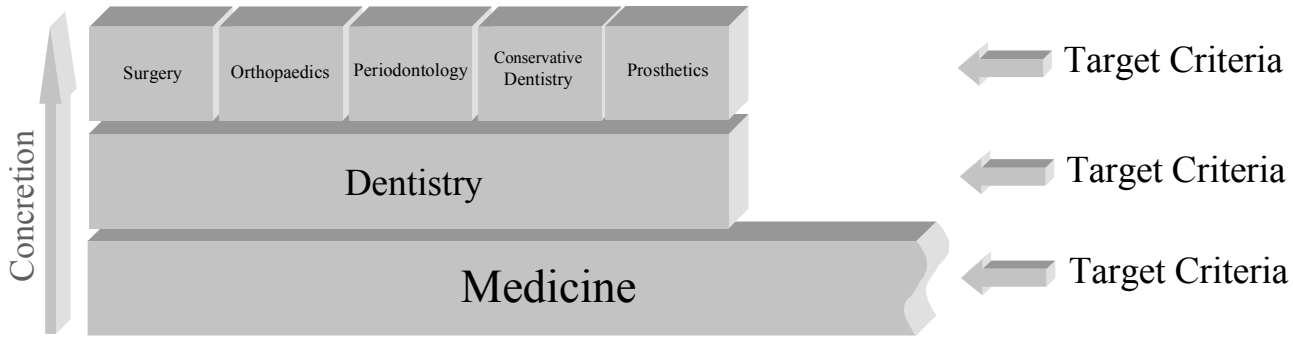

Figure 7: Sub-systems of dental medicine. The sum of the dental sub-disciplines must cover dental medicine. They not only contribute to the overall treatment success, but are also responsible for the respective dental procedures they cover. Dental medicine is, in turn, a sub-system of medicine.

In order to embed dental medicine within its natural environment, medicine is declared the super-system, while dental medicine is one of its sub-systems[16]. Prosthetics, conservation dentistry, periodontics, dental and oral surgery are, in turn, sub-systems of dental medicine. The system inherits certain characteristics to the respective subsystems[17]. This corresponds to the delegation of responsibilities.

Ideally, overlapping tasks and responsibilities are avoided among sub-systems. Otherwise, medical deficiencies and errors can not be traced uniquely to a certain sub-system[18]. Goals must be defined for each sub-system, which, in turn, refine or substantiate certain tasks and goals of the higher-ranking system. The resulting canonical hierarchy[19] unitizes tasks, rights, responsibilities and, from a research perspective, is of underlying importance to refining a structured medical decision methodology.

Definition 12: Medical "super"goal

The goal of medicine is to ensure the short and long-term well-being of

[16] Compare system theory in Chapter 2.4

[17] Compare object-oriented view [57].

[18] This is a difficult task considering the changing boundaries within medicine. With the appearance of new research results, the boundaries must be staked anew accordingly.

[19] A canonical break down fully classifies a set, without gaps.

patients from a physical, mental, and social point of view [40].

Medicine concerns itself with the science of healthy and sick human beings, as well as treatment activities. Here by, it focuses on the earliest possible recognition of diseases, their causes, and treatment [78].

Defining medical goals is of importance here, because dental goals should be derived from them. Dental medicine should, in turn, aim to achieve the overall medical goal set for the stomatognathic system. Furthermore, the goal of a practicing dentist can not be limited to serving the needs of the stomatognathic system alone, since the dentition strongly interacts with the entire organism. However, in terms of a clear task definition, and to place full concentration on the needs of dental medicine, this research work defines that all boundary conditions set by general medicine must be fulfilled prior to beginning with dental treatment. In other words, dental treatment can take place only if no general medical reasons speak against dental treatment.

Definition 13: Goals of dental medicine

Dentistry is the occupational establishment and treatment of dental, oral and jaw-related diseases, based on scientific knowledge from the area of dental medicine. Every abnormal mouth or jaw-related occurrence is considered a disease, including tooth misalignment and gaps (compare **Gesetze für Ärzte und andere Heilberufe, 1995**).

Dental medicine is responsible for fulfilling the medical goal set for the area of the stomatognathic system. It aims at helping patients achieve and sustain a functional, complaint-free, and aesthetic dental and oral state. This especially includes supporting preventive measures to enable patients to sustain durable and long-lasting dental structures.

Before describing the goals criteria of dental medicine in more detail, the treatment areas of dental medicine must be defined[20].

[20] In this respect, the tasks of dental medicine and the tasks of a practicing dentist must be separated clearly. A dentist can, to a certain extent, initiate medical measures that do not directly belong to dental medicine.

3.1.1 Functional analysis of the dentition

Prior to performing a functional analysis, it should be pointed out that the terminology varies slightly among text books and literature. Therefore, a glossary containing the most important definitions has been appended to this work.

The functional aspect of the problem area centers around a person's mouth. Body structures, such as the 'jaw' ('bone' and 'joint'), 'muscles', 'mucous membrane', and the 'teeth' ('crowns' and 'roots'), play a major role herein, since tasks and responsibilities are to be defined for them. Should problems arise during the fulfillment of these tasks, measures must be undertaken to reinstate a satisfactory condition. To be able to comprehend the causal relationships, dependencies, which (at least indirectly) include all structures present, must be defined based on the goals. In the following, a model will be derived without, however, going into the characteristics and functions of the mentioned objects.

In healthy dentitions, dental crowns are connected to the jaw via an abutment. They allow mastication, during which the lower jaw moves against the upper jaw via the temporomandibular joint and the masticatory musculature. The interactions among functionally neighboring objects help to define the tasks of each structure. In case of a healthy dentition, the dental crowns are responsible for mastication[21]. The dental root holds the dental crown, whereby, simplified, the dental cervix (or tooth neck) is considered part of the dental root. The dental root is connected to the jaw via the periodontium, which, in turn, is moved by the musculature. Hereby, the temporomandibular joint provides the necessary freedom of movement. The mucous membranes protects the periodontium, the jaw, and the musculature from contamination and micro-mechanical exposure. The cheeks surround the oral cavity, creating a hollow cavity in which food is contained during mastication. The teeth and the alveolar ridge are located between the tongue and the cheek structures, which also participate in churning the food during mastication. Part of the teeth are visibly located in the oral opening, whereby the first three per quadrant are normally used for biting. The

[21] A "normal" dentition functionality is assumed during the course of the analysis. Although other constellations are conceivable in practice (e.g. mastication with an adental jaw), they are irrelevant for defining the target system.

teeth interlock when clenched, which additionally guides the jaw. The saliva glands secrete the necessary saliva for mastication.

Further explanation of the masticatory control mechanisms – especially a complete overview of the soft tissue and central nervous system – is forgone at this point, because the material would go beyond the intended scope of this research work. However, it should be mentioned that a complex neuronal mechanism is required to control the masticatory processes. Cybernetic circuits can help to better describe these processes, and to provide a deeper look at the aspects of information processing involved.

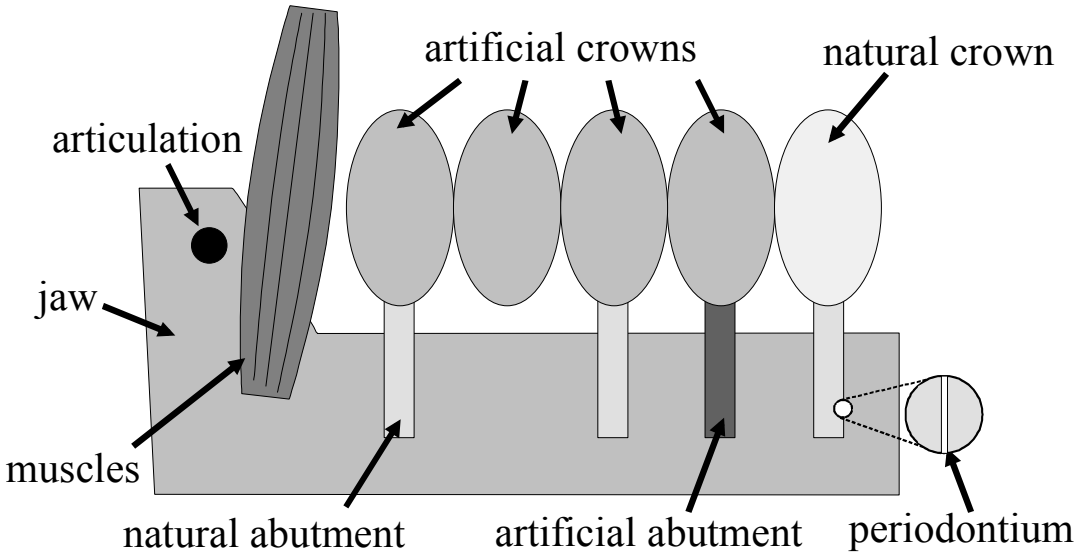

Figure 8: Strongly simplified, schematic presentation of a lower denture without the mucous membrane (and not to scale). The upper jaw looks similar to this schematically, but does not possess its own joint or masticatory musculature.

The most important functional dependencies of the stomatognathic system can be summarized in the following order(in accordance to Figure 8):

Summary 4: Functional dependencies of the stomatognathic system (compare [79])

1. Technically speaking, a dental crown is a mastication tool. It carries the masticatory surface and is responsible for food comminution without damaging soft tissue in the process.
   The front 5 crowns of each quadrant are normally located within the

visible portion of the mouth[22]. The teeth of the regions 1-3 are known as incisors and canines. Their primary task is biting off food. The teeth located in regions 4-8 are known as premolars and molars. Their primary task is the actual mastication.

2. The dental root carries the dental crown (and the dental neck).
3. The periodontium fastens the dental root to the jaw and, thereby, the entire tooth.
4. The jaw holds the periodontium.
5. The temporomandibular joint provides the lower jaw with the necessary freedom of movement.
6. The musculature guides and moves the lower jaw. Clenching the teeth leads to interlocking of the dentition.
7. The upper jaw is part of the skull.
8. The upper and lower jaws interlock when the teeth are clenched together. This results in additional guidance of the lower jaw.
9. Mastication is the combined result of all moveable elements and their neuronal controls.
10. The tongue and cheek structures are responsible for churning food.
11. Glands secrete saliva.
12. The mucous membrane protects the intra-oral structures from micro-mechanical, chemical or bacterial damage (this definition takes a very simplified view of the soft tissue of the stomatognathic system, but it suffices for an initial functional analysis of the dentition).

The following depicts a normal dentition and is divided into 32 regions (4 x 8 regions), since the appearance of 9 teeth is an exception.

A basic difference is made between the actual tooth and its surrounding structures (compare. Figure 9). A tooth can be fully natural, fully artificial, partially natural, or partially artificial. The surrounding structures of a tooth are generally natural. Although there are exceptions (e.g. jaw resections), these will not be discussed here.

[22] The number of crowns has been predefined to 5. Although this number can vary in individual cases, it plays no major role in the methodology.

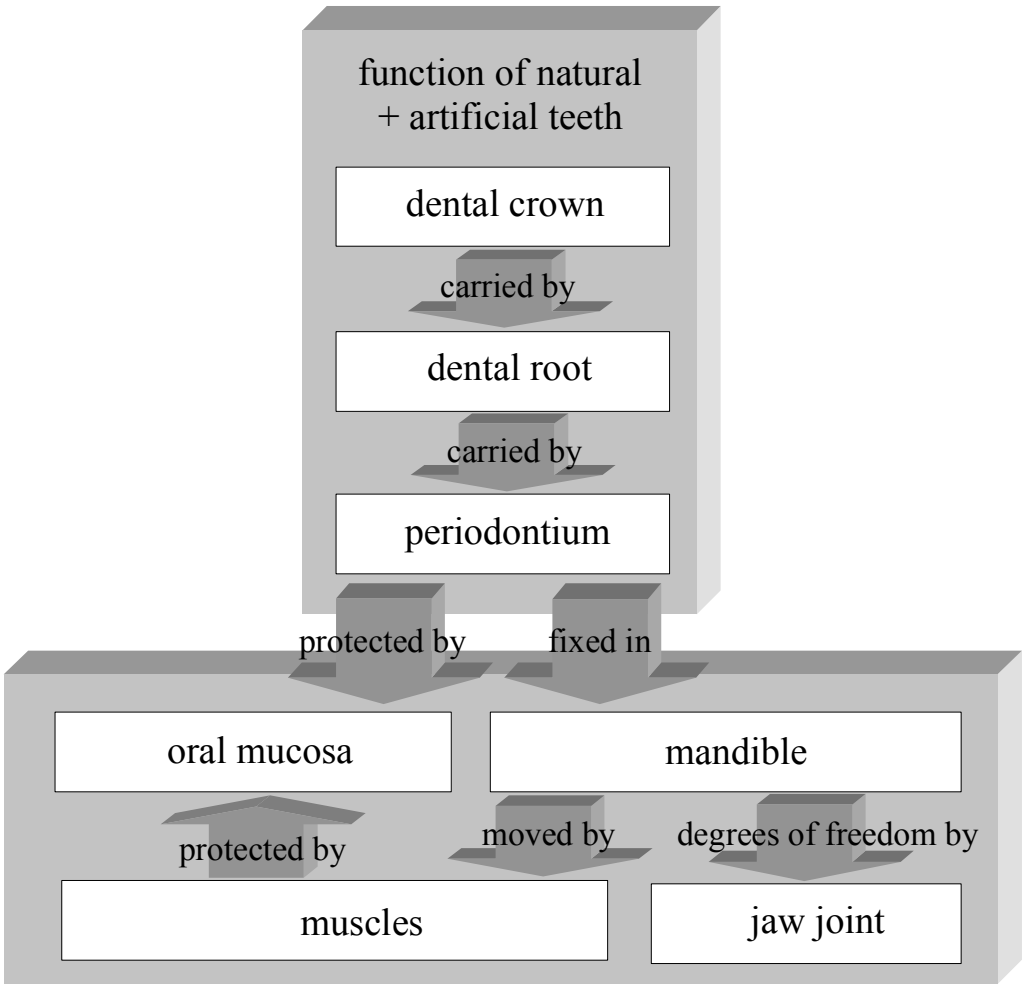

Figure 9: General requirements for healthy dental functionality. This figure shows a simplified view of the main tissues involved in mastication and their interactions.

Although the relationships presented in Figure 9 are strongly simplified, they serve to show the interactions existing between the various structures of the stomatognathic system. These overlapping structures can, in turn, be broken down further (e.g. a tooth is made up of enamel, pulp, etc.) without ignoring their interactions with neighboring objects. Goal criteria is required for the structures listed below:

Definition 14: Structures requiring goal criteria

- Dental crown (natural, artificial)
- Abutment (natural, artificial)
- Periodontium
- Jaw
- Masticatory musculature
- Oral mucous membrane
- Tongue
- Glands

• Temporomandibular joint	• (Ligaments)

Each of these areas can be influenced by treatment. Therefore, the treatment of each must be planned in such a way that it helps to fulfill the overall treatment goal. Based on the general overall goal, the dependencies between the structures can be used during planning to define sub-goals for each object, and to define the overall treatment goal.

As will be described closer in a later part of this work, the most important treatment requirements result from just a few goal criteria. Conservation, orthopedic, prosthetic, periodontal, and pharmaceutical measures can be used to satisfy the goal criteria, whereby mixed forms are also possible. Beside macroscopic, or physical, forms of treatment, medication is also available to reduce, or eliminate, microscopic, biochemical symptoms and causes.

Figure 9 makes clear that underlying requirements and goal definitions can be derived from the mastication functionality and from dental crowns, since dependencies result from them, rather than effect on them. From this perspective, all of the other structures are fit to the structure and position of the dental crowns.

Summary 5: Structural dependencies of dental medicine

The underlying dental requirements can be derived from the goal of fully functional and aesthetic dental crowns. Hereby, the other structures of the stomatognathic system may have individual goals and tasks that can not be derived from the overall goal.

For the sake of clarity, the following will focus only on the objectives of the teeth, since they represent the central structure of the dentition[23]. The class diagram in Figure 10 describes the basic structures possible for constructing a tooth.

[23] It is assumed here that the “lower” laying structures either allow treatment or lead to the elimination of a treatment alternative (see Chapter 4.1.1).

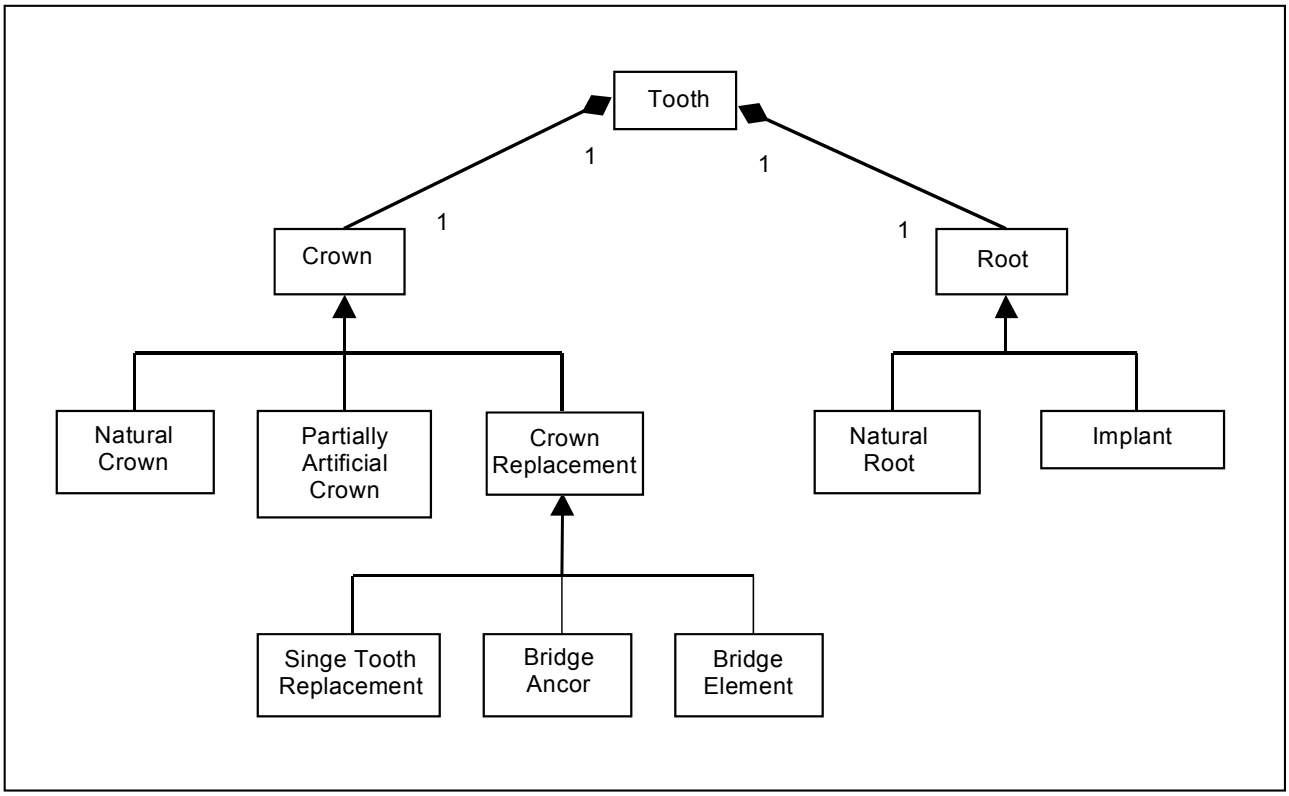

Figure 10: Simplified class diagram "tooth". The possible ways to construct a tooth are shown.

3.1.2 Description of Anamneses and Diagnoses

Among others, one goal of anamneses is to identify high risk patients. Hereby, precautionary measures aim at reducing the risks for the patient, the physician and the assisting personnel. Hereby, systematic factors, the aim of pain-free treatment, and calming the patient are of special importance [14]. Rather than going into medical details that may change over time, general characteristics are shown from which a basic handling of anamneses during treatment planning can be derived.

Definition 15: Anamnesis
The anamnesis is the sum of the subjectively recalled prior diseases by a patient in form of a patient case history [78]. It includes the general medical and dental occurrences and conditions.

The anamneses can be understood as the record of all past results and diagnoses. Therefore, the diagnosis can be described ideally as conditions and transitions.

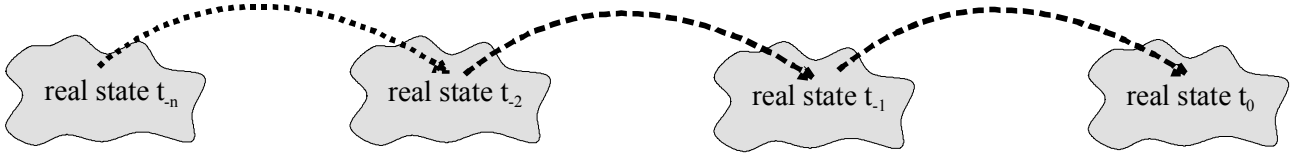

Figure 11: The timely record of a patient's health condition is idealized as the transition of conditions. Normally, the conditions describe the situations during diagnosis by the dentist.

Because the information contained in the anamnesis has always been collected in the past, in regard to time point t_0, that particular information does not change in the future. Therefore, it can simply be described as "Anamnesis at time point t_0", or shorter "Anamnesis A_0". The anamnesis at time point t_1, following t_0, can be described as the Anamnesis A_0 plus the changes to the anamnesis that have occurred between t_0 and t_1. It contains the general anamneses (personal data, familial anamnesis, personal-social anamnesis, general condition and history, personal and environmental), as well as the special anamneses (risk anamnesis, oral- and periodontal condition and history).

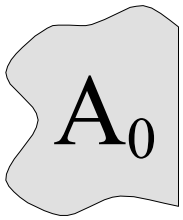

Figure 12: The Anamnesis A_0 at time point t_0 contains the anamneses of the patient up to that time point.

The diagnosis, on the other hand, describes the current condition of the patient. Generally, the diagnosis contains all of the partial diagnoses for a specific patient, including those made outside the scope of the treating specialist of a specific field. Therefore, all other problem areas somehow or potentially involved with dental medicine are also included in the concerned specialty area[24].

[24] Deviating definitions exist alongside this one, such as 'a diagnosis is a personally collected treatment result'. To clearly separate the current condition of the patient and his status description, a modified definition has been used.

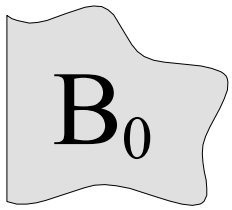

Figure 13: The diagnosis describes the current general medical and dental condition of a patient at a specific point in time.

According to Gross ([42], p.342) retrognosis is the knowledge of that which has already occurred. Thereby, it includes the diagnosis and the current state at the time of the examination. It must be possible to make a prognosis based on the retrognosis. The prognosis enables an estimation of the possible future development.

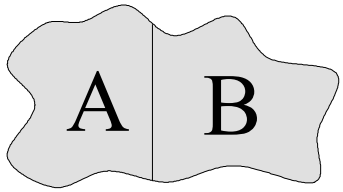

Figure 14: The retrognosis of a patient at the time point t_n is summarized by the status, and includes the anamnesis and the results at that time point.

A general statement regarding possible treatment alternatives can only be made based on a comprehensive assessment of the patient. Due to metrological, timely, invasive, and financial reasons, it is not feasible to collect fully complete, or absolutely exact, patient data. Therefore, an incomplete status description must suffice for generating treatment alternatives.

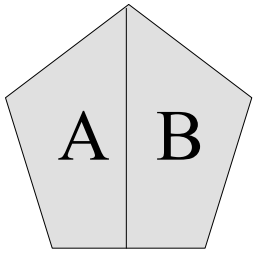

Figure 15: The description of a patient's status, compared to his actual condition, is idealized, because it is innately incomplete (due to limited time and funding).

Therefore, the following questions arise while determining the patient status:

Summary 6: Questions arising during status determination

- How can the status be determined?
- How exact are the results?
- How complete are the results?

The dentist can , of course, question a patient to his medical history, but he can not expect a dentally qualified answer. Therefore, the professional opinion of dentist receives special emphasis through the diagnosis.

Definition 16: Dental diagnosing [14]

Dental diagnosing involves the objective examination of the entire stomatognathic system by a dental specialist. The goal is a complete[25] record of extra- and intra-oral results leading to a diagnosis of the periodontal, caries, endodontic, and masticatory functionality. Of basic importance, hereby, are: skin, head, neck, halitosis (bad breath), the mucous membrane, teeth, muscles and joints.

The status can, therefore, be defined as the overall sum of all diagnoses and the patient's history up to the time point t_n.

Definition 17: Status

The status is the condition of a patient at a give time point. It includes the anamnesis and all results up to that time point (compare. [80])

3.1.3 Pre-structuring the Status with Help of the Diagnosis

Diagnosing refers to the recognition and separation of one disease from another [78]. Hereby, structures are created within the knowledge domain and combined to form the diagnosis. Diagnoses are time-bound singular statements that rest upon mini theories, so to speak [42].

[25] Here, 'complete' is not used in the sense of 'absolute'. Rather, it refers to an acknowledged diagnosing standard.

Definition 18: Goal of a diagnosis [14]
The goal of a diagnosis is to create the preconditions for systematic treatment planning.

According to Gross [42], a diagnosis consists of two parts:
1. the nosological, scientific, seemingly objective part and
2. the personal, subjective, individualization part.

From a model perspective, the diagnosis can be seen as the logical pre-structuring of examination results, even if the underlying logic is not always recognizable.

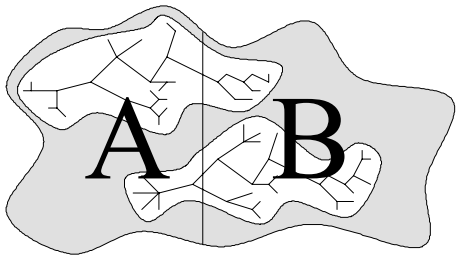

Figure 16: The diagnosis helps to pre-structure certain treatment results concerning the status of a patient at a given time point t_n.

In a technical representation, individual results are pieced together causally to form a diagnosis. The purpose of this pre-structure is to derive treatment measures more easily. This applies especially to acute problems (e.g. pain) and their respective measures, since such cases rarely allow sufficient time for planning. For this reason, use of the term "diagnosis" makes sense only in certain cases. For example, circumstantially, specific changes in dental translucence appearing in combination with certain x-ray results, allow the conclusion that a tooth has caries. In this case, complex individual results are reduced to one overall term. Specific treatment measures can then be derived from the term "caries".

The diagnosis not only summarizes all examination results logically, but also helps to clarify the causes. Thereby, the required preparatory measures are pre-structured to help support the systematic clarification of the causes. The collection of patient specific information is necessary to make a diagnosis. The diagnosis, therefore, includes the anamnesis as well as the process of collecting the examination results.

Definition 19: Diagnostics
Diagnostics includes conducting an anamnesis, examining the patient, and, possibly, his bodily fluids, excretions, tissues, cells, as well as the possible use of radiation, bioelectrical waves, or sound waves [78]. Therefore, it completely includes the process of diagnosing.

Information reduction, in the sense of diagnosis, is not useful in many cases, such as complex prosthetic problems. Detailed information of the location, size and environment of the diastema is required. A diagnosis is successful only if a small number of conclusions and treatment alternatives can be drawn from a certain number of examination results. If, however, the case involves a large number of different conditions[26], the scope of simple manageability is exceeded by far. Therefore, in such cases, other methods must be selected to generate treatment alternatives from the examination results.

3.1.4 Anticipating decisions through planning

Some general information in regard to planning must be given before describing dental goals. Different definitions of planning exist that, if used in combination, offer a useful view of the approaches used at a later. While, in a narrow sense, planning refers only to the preparations necessary for making decisions, other, more broad views, also include the actual making of decisions [81]. The broader, more theoretical, concept will be used in the following, which sees planning as the complete anticipation of decision making. Treatment, therefore, is the strict execution of the finished treatment plan. The concept of planning used in the following, demands that a treatment is the result of a strict treatment planning process. No further questions, therefore, should arise from treatment itself [82]. This idea covers another definition of planning, in which it is a form of "thinking". Herein, planning is an instrument for collecting information that can reduce psychic discomfort, thereby, reducing insecurity [82].

[26] Example: partially edentulous arch with 2^{32} different arrangements possible for missing and present teeth.

This approach assumes, from an operative view, that a dentist can conduct a treatment if the required information to do so is available to him. Prior to treatment, a description of the targeted condition is necessary. This description is , innately incomplete, due to practical reasons, and is, therefore, an idealized view. Intermediate steps necessary for decision making (compare Figure 17) cans be derived in accordance to model theory [62][27].

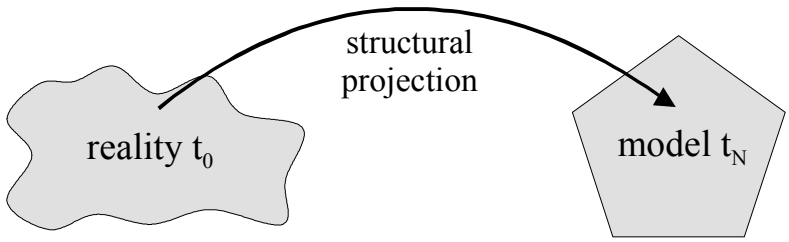

Figure 17: A model is a representation of reality, and, consequently, is a simplification (compare [62]).

A model of reality can be used to help predict future conditions. For this purpose, a representation is needed that transforms a condition at a given time point t_0 into the condition at a later time period t_1, (compare Figure 18)[28].

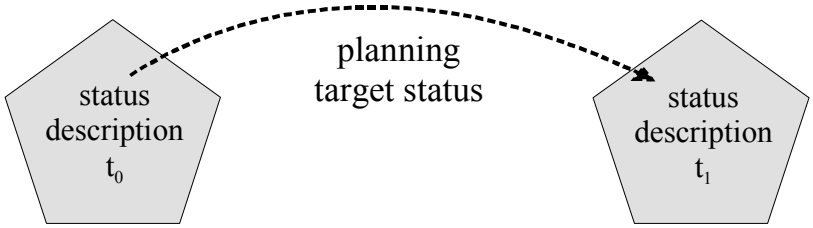

Figure 18: Treatment planning is the transformation of one condition at a given time point t_0 into a condition at a later time point t_1.

The respectively transformed condition is then transferred back to reality in such a way that treatment alternatives can be derived from it (compare Figure 19).

[27] In contrast to reality, this incomplete representation of reality is depicted as a pentagon.

[28] Hereby, equally admissible treatment alternatives can occur.

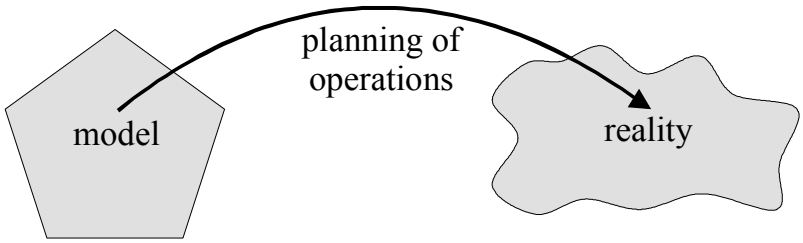

Figure 19: Treatment planning describes the transition from a patient's current condition to a theoretical condition in the future.

Once the treatment alternatives and the respective treatment processes are available, additional information required for selecting a treatment can be added, such as pictures, schemas, film material, and prognoses.

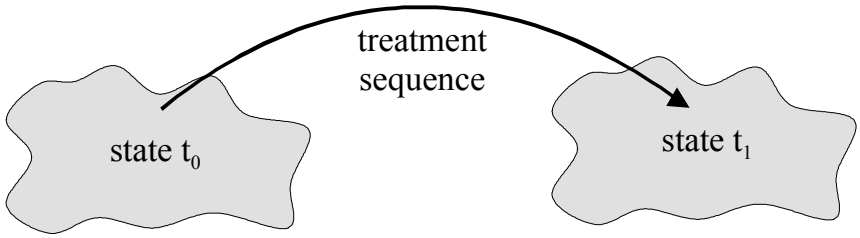

Figure 20: Actual treatment process: During treatment realization, the treatment plan is actually carried through. Difficulties can occur at this point if the either the model, or the interpretation of the results was not carried out correctly.

The procedures brought forth so far may, at first glance, seem very strict. The justification for this, however, is that any additional result appearing during treatment, generally questions the entire decision making process. This, in turn, may then require that a new treatment planning process be conducted. For this reason, it must be clear when which aspect is planned, and when it is to be carried out.

A difference must be made between general social premises and individual, patient-specific statements and conclusions during decision making. By using decision theory (compare Chapter 2.4), it becomes possible to break down the decision model into several parts:

Definition 20: The systematic steps of dental decision making

1. Define general goal criteria for the dental domain.
2. Derive goal criteria for an individual patient from the general goal criteria.

3. Generate treatment alternatives from the patient specific goal criteria.
4. Develop treatment plan for the respective treatment alternatives.

The same person must not necessarily carry out all parts of treatment planning himself. Experts, for example, can define the general goal criteria from which the practicing dentists can generate treatment alternatives. The treatment plan should, however, be generated stringently from the respective alternatives. To avoid misunderstandings, the difference between definitively decidable and ambiguous criteria must be made clear. For example, probabilities are often not fully known, even if they are commonly used to estimate working hypotheses. Awareness must generally be placed on the transparency of the reliability of the underlying knowledge.

If more than one treatment alternative is available during treatment planning, and a clear selection between them can not be made based upon on scientific criteria, these must be considered equal. Chapter 5 describes which additional methods can help in selecting a treatment from the proposed alternatives.

The checklists used in dental medicine already describe the result of dental treatment planning: Following anamnesis, comprehensive examination and diagnosis, a systematic treatment plan is to be presented to the patient (e.g. [14]).

The treatment plan, however, should not unnecessarily limit neither the patient nor the dentist in selecting a certain treatment. According to decision theory, as many alternatives as possible should be shown that fulfill the goal criteria and, therefore, basically, are possible [75,76,83]. Consciously not mentioning a possible and suited treatment is hardly justifiable to neither the dentist nor the patient.

To understand the inner decision methodology, and, therefore, open it to criticisms, the following requirements have been set:

Definition 21: Basic assumptions for decision making

- The treatment alternatives are generated based solely upon determinable knowledge.
- Every decision must be founded, whereby comments can be summarized and simplified on an abstract level.
- Every form of uncertain knowledge is factored out of the inner methodology, since only a strict and hard decision structure can be criticized (see Chapter 0for more on the use of uncertain knowledge).
- If, based on the underlying goal criteria, a clear selection can not be made between two alternatives, both alternatives are presented.

Planning can only take place in this simplified form, however, if all necessary information is available. Since an exact interpretation of the results is not possible, because of metrological, timely, and financial aspects, as well as the limits to burdening the patient, the following assumes that a consistent oversupply of solution alternatives must be generated. Respectively, whether the individual alternatives can actually be realized must then examined in detail. Any additional information can, therefore, limit the solution set or serve as exclusion criteria for one or more of the proposed alternatives[29]. Therefore, need-oriented diagnosing, and diagnostics, is required (compare [21]).

[29] Similar to solving a mathematical equation with several unknown variables, the definition of parameters limits the solution set.

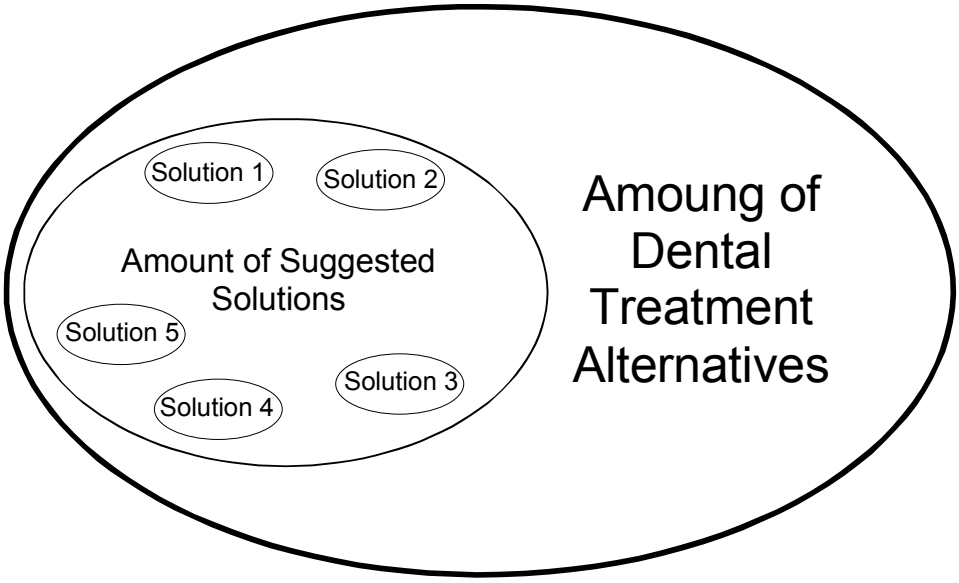

Figure 21: The actually possible dental treatment alternatives are a subset of the suggestion set, which, in turn, is a subset of the dental treatment alternatives.

The set of solutions suggested during a planning phase is defined as follows: Every solution suggested by the methodology for a given diagnosis actually exists and makes sense in itself. Therefore, all of the alternatives are possible based on the given patient information.

A suggestion space is spanned first. This helps to navigate through the alternatives in the next step, in order to find a suited treatment alternative. In other words, a decision methodology is similar to a proposal system that quickly navigates, its user to a suited solution. To which extent a dentist is lead by the system, should depend on the individual patient situation and serve his benefit and needs.

Summary 7: Navigation during planning

1. All possible treatment alternatives should be presented to allow for a comprehensive, unbiased decision.
2. The decision support methodology should offer an oversupply of alternatives during each decision making step despite an innately incomplete interpretation of the examination results. Incomplete in the sense that no interpretation can be complete, due to limited funding, metrological detail, etc. This should allow the dentist and the patient to make a decision based on the individual, given patient situation.
3. The methodology should offer the user step-wise support in reducing the overall number of proposed alternatives to a set of actually realizable alternatives by collecting further information.

In this regard, Lang emphasizes the following underlying questions for comprehensive dental treatment planning:

Summary 8: Underlying questions of dental treatment planning [14]

1. Which teeth can be conserved?
2. Which teeth can not be treated, are ‚hopeless cases', and should be extracted?
3. The conservation of which teeth is problematic or questionable?

Now that the general requirements for decision making have been described, they should, in accordance with prior statements, be transferred to the dental problem at hand.

Summary 9: Functional dependencies (without control mechanisms)

1. The dental crown is held by the root.
2. The root is, in turn, held by the periodontium, which is
3. fastened to the jaw, with which
4. mastication takes place via the jaw joints.
5. Therefore, all of these structures must be included in treatment planning.

From this perspective, each previous step forms the basis for the next step. All treatment steps are then preparatory measures for achieving the treatment goal.

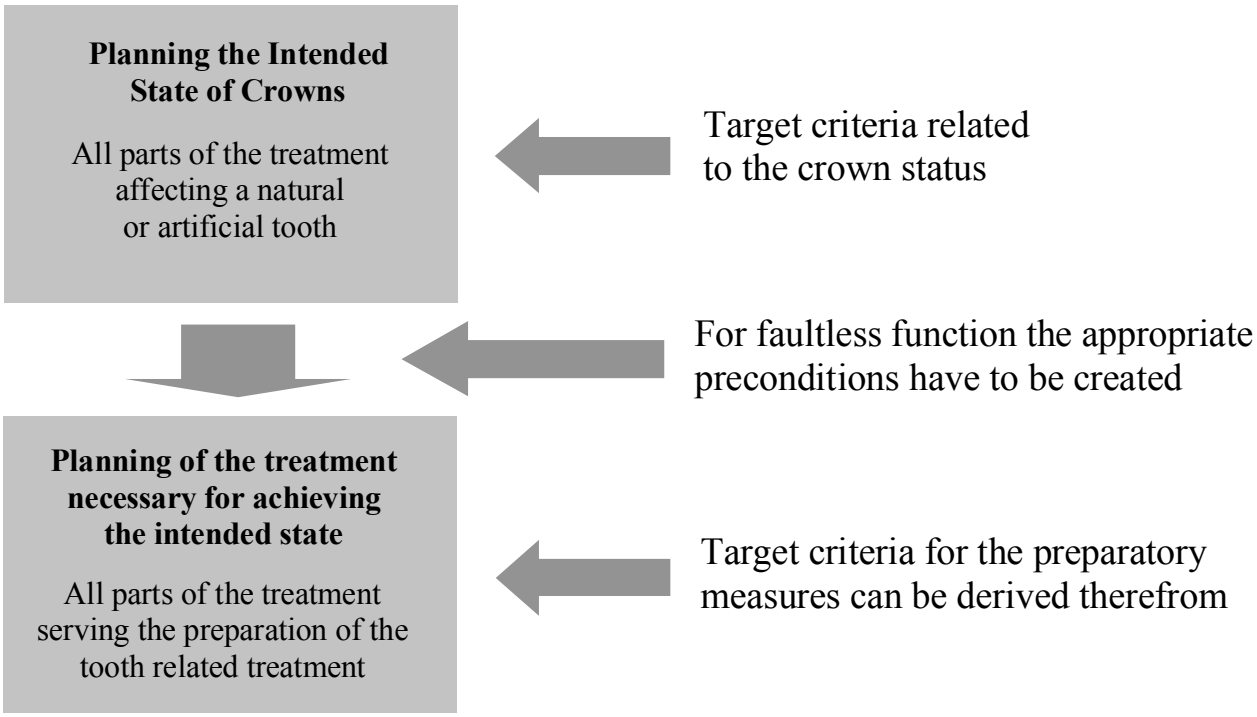

Figure 22: The dental crowns hold a central position in the stomatognathic system, because their surfaces are of immense importance for mastication. To ensure their full functionality and aesthetics, adequate conditions must be given among the surrounding structures.

A basic distinction is made between regeneration[30] and reconstruction during the planning phase. The first deals with the regeneration of natural structures, in as far as this is possible. Reconstruction offers methods and technical material to bridge the differences between the actual condition and the targeted condition of structures that can not be regenerated naturally. The fact that treatment should – as far as timely and medically possible - first regenerate natural material and then reconstruct, clearly follows from the above. It is purposeful to define goal criteria by which a planning sub-task can take place for each treatment step.

Various types of regenerative and reconstructive treatments are available in dental medicine today. These types of treatment should be grouped according to

[30] In many reference books (e.g. [78]), therapy is defined as the regeneration of natural structures.

the treatment method used in order to assign them to specialty groups later. These groups can be formed by specialty areas of dental medicine, such as general dentistry, pediatric dentistry, oral surgery, orthodontics, and so on. Complex interactions may result for treatment planning depending on the perspective of each group. This requires the introduction of additional mechanisms that represent treatment as an algorithm within the just mentioned context.

The areas of prosthetics and implantology, for example, have far-reaching consequences for the entire dental profession. They can contribute greatly toward achieving high quality patient care following fine-tuning with other dental disciplines (dental conservation, etc.). The highest priority of the methodology must not, therefore, be to propagate prosthetics or implantology for a certain dentition state. Rather, it must be to consider which strategy will lead to substance conservation, and will avoid prosthetics and implantology wherever possible.

However, dental planning can not be conducted satisfactorily if prosthetic needs are not sufficiently considered. If prosthetic treatment is required, the prosthetic must be fastened to an available abutment, which may include conservation treatment. This dilemma of interdependency often exists in dental practices today, especially in cases of transfer patients.

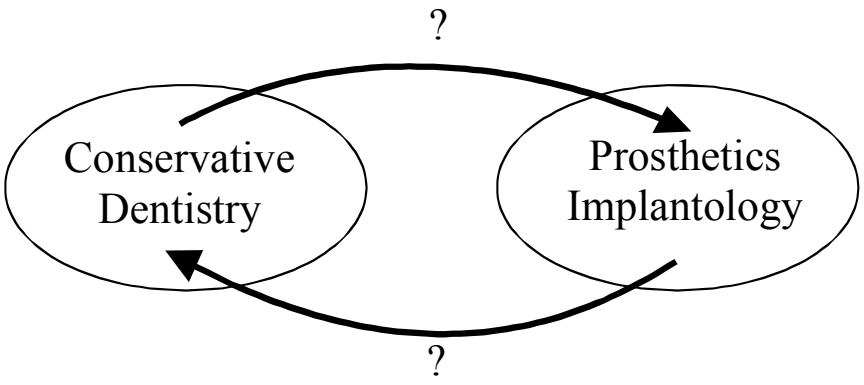

Figure 23: Idealized view of the dilemma of interdependency: Planning conservatory measures is neither possible, nor sensible, without considering the prosthetic necessities and visa versa.

The problem can only be solved using a module that suggests all possible solutions for a certain case. The solutions are then reviewed by another module

in terms of feasibility (see Figure 23). A minimal solution set only is presented for each type of solution. The set is expanded only if the solution is insufficient (e.g., abutment reproduction in cases of insufficient stability) by involving yet another module.

This process creates a rough design with one module and fine-tunes it with another module, whereby the exclusion of a specific solution is also considered fine-tuning.

3.1.5 Routine Examination through Recall

Dentists often consider recall a separate treatment step, since it focuses on specific questions. From the perspective of algorithmic treatment planning however, recall is a combination of time scheduling and the beginning of a new planning phase[31]. Since recall is part of the normal treatment planning process, which can also have the result "no treatment necessary", it is not considered a separate planning step, but rather has been included in the scheduling process.

3.2 GOAL CRITERIA OF THE OVERALL TREATMENT

In the following, the goal criteria are formulated for the overall treatment process in accordance to decision theory. Horch describes the legal responsibilities of a dentist as follows:

"Dentistry is a medical domain, and complete within itself. It is defined as the study of anatomy, physiology, and pathology of the dentition (including the periodontium, jaw and gingiva). It is practiced in the areas of diagnostics, prevention and therapy. The dentist is a physician who, due to his education, is qualified and authorized to diagnose and treat dental, oral and jaw-related diseases, based on scientific knowledge (Statute dated March 31, 1952)" [84].

This process takes place through anamnesis and diagnosis within general and dental medicine. In other words, care provision includes not only the treatment as such, but also diagnostics and treatment planning. According to Chapter 2.4,

[31] It must be kept in mind that a patient's condition can change dramatically from one treatment to another, for example due to an accident. Such changes must be included in a new assessment of the condition, and must be resolved within a following, new, planning process.

planning should be understood as the preparation of decision making. Whereby, information collection of is of underlying importance for any decision making process.

Summary 10: Dental Care

Dental care includes diagnostics, planning and treatment.

- Diagnostics is responsible for collecting and structuring information.
- Planning is the anticipation of decisions [82].
- Ideally, treatment is limited to execution of the treatment plan.

Since a planning process is measured by its expected result, decision theory demands planning must begin with the definition of the general goal criteria. Horch defines the minimal criteria of dental treatment quite generally as follows: "No damage may arise to any part of the organism due to the teeth or jaws" [84].

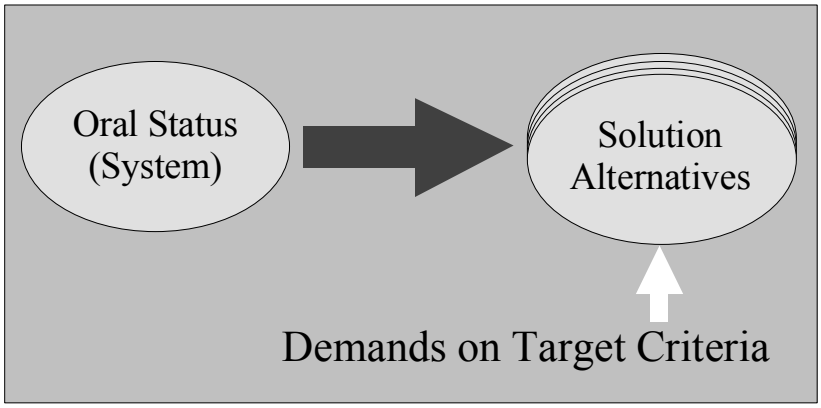

Figure 24: Before treatment alternatives can be generated for a specific dentition, goal criteria must have been defined by which the treatment alternatives are to be fulfilled.

Since the mouth and teeth are essential parts of the face, aesthetic aspects also play an important role in dental medicine. A lacking in this area may have psychic or strongly negative effects on the patient. Therefore, aesthetics play a major psychological role and must be considered during treatment planning[32].

[32] Phonetic functionality and the psychological image given by the teeth during stressful situations (e.g. "to grit ones teeth") are neglected in this simplified, static perspective.

Summary 11: Requirements placed on dental goals

- Full functionality is required for mastication. Hereby, functional relationships must be taken into account.
- Full consideration must be given to aesthetic aspects to support the psychological well-being of the patient.

As mentioned previously, the cost aspect must be kept out of the actual medical goal and the basic treatment alternatives generated, to prevent accidentally excluding treatment alternatives during planning[33]. Therefore, the definition of the actual medical goal criteria is derived from the requirements placed on functionality and aesthetics. The costs can then be calculated for each medical alternative and compared with the quality of each solution.

[33] The decision model offers dental solutions, which serve as the essential baseline between sensible treatment alternatives (sensible in the sense of the guideline). A sensible alternative can then be selected based on a certain motive, which can be selected, or preferred, from a selection of motives. One such motive is, for example, the price.

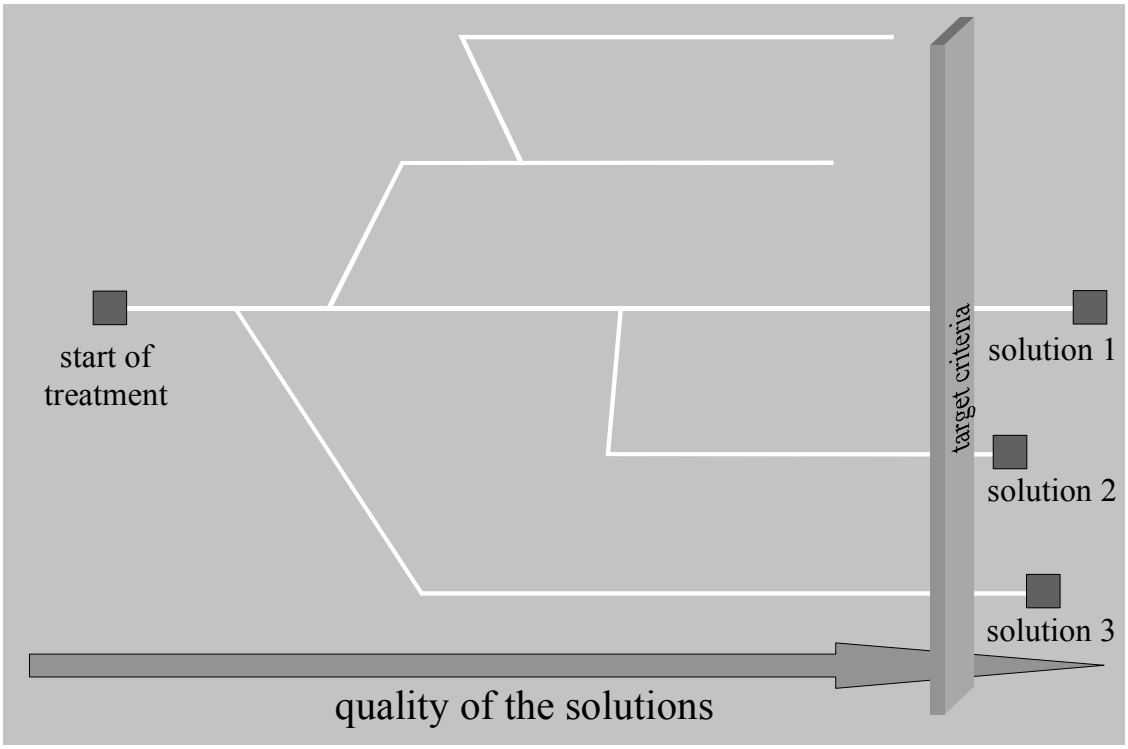

Figure 25: The possible treatment steps, the treatment alternatives and the quality of their outcome: The routes represent treatment phases and their effect on the quality of the outcome. The quality of the outcome can decline within individual treatment phases, for example by preparing teeth for use as abutments in bridge constructions. This temporary reduction in quality may be necessary to increase the quality of outcome of following steps, and, therefore, of the overall outcome.

The case-specific quality of treatment should, therefore, meet certain goal criteria. The level of aspiration (see [83]) should at least be reached, better yet surpassed. The set quality criteria must be met. In other words, they are not optional, but rather represent minimal requirements for sound treatment[34]. At the same time, from a biological-physical view, a systematic ideal state should be targeted, in case an exact state can not be reached.

In accordance to decision theory, further conditions can be defined for the general framework of the treatment process:

Definition 22: Steps necessary for the treatment process

[34] It should be said that the quality of treatment does not depend on the dentist alone. The role of the patient should not be underestimated for achieving treatment success.

1. Individual planning of the treatment goal to fulfill the general goal criteria.
2. Generation of possible treatment alternatives.
3. Planning the steps of the treatment process.
4. Collection of additional information to support the decision process.
5. Discussion of the selection of suitable treatment alternatives.

To sensibly structure dental goals, a super-system (compare Chapter 2.4) must be found that is able to describe the occurring interactions with sufficient precision. Hereby, the question arises, how such a system can be structured. Which areas are to be excluded from the planning process must be brought out clearly.

A large share of the treatments in general medicine, for example, do not include dental treatments. Acute diseases, which do not allow dental treatment[35], can not be included in the actual planning process. These cases must be allotted other medical areas to avoid overlaps. This is why they are not included in the decision methodology. Cases also exist within dental medicine itself that make their integration into a comprehensive treatment plan impossible. This may be because either not enough time is available for treatment planning[36], or the problem, due to its abnormality, must be viewed fully independently of the others[37].

Both cases have also been excluded from the methodology. Pain, however, is generally a condition that should be alleviated and, therefore, should be included in the planning process. In the following, goal criteria are presented from which a planning process results. Even if the goal criteria have only been described

[35] Example: Hemophiliacs.

[36] Example: Extreme pain.

[37] Example: Tumor treatment must precede all further dental treatment planning. It can, however, have an underlying effect on any further planning. For example, the successful application of a jaw prosthesis/epithesis following gnathic resection. Facts may arise from the treatment that may be of importance to a following diagnosis. After repeating the treatment planning process, these new facts may flow into the overall treatment plan for the first time. Tumors are generally not a dental problem alone, because they stand in close interaction with general medical problems.

roughly at this point, a selection of treatment alternatives can be derived from them, as the following chapters will show.

3.2.1 Function of the dentition

As mentioned earlier, the dentition offers the vital function of preparing nutrition for digestion. Simplified, mastication occurs by grinding movements of the jaw, by which food comminution takes place between the masticatory surfaces of the dental crown. The individual teeth should be positioned in a row, without gaps. Also, every tooth must have an antagonist, to prevent its elongation.

For humans, it is, therefore, essential to have a complete, well-positioned set of teeth[38]. Respectively, the dental row is fastened to both jaws, which, in turn, supported each other[39]. The function of the dentition should be lastingly secured, to prevent unnecessary invasion of the oral structures.

Summary 12: Functional goal of the dentition (simplified)
The functional goal of the dentition is mastication, which prepares food intake by the digestive system. This function must be secured lastingly.

Full dentition functionality means:

- That functional dental crowns must be available on the alveolar ridge to ensure that mastication can occur.
- The antagonistic dental crowns must be moved against one another via the jaw, its joints and muscles to allow mastication[40].
- The teeth support the lower jaw during the mastication process and, thereby, relieve the jaw joint. Therefore, the dental row should be long enough

[38] Completely in the sense that minimal criteria must be fine-tuned.

[39] Phonetic development and the possible development of postural anomalies over time have not been included in this static perspective of dental medicine.

[40] The entire movement can be reduced to a back and forth, as well as left and right movement.

3.2.2 Dentition Aesthetics

The teeth not only fulfill functional criteria. Their shape and color must also meet aesthetic criteria. They be positioned in a harmonious row. A balanced, aesthetic appearance can be seen as an important moment during treatment planning. Therefore, aesthetics also fulfills a function. However, since it can not directly be derived from topological interactions, it must be defined separately:

Definition 23: Aesthetic goal of dental medicine
The aesthetic goal of the dentition is the advancement of the psychological well-being of a patient. Aesthetics should be ensured permanently.

The focus of aesthetics in dental medicine is placed on the visible area of the dentition. Therefore, the proposed definition of goal criteria for aesthetics also includes the dental crowns. As long as the remaining teeth are in a correct position, aesthetic rules can be defined for the targeted state of the dentition. It must be said in this regard, other structures of the stomatognathic system also possess individual aesthetic goals that bring on additional boundary conditions.

All dental crowns within the visible area of the oral cavity should be present, since a gap does not correspond to our perception of aesthetics. In the following, we, therefore, assume that the first five[41] dental crowns should be present in each quadrant, since only these are visible from the outside. To transport the impression of a healthy dentition, the dental crowns should form a regular arch and be regular in the size and color.

[41] The number “five” stands for the minimal number of present crowns. This parameter can be adjusted if needed. The following approach does not depend on the definition of this figure. It has been defined here for the purpose of easier comprehension.

Summary 13: Aesthetic goal criteria[42]

- A complete dental row should exist within the visible area of each jaw, at least the first five (visible) dental crowns per quadrant.
- The dental crowns should have a (relatively) natural size.
- The dental crowns should possess a natural color.
- The dental crowns should form an inconspicuous, harmonious dental row.

As was shown in the functional analysis, the dental roots, jaws and mucous membrane, etc. provide the basis for realization of the targeted condition of the dental crowns. One can only speak of a fully functional dentition if a fully functional topology of the dental crowns is given based upon a fully functional constellation of the underlying structures. The further model defines the minimal aesthetic goal criteria in a simplified form:

Definition 24: Minimal aesthetic criteria

- Dental crowns 1 – 5 should be present in each quadrant.

3.2.3 Cost of Treatment

An estimation of the costs is relatively easy based on the standing regulations, laws, and payrolls. A standardized treatment and budget plan can be established, because the required materials, the duration of treatment, and the treatment effort involved following planning are known. The costs themselves do not influence the generation of possible treatment alternatives. They do, however, pose an important boundary condition for selecting a specific therapy.

It is in the best interest of the patient to keep the cost of treatment as low as possible, without letting the quality of treatment sink. Since the costs often oppose the improvement of the quality of treatment, an optimization of the cost-benefit relationship must be strived. The treatment costs are kept out of the medical argumentation, because coherent treatment alternatives must be presented first. After the individual treatment alternatives have been generated, it

[42] Dental measures can also, for example, be to make sunken lips appear more youthful by supporting the teeth. This, however, plays a minor role in defining the basic dental treatment alternatives and is not described further here for sake of clarity.

is conceivable to limit the selection based on the price, thereby not giving the more expensive therapies further consideration. However, within the scope of comprehensively informing the patient, it is necessary to present even high priced solutions – with all their advantages and disadvantages. The basic possibilities must be discussed with the patient. An expensive therapy can, under certain circumstances, be more affordable in the long run than the follow-up costs involved in a seemingly affordable alternative. This relationship can, however, not be predicted with absolute assurance, since prognoses always involve a certain degree of uncertainty.

Summary 14: Cost framework

1. The costs have no place in the investigation of the medical problem area.
2. Therefore, in accordance to decision theory, a medical model should be developed to generate sensible treatment alternatives.
3. A higher-level methodology to calculate the costs can be added to the medical decision model. The treatment alternatives can then be compared according the costs they accrue.
4. The cost of a certain treatment alternative should be kept to a minimum wherever possible.
5. This often opposes the improvement of the quality of treatment.
6. Therefore, an optimization of the cost-benefit relationship is required.

3.2.4 Epicrisis[43]: General Goal Criteria versus Under and Over Treatment

The distance between the expected treatment results and their ideal state must be estimated and translated into a quality measure to allow a neutral evaluation of the proposed treatment alternatives. The closer the result meets the ideal state, the better the treatment quality is evaluated. Hereby, it is important to allow a

[43] Epicrisis (compare [78,85]): Conclusion; the final critical evaluation of the course of a disease, mostly in form of a report including differential diagnostic findings and the final diagnosis. Since planning does not have an ex-post effect on treatment, the possibilities of over and under treatment are discussed here.

comparison to other treatment alternatives In other words, not to define the quality absolutely. The units of measure of the distance can be defined freely. Each of its dimensions represents only one verifiable aspect of the overall treatment plan.

It is not important whether the distance to the ideal state is measured in terms of length, size, weight, cost, or life span. Since evaluations always include personal assessments, it is not possible to draw a normative measure directly from nature. People with physical disabilities can encounter certain problems with prostheses due to their handicap. For example, certain aspects of dental hygiene can not easily be mastered. Another example, is an actor, who needs very (aesthetically) good teeth for his profession. The examples show that the priorities can shift, which can not be stated in scientific rules. Therefore, a definition must, if necessary, include experiences based on the consensus of the social groups involved.

Criteria are required to recognize the signs of over and under-treatment, and to allow verification that the treatment results are based on generally acknowledged, scientific methods (compare [83]). Under-treatment can be recognized easily based on the general goal criteria and the patient-specific criteria drawn from them. Under-treatment is given if at least one goal criterion has not fulfilled. Therefore, the necessity for further treatment can be taken directed from the treatment methodology.

Recognizing over-treatment is more complicated, since it may be overseen by the minimal goal criteria. Basically, from a purely medical standpoint, a slight amount of over-treatment must be expected, since the quality criteria should generally be improved. The counter question here (What is absolutely necessary?) can only be answered with great difficulty, because the individual differences and patients needs contradict a uniform argumentation. The consequence of this is: Scientifically founded evaluations for comparing treatment alternatives can not be drawn at this point, even though good planning delivers arguments for the reliability of specialized treatment, and helps to extend the boundaries of minimal treatment. From a medical perspective, an absolute evaluation does not make sense, since the ideal state can only be approximated, but not reached, e.g. in cases of reconstruction.

In addition, over-treatment can only be estimated in relationship to the efforts arising from it for the dentist, patient and society. Such questions surrounding over-treatment apply mostly to costs and, therefore, do not belong to the medical questions concerning the case.

The difference between medical problems and their financial aspects is grave considering that decisions in each area are made by fully different entities. Since this research work centers around medical argumentation, further examination of the possible treatment alternatives regarding other aspects is not conducted. The risk of over-treatment is reduced, however, by informing the involved parties of the possible alternative as soon as possible.

In how far society is willing to take over the costs of treatment should be detached from the argumentation of medical decision making. Dental over-treatment is not usually harmful, as seen from a purely medical perspective. The highest amount of conservation of natural oral structures and a dentition that meets the dental goal criteria are strived while minimizing the resulting costs. No desired, however, is an undue destruction of natural structures and the burden resulting from unjustified costs.

Therefore, the term over-treatment should not be judged generally, but rather according to standardized treatment methods. The goal criteria are, therefore, used as the lower boundary for solution alternatives only. Each concrete treatment alternative is described comprehensively.

Summary 15: Types of over-treatment

- Excessive destruction of natural structures[44].
- Excessive timely and physical burden due to treatment.
- Excessive efforts for all parties involved in the treatment.
- Excessive costs[45].

A measure for over-treatment must be defined based on the goal criteria. If the minimal treatment requirements can be derived directly from the goal criteria, over-treatment should not occur in the first place.

[44] This type of over-treatment reaches into the area of bodily harm.

[45] As mentioned earlier, this evaluation takes place outside of medical argumentation.

3.3 TREATMENT SUB-GOALS

Patient-specific treatment sub-goals can be drawn based on the higher-level definition of the treatment goal. These individual goals should be derived from a combination of the general goal criteria and the patient-specific status. This guarantees the stringent combination of the individual case with the general methodology.

As described previously, before dental treatment can take place, the general medical requirements must be met that could cause the exclusion of all or one treatment. Since the underlying medical questions do not directly effect dental medicine, we assume that non-dental problems must be clarified prior to conducting treatment planning as discussed here, even if they are a part of the dental work.

The conservation of the natural structures of the dentition is strived as far as possible during treatment. Conservation can occur only after defective areas have been regenerated. With the help of modern treatment methods, musculature, bones, and nerves can be regenerated. Upon this basis, even completely missing structures can be reconstructed nearly completely.

The dental substance itself can, however, to date, only be replaced by unnatural substances, since the ameloblastic tissue degenerates after the crown has matured. From then on, the enamel is supplied with minerals only. Therefore, the dental substance can be strengthened therapeutically, but it can not be regenerated.

Modern materials are used for dental restorations. While there are a number of treatment methods available, the following will draw upon minimally invasive methods. Only if these are not sufficiently stable, the minimally invasive treatment method will be expanded upon.

Basically, due to their different characteristics, treatment methods can not always be compared directly. As long as a unique evaluation criterion is not available, the methods are considered equal. Future developments, especially clinical studies in the area of EBD, can help to identify superior alternatives.

3.3.1 Goals of (Preparatory) Non-dental Measures

A dentist must not only see the dental problem at hand, but also the acute problems that correlate indirectly with dental medicine. This may lead to a transferal (e.g. circulatory disorders) or even to acute measures (e.g. bleeding).

These underlying conditions must be cleared before beginning dental treatment planning, or treatment, can begin. Since the field of general medical problems is very wide, from the perspective of system theory, it can not be the task of dental medicine to deal with them. Therefore, these problem areas have been left out of the methodology presented here. The general medical measures required are seen as the preparatory measures required for beginning with dental work.

The knowledge a dentist must have beyond dental medicine must be clarified by a higher-level entity. This entity is responsible piecing the individual medical domains (dental medicine, internal medicine, dermatology, etc.) together to form the overall field of medicine. It must also delegate the responsibilities to the domains accordingly.

Summary 16: Demand for treatment feasibility

Dental treatment can only be conducted if acute problems existing outside of the stomatognathic system, which could limit or hinder the treatment measures, have been eliminated.

3.3.2 Goals of therapy

After clarifying the preparatory measures, the existing natural structures should be recovered as far as possible to meet the general and patient-specific goal criteria[46]. This will be known as therapy in the following. It builds specifically upon the clinical and laboratory examinations and pursues the goal to treat or heal patients. In other words, the greatest possible regeneration of natural structures to come as close to the ideal state as possible[47]. Undertaking

[46] Patient-specific goal criteria are not defined by the patient alone. Moreover, they represent the transferal of general requirements to an actual case.

[47] This can be limited in part by the goals of reconstruction. Specifically, the use of prosthetics can make adjustments to natural substances necessary.

precautionary measures to avoid damage to natural structures is also a task of therapy.

Definition 25: Types of therapy [78,80]
(with overlapping application areas)

- Measures for healing diseases
- Etiotropic or causal therapy to remove the causes and triggers of diseases.
- Symptomatic therapy to ward off the appearance of disease
- Unspecific therapy (aims at generally supporting the healing process).
- Conservation therapy without surgery, possibly with help of medication
- Operative therapy using surgical measures
- Also, radiation, dietary, functional, hormonal, physical, and manual therapy
- Intermittent therapy, psychotherapy

The goals of therapy regard functionality as well as aesthetics. Wherever possible, the attempt should be made to treat masticatory disorders by conserving and regenerating natural structures. Within this context, acute problems should not reappear during treatment. Pain, infection and severe functional defects can lead to impairments of the processes surrounding mastication. Therefore, these problems must be remedied during therapy, even if unnatural substances must be implemented to restore or conserve natural structures (e.g. fillings or root pins). The conservation of natural structures is always the primary objective. Artificial materials are considered supports for natural structures[48].

[48] Although artificial materials are used, these forms of therapy are considered conservation measures, since their purpose is to conserve natural structures.

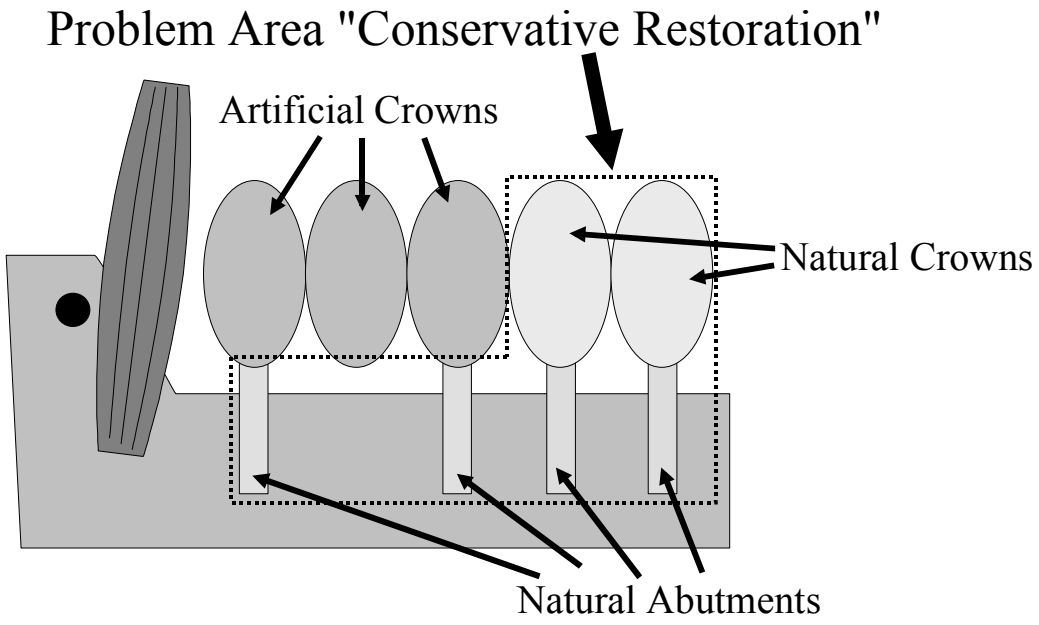

Figure 26: A schematic example of a therapeutic problem area: the natural structure of the teeth

3.3.3 Goals of reconstruction

Natural structures can not always be regenerated to the extent that the general goal criteria can be fulfilled (e.g. a missing tooth that must be replaced). Because a "permanent" tooth[49] can not grow back, its goal-oriented regeneration in the sense of therapy is impossible. In such cases, the attempt is made to approximately achieve the aim set by the goal criteria by using a suitable construction. For such problems, prosthetic and implantology measures are available for permanently applying artificial material to the stomatognathic system of the patient. An important criterion, hereby, is that the artificial constructions may be applied only to the extent to which they are absolutely required. A minimum of prosthetics should be planned to meet the general goal criteria.

The restoration, in this context, serves to conserve the natural structure. The reconstruction replaces missing structures to the extent of reaching the goal criteria as closely as possible.

[49] dentes permanentes =: permanent teeth; Dentes decidui =: deciduous or milk teeth

Definition 26: Reconstruction

- Support the conservation of natural structures by using artificial materials.
- Complete or replace natural structures by using artificial material in order to reach the targeted state.

To define the necessity of reconstruction, non-regenerative natural structures must be defined. A first approach to such a definition is the description of dental regions. The shapes of the possible constructions play a minor role in this case. More importantly, the actual problem areas must be highlighted and defined. The actual construction may extend beyond the problem area. This may be necessary, for instance, if the construction can not be fastened within the defined area.

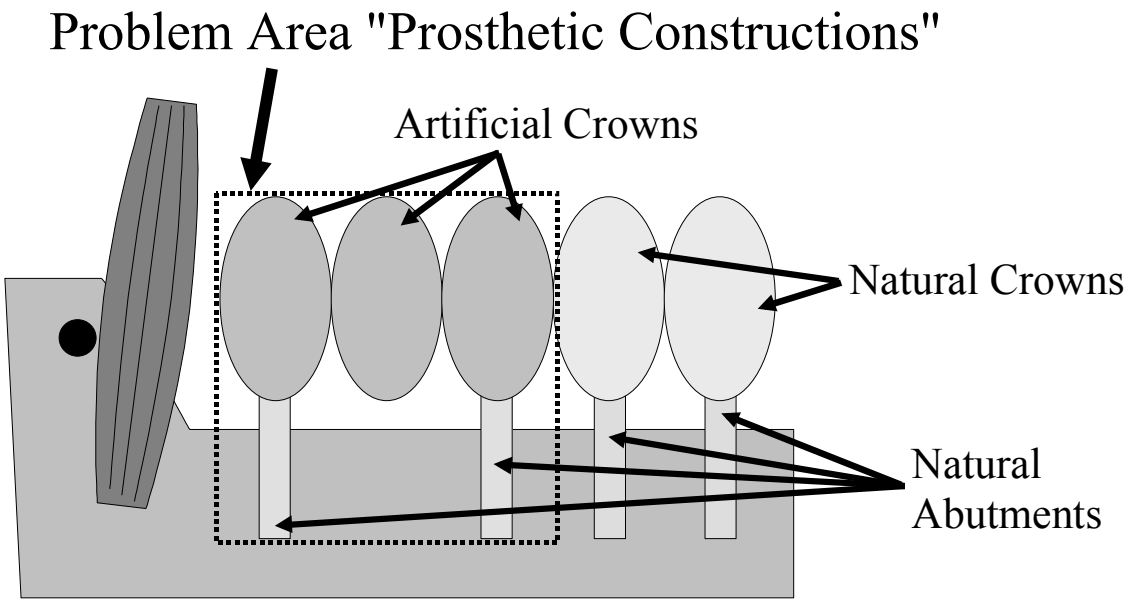

Figure 27: Problem area "prosthetic construction". The area requiring reconstruction, however, is defined without mentioning possible solution constructions. This approach supports the view of cause, effect and planning.

3.3.4 Interactions between Therapy and Reconstruction

Since the artificial structures must be attached to natural ones – with as little, or no, damage to these as possible –, it is necessary to plan the least amount of prosthetic support required. Least refers to the biological and mechanical

burden, as well as to the required degree of invasion posed upon the natural structures during insertion. The effects of the construction on the natural structures should be estimated and be clearly presented to those involved in the planning process. This is important to comprehensively evaluate the benefits and the burdens placed on the patient.

Summary 17: Consequences of the interactions between therapy and reconstruction

1. Plan a low-burden construction while considering the benefits and efforts involved .
2. Assess the effects the construction will have on the natural structures.

Since the goal criteria of therapy and reconstruction overlap, a their definitions differ only in details. Both treatment approaches complement one another. Therefore, the goal criteria of the overall treatment should be formulated on a higher level. The requirements therapy and reconstruction place on the goal criteria lead to boundary conditions. These conditions have an impact on the generation of treatment alternatives.

3.4 SUMMARY OF THE MODEL FOR DEFINING DENTAL GOALS

This chapter began by deriving the goals of dental medicine, including their tasks, from the overall goals of medicine. Thereupon, it analyzed where decisions are required in dental medicine. This question is directly connected with a topological analysis of the human dentition. For this reason, functional relationships were explained. Beside dental function, dental aesthetics play a major role in dental medicine. The aesthetic demands can, , be seen as an extension of the functional goal criteria in this context.

As explained, the costs must be kept out of this medical argumentation. Concerning deterministic decision making, there is no scientifically proven connection between medical decision making and financial argumentation, because personal aspects play a too large and important role.

The comprehensive dental goals defined can be broken down into sub-goals for which goal criteria can be defined:

Summary 18: Procedures for defining dental goals

1. Clarify the goals for the preparatory measures outside of dental medicine.
2. Set goals for dental therapy.
3. Set goals for dental reconstruction .

Basically, all dental measures can be seen as preparatory measures for reaching the overall treatment goal. From the perspective of dental therapy, preparatory orthodontic and oral surgery measures must be given consideration in planning stages of their own.

4 GENERATING TREATMENT ALTERNATIVES

As described in Chapter 2.4, planning includes the anticipation of decisions. Above, the medical and dental goal criteria that should be met by planning were defined. They are the constants of the treatment planning process, since they must be met for all people and are, therefore, invariant. They can also control all of the treatment quality criteria (structural, process and outcome).

The process of generating treatment alternatives is to be discussed in this chapter. In combination with each status description, a call for action must be drawn from the general goal criteria. The following will distinguish between the generation of treatment alternatives (status after treatment) and the generation of the respective treatment processes (timely sequence of the treatment steps) for the sake of clarity.

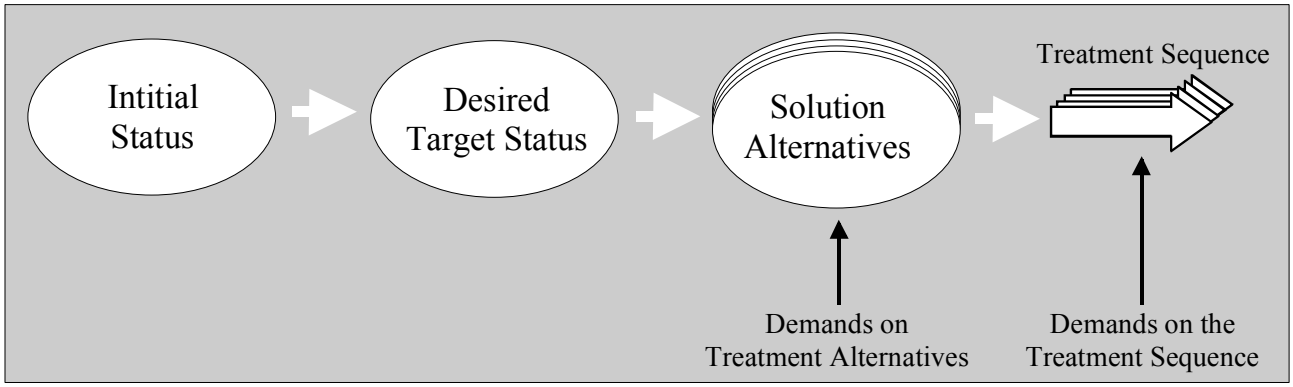

Figure 28: The steps and means of treatment planning (status after treatment) and treatment process planning (timely sequence of the treatment steps) are discussed in this chapter from a dental perspective.

The following understands treatment planning as the transformation of a patient's status to its targeted state. The treatment process is generated based on these transformations. This planning phase treats decisions in such a way that, ideally, treatment is the mere realization of the completed treatment plan.

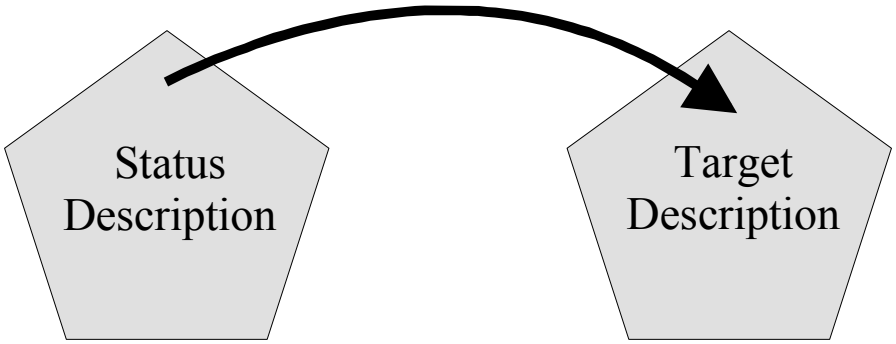

Figure 29: The patient status is, in accordance to model theory [51,52], a simplified representation of its real state.

At this point, it should be repeated that the practicing dentist may expect the discussion of certain related topics areas. Again, we recommend the reader gain an overview of the structure of this research work before reading this chapter.

4.1 BASIC STRUCTURE OF THE IDEALIZED DECISION METHODOLOGY

From an information technology perspective, a decision methodology is a structure into which information is given, is processed by it, and, finally, outputs the results. The methodology is represented by actual knowledge. This knowledge is used to draw each conclusion and, thereby, tightly fastens the inputted information to the outputted information. The methodology should be flexible enough to adapt to new circumstances and be expandable. Therefore, its status can be taken as the current convention of decision making.

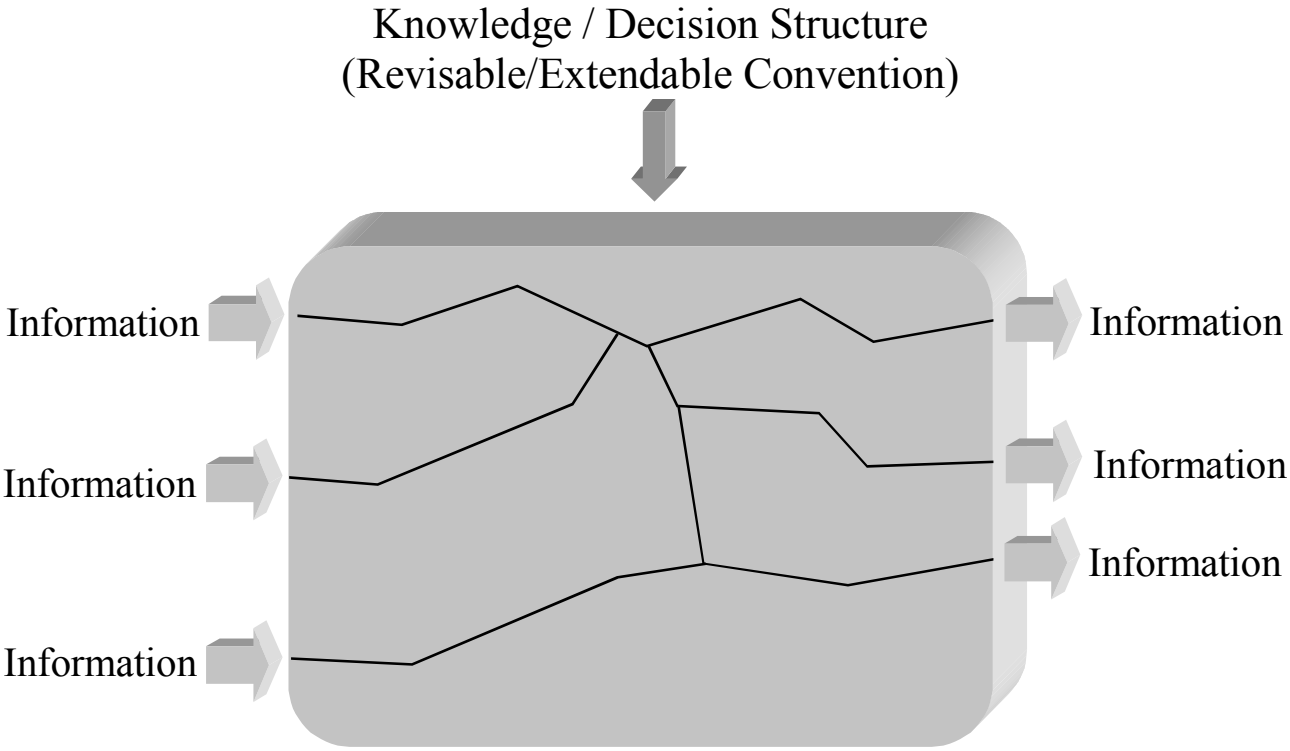

Figure 30: Information and decision structures: The methodology defines an expandable convention.

According to Gross and Löffler, information can be sorted into three categories "secure", "risk" and "insecure" [42]:

- In the first case, all information required for a decision is available. Therefore, one can speak of "certain knowledge".
- Although the information" "required" to make a decision under risk is available, it is available in form of probabilities. Therefore, one can not speak of "complete, or perfect knowledge".
- In contrast, a decision is "uncertain" if not even probabilities are given. In this case, only processing aides, not fixed rules, are available,.

Certain knowledge is required for a dental decision methodology to reach an unique decision for an individual planning case, and to define its unique treatment steps. In addition, a strict formulation makes the model criticizable and, thereby, supports its targeted improvement. Based on this, a scientific improvement of the methodology and the continual success of the approach are made possible.

Uncertain knowledge flows into the overall methodology, but is not modeled explicitly. Rather, uncertain decisions are considered a "black box" whose

possible outcome conditions are listed as decision or action alternatives. This leaves the option to fine-tune a model or to define preferences between alternatives open for the future. The strict modeling of uncertain knowledge does not stand in conflict with the development of a higher-level decision methodology for dental medicine. Rather, it brings many respective research questions to light.

To answer the question of how planning is best conducted, again, general known modeling rules should be used: In accordance to decision theory, Wittmann defines a decision model as a formal representation of a decision process that has a defined goal and from which alternative solution can be drawn. The set of all alternatives is known as the decision space or permissible range. [74]

Dental medicine (in contrast to other medical domains) has the advantage, that the oral region can be accessed comparatively well. Many functional structures can be evaluated visibly and manually, so that the status of the patient can be determined quite accurately. Due to the predominately uniform language used during diagnosis, the patient status can be described with one completely filled out standard diagnosis form, making the selection of an individual solution possible. Therefore, we will investigate in how far the basic direction of the treatment can be determined from this basic information.

decision and system theory methods are used to restrict the underlying problem area to dental medicine. This will give structure to the underlying methodology. As decision theory demands, the basic goals of medicine have also been included in the methodology (compare Figure 31).

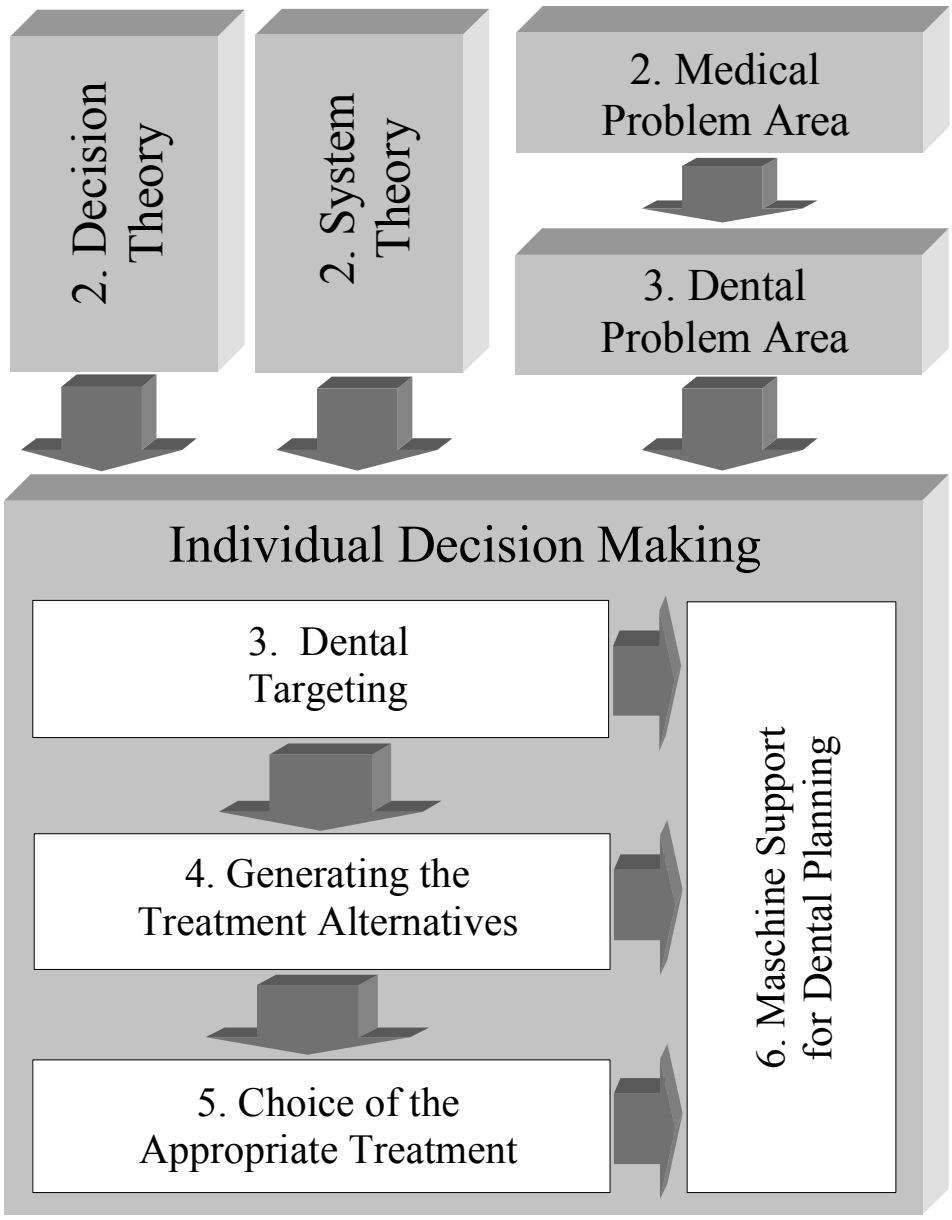

Figure 31: The foundation of the decision methodology results from decision and system theory, as well as from the medical goals. In combination with patient-specific data, individual decisions can be drawn (the numbers listed before each phase corresponds to a chapter of this work).

4.1.1 Basic Decision Module

As described in Chapter 3.3.1, non-dental measures are kept out to the following observations, since they are the responsibility of other medical domains. Both the order in which the problem areas are presented and, later, the definition of a decision process, are limited to the dental domain.

The goals of dental treatment were presented in Chapter 3. Now, in accordance to decision theory[50], conclusions are drawn based on the treatment alternatives. To guarantee goal-oriented individual planning strategies, a common informatics approach is put to use: Backward chaining (compare [38,86]) allows backward planning by beginning with the final goal criteria. This way, it can be guaranteed that a reliable solution is found, without having to search for it. Other methods would require additional control mechanisms to determine whether the solution complies with the goal criteria. This would, however, not support the clarity desired from a targeted approach.

A simple example can help to improve understanding: the application of dental crowns can be planned in the required number, position, color, etc. by beginning with the goals of functionality and aesthetics. Requirements are derived and passed on to the underlying structures based on the general definition. In other words, the remaining structures are not changed "randomly". First, an acceptable result is found. Moreover, all necessary preconditions must have been met in order to find an acceptable solution. Each measure that supports meeting these requirements can be seen as a possible alternative. In other words, as seen from the perspective of the module, requirements are also goal criteria for following subsystems.

"Underlying" oral structures can also possess own goal criteria (e.g. gingival condition). This is why it can occur during planning that a goal criterion of a possible alternative is excluded, relatively or absolutely. In case of a relative exclusion criterion, certain additional measures can be undertaken to resolve the exclusion. In case of an absolute exclusion criterion, on the other hand, a specified goal criterion can not be fulfilled. This leads to the definite exclusion of the alternative.

Definition 27: Relative and absolute exclusion criteria

- A goal is excluded relatively if the exclusion criterion can be resolved by an additional measure.
- A goal is excluded absolutely if the exclusion criterion can not be resolved by additional measures.

[50] Compare also phase theory in Chapter 2.4.

4.1.2 Areas Not Included in the Model

4.1.2.1 Pediatric dentistry

Pediatric dentistry holds a special position in dental medicine. Since the childhood dentition is not completely developed, a different type of balance must be found than for adult dentitions. An analysis of the special aspects of this area of dental medicine is postponed until the analysis of adult dentistry has reached an acknowledged standing. In accordance to backward planning, developing dentitions should be supported in such a way that the goal criteria can be reached optimally.

The developmental phases of the dentition can not yet be dealt with in this static view of dental medicine (compare Section 1.5). Therefore, the follow will not go into pediatric dentistry. It should only be pointed out that the age of the patient demands an additional criterion for treatment planning. Accordingly, the overall methodology should be structured in such a way that a later inclusion of pediatric dentistry can be seen as a further specification of the already available measures.

4.1.2.2 Acute exceptions within adult dentistry

Before a comprehensive approach to treatment planning can be described, it must clear which measures are to be excluded. In cases of severe pain, for example, it is not possible to collect comprehensive information for treatment planning, due to a limited amount of time[51]. Therefore, measures must be undertaken to alleviate the acute condition prior to beginning treatment planning.

Certain problem constellations require quick action. An example besides acute pain, is treating infections. A process quality standpoint shows that, although

[51] The definition of which problems are acute and can, therefore, not be included in comprehensive planning will surely change in the course of future research and technology. The aim for the long run should be to one day include all dental problem areas into the overall treatment planning concept, in order to be able to conduct treatment overall upon a founded basis.

desired from a outcome quality perspective, it not always possible to establish a long-term treatment strategy, even after carefully assessing the possible treatment measures.

Therefore, acute measures must be adhered to prior to comprehensive planning, even if this does not coincide with the purpose of planning. However, the measures taken can be seen as preparatory measures for the actual dental treatment.

Which measures these are in detail can not be defined theoretically alone. Rather, it is often a matter the discretion between the dentist and the patient (e.g. how much pain is acceptable). The processes actually being used in practices play an important role, since they have a strong influence on the timely framework. For the goals set so far, it has been assumed that planning and treatment are not limited by time. This does not apply in acute cases. It should not be overlooked that acute cases can considerably influence the entire treatment planning process[52].

4.1.3 Areas of the Underlying Model

Once the acute problems have been solved, dental treatment planning can actually begin. Hereby, a strong interaction exists between (a) the regeneration of natural oral structures (therapy), and (b) complimenting natural structures by using artificial constructions (reconstruction).

It should be pointed out that in the following sections, the order in which the results (of the above analyses) appear is the order in which the analyses were discussed. This does not necessarily comply with the order of treatment planning procedures used by a dentist.

4.1.3.1 Conservation and strengthening of natural teeth and roots

Defective natural teeth can often be repaired by using artificial materials. The conservation of natural structures can, in some cases, actually be made possible only by use of these materials. Therefore, in cases of restoration, two distinction must be made:

- Conservation of a tooth/abutment integrated in a prosthetic construction.

[52] An apical root end resection/apicoectomy, for example, will have an effect on the value of the abutment, as well as on the prognosis of a tooth.

- Conservation of a tooth not integrated in a prosthetic construction.

The following questions arise for natural teeth and roots.

1. Are the effected teeth worth saving? Can they ensure full functionality and aesthetic requirements on a long-term basis?
2. Are the abutments used to fasten prosthetic constructions sufficiently stable for long-term anchorage? Are additional abutments needed in the construction to ensure the necessary stability? Is an extension of the prosthetic possible if necessary?

the minimal requirements in terms of invasiveness can be estimated by answering these questions. Restoring natural structures may not make sense, for example, if the effected abutment is to be used in a prosthetic construction.

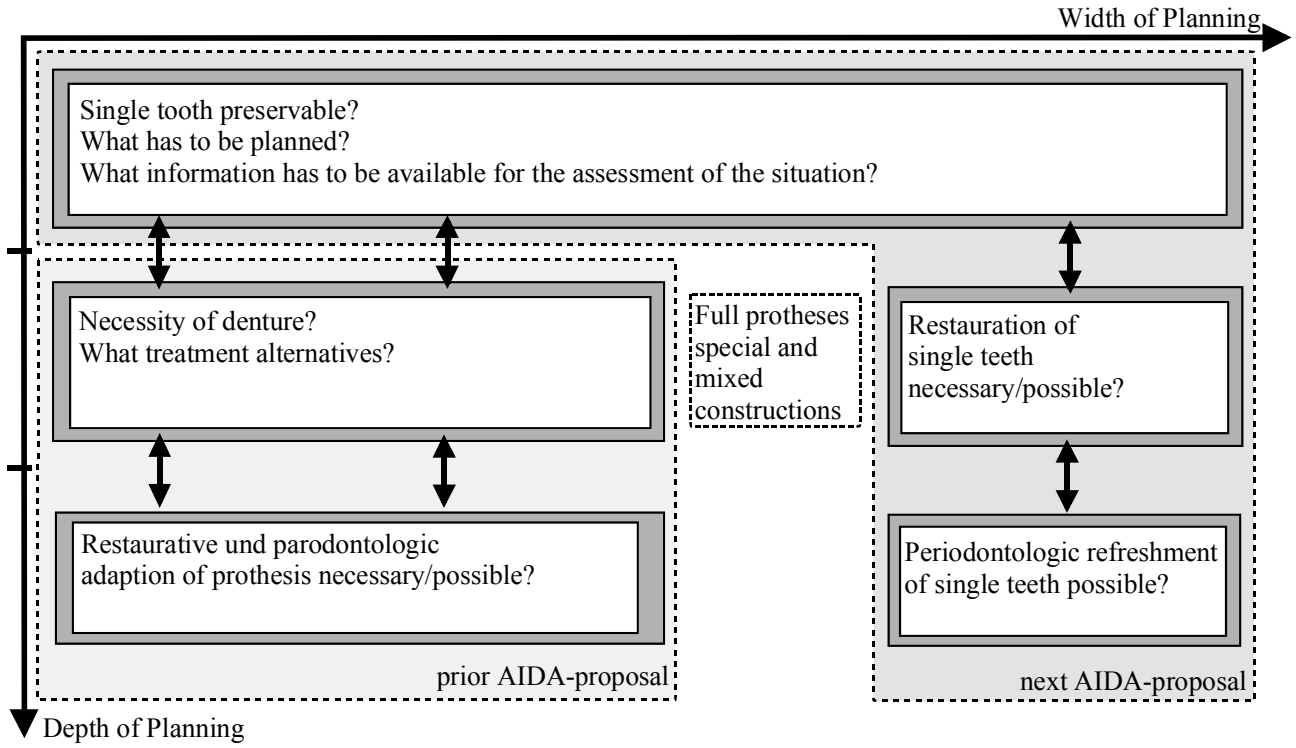

Figure 32: Relationships within conservation treatment, with and without consideration of prosthetics.

4.1.3.2 Improving the value of an abutment

Especially the periodontium must be examined to estimate the value of an abutment. The periodontium links the natural root with the jaw. Evaluating the capacities of these structures may help determine whether special measures are

required to strengthen them and to ensure their future capacities. In this regard, the following questions arise:

a. For a natural tooth:
    1. Is the periodontium capable of lastingly compensating the forces acting upon it on?
    2. Can or must the value of the abutment be improved?
b. For implants:
    1. Is the implant capable of lastingly compensating the forces acting upon it?
    2. Can, or must further abutments be included/implanted to stabilize the construction?

Measures may become necessary to answer these questions. In case the periodontium is not capable of carrying the prosthetic construction, either an extension of the prosthetic construction offers more stability, or an absolute exclusion criterion is given. In this case, a leap back into the dental crown planning phase must be made (see Chapter 4.1.3.1).

4.1.3.3 Closing a partially edentulous arch or an incomplete dentition

Whether a prosthetic is needed can be estimated after determining the value of the teeth and the abutments. A functional and aesthetic analysis shows that only the goal criteria of the dental crowns are not subject to further dependencies. Much more so, the requirements upon which the "underlying" structures are based result from the crown goal criteria, which is why treatment planning begins with the dental crowns.

In order to evaluate the position and condition of the teeth and dental crowns, however, dental crowns must be present. In case of gaps, the question or necessity of a so-called gap closure arises[53]. This term most often applies to orthodontic measures used to close a dental gap. Every form of dental crown restoration can be referred to as a gap closure in order to allow a comprehensive discussion of the matter.

Definition 28: General gap closure options

[53] Not every gap requires closure. Within the scope of reasonability, it must be clarified if a gap can be left open, e.g. in cases of financial restrictions.

- Minimizing the gap/ gap closure using orthodontic measures.
- Minimizing the gap/ gap closure using reconstructive[54] measures.
- Minimizing the gap/ gap closure using a combination of orthodontic and reconstructive measures.
- Gap closure using prosthetics.

Since a solution not using artificial material is preferred one using artificial materials, an initial examination of possible orthodontic measures must be conducted. If orthodontic measures are not possible, an attempt should be made to close the gap using conservation or prosthetic measures. The need for dental crown restorations can be drawn from this demand. Crown restorations are fastened to natural structures. Necessary abutment constructions are derived from the selected crown restorations.

4.1.3.4 Surgical measures

Surgical measures can be considered in case a solution can not be found using the measures mentioned above. In certain cases, for example, teeth/abutments must be extracted to improve the functionality or aesthetics of the dentition. Hereby, the condition of the dentition may worsen temporarily, only to lead to an improvement of the overall condition at a later time.

It may be necessary to jump back to a previous planning module after extracting a tooth. Therefore, the following questions arise:

- Is it necessary to pull a natural root if its prognosis is poor?
- Is jaw surgery necessary?
- Is periodontal surgery necessary?

If a good foundation for treatment can not be achieved even with surgery, it may be that treatment is not possible at all due to medical reasons.

4.1.3.5 Positioning the jaw and teeth

It may be necessary to change the position of the jaw or the teeth in order to provide full masticatory functionality and aesthetics. This can, to a limited extent, be done via the jaw joint. Surgical options also exist to correct the jaw position. In addition, the position of the teeth relative to the jaw can be changed,

[54] Often known as restorative measure by dentists.

for example, by making use of orthodontic measures. This influences the occlusal position and, therefore, the position of the jaws relative to one another.

The muscles play an important role in guiding the lower jaw, and, therefore, is partly responsible for positioning the teeth, since they are attached to the jaw. During biting, the teeth, in turn, guide the jaw somewhat, due to the interlocking effect of the crowns.

4.1.4 Navigation: Decision Making Despite Incomplete Diagnoses

Up to now, we have described which planning modules generally exist and in which order they ideally come to play. However, such proceedings require that the necessary information is available before planning can begin. This can not be expected in practice however. Most likely, the proceedings would lead to an incomplete diagnosis [87]. Ideally, the methodology could decide on its own which information is required when. Actually, however, This decision can only be made during treatment planning, since this is where the focus of the treatment becomes apparent. Therefore, a closer look at the diagnosis is required.

The analysis will take place later using actual examples – such as a standard diagnosis form –, since the information liable to change over time. For this reason, general remarks will be made here regarding the limitations of diagnosing.

Guideline 1: Initial state of the diagnosis

Due to timely, invasive, and technical reasons, it is practically impossible to collect all of the examination results in full detail for the entire planning process. In practice, therefore, it can not be expected that a completely exact diagnosis is available. Therefore, a planning methodology must be able to deliver sensible treatment alternatives based on an innately incomplete process of diagnosing.

It must be possible to draw a rough estimate of the individual case from the diagnoses available. The planning process is, therefore, not only a question of medical knowledge, but also of treatment ergonomics.

The characteristics of diagnosing must effect how decision making is designed. If certain results remain unknown, it must be assumed that either (a) no problem exists, or (b) it must be examined whether the status differs from the targeted state.

A decision methodology can not take over or guarantee such an examination. In this sense, the methodology is a consultant that shows the planner which exceptions regarding a certain alternative coincide with the goal criteria.

Therefore, it always also depends on the extent to which the treating dentist makes use of the decision methodology. He can, for instance, decide whether to extract a severely damaged tooth or to examine the circumstances with help of the detailed criteria defined within the methodology. It must be left open to the dentist to leave the given chain of argumentation if he feels it is necessary. Whereby, it should be made clear to the dentist at which point he left the methodology and why.

4.1.4.1 Treatment alternatives and their feasibility

Due to technical and timely reasons, a exact diagnoses are innately impossible. Therefore, treatment planning must be possible despite this incomplete description of the patient's condition. Since the reasons for excluding a certain treatment alternative during treatment planning may be unknown, it can not generally be assumed that a methodology can offer exactly the solutions that can actually solve the case. Therefore, a methodology is needed that is able to generate all of the temporary alternatives, and, independently, ask for the required details.

A missing alternative is not acceptable, since decision theory demands that all alternatives are known. Therefore, the only possibility left is to offer an oversupply of alternatives. Each offered solution must then be examined in terms of feasibility.

Therefore, the following assumes that feasible solutions will be offered based on the available information. In summary, the following requirements are placed on treatment planning:

Summary 19: Requirements placed on treatment planning

- In case insufficient decision criteria is available, the various alternatives are presented. Therefore, if insufficient information is available, the methodology presents an oversupply of solutions so that no required solution is missing.
- Hereby, it can occur that a solution is proposed and later excluded based on exception criteria[55].

The solution then represents a rough draft that can be fine-tuned in following steps (compare establish and refine [51,52]). In this sense, navigation refers to leading the user to the desired solution set. This applies even then if the actual goal initially becomes apparent during navigation. The feasibility of a certain alternative can be fine-tuned to the desired degree, which, in turn, allows a constant expansion of the methodology. Exclusion criteria must be examined in detail for each of the alternatives offered to ensure the most realistic argumentation possible.

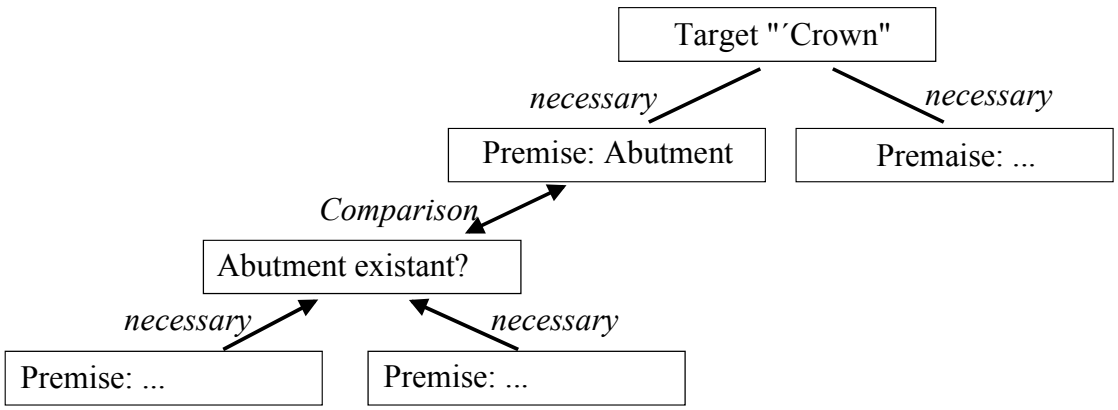

Figure 33: Excerpt of the evaluation of the requirements. Abutments are a necessary requirement for fastening dental crowns. Then, the necessary requirements for the abutments themselves must be examined, and so on.

[55] The generation and evaluation of treatment alternatives serves to argument why a solution that seems feasible at first glance can not be realized. In order to strengthen the trust during patient consultation, it may be important to name the exception criteria.

The above shows that a direct interaction exists between decision ergonomics and the knowledge required for decision making. In turn, it does not make sense to discuss the underlying knowledge without defining the degree of detail required by the decision methodology. Obviously, decision knowledge and decision ergonomics can not be viewed separately.

Before beginning with the actual planning, some premises must be defined concerning the responsibilities of the planning modules. Prosthetic measures, for example, can not be planned without considering conservation. In turn, the conservation measures can not be defined without considering prosthetic measures. Due to this dilemma, a suggestion methodology offers all reasonable prosthetics solutions for an individual case. The conservation dentistry module then examines the feasibility of each of the suggested solutions from its own perspective, which may lead to the exclusion of a certain treatment.

Generally speaking, each planning step must allow the dentist the option to decline all of the proposed solutions. Whereby, the question then arises if and from where treatment should be continued.

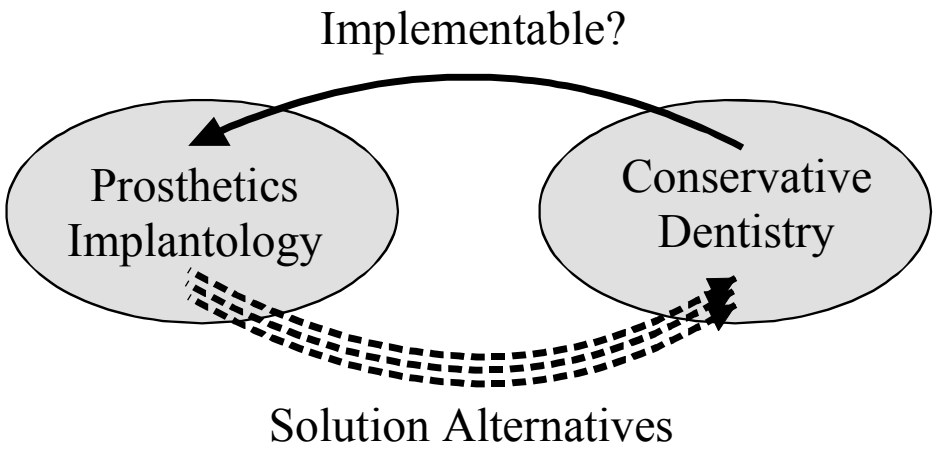

Figure 34: The dilemma of dependencies between dental disciplines can be solved by introducing a "planning module" that makes suggestions, which are, in turn, evaluated in terms of feasibility by the other module.

Under these circumstances, the option of not to use a prosthetic construction must also be legitimate, provided is not required for fulfilling the goal criteria. The system suggests all conceivable solutions based on the current diagnosis. Intuitively, the dentist can select a suggestion and then examine it closely in

terms of feasibility. Hereby, exception criteria is examined and preparatory measures are planned (see Figure 35).

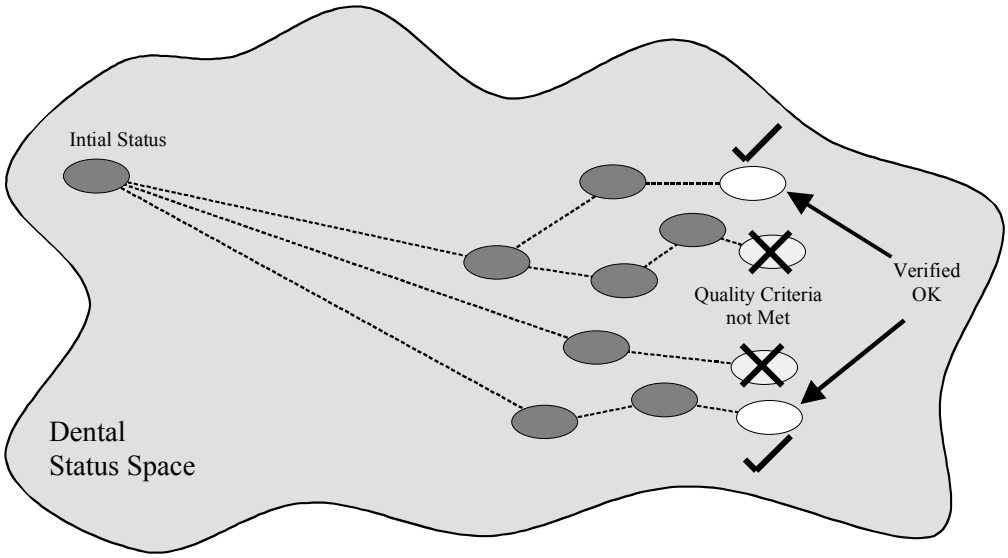

Figure 35: Constraining the solution alternatives by examining the exclusion criteria. Treatment alternatives are initially generated for each planning step and then individually examined in terms of feasibility.

In a nutshell, the decision methodology delivers an oversupply of alternatives and then realistically limits the number of offers by examining the preconditions in a multistage process. The more information available, the more exact and reliable the suggested alternatives are. A solution is reliable if all important boundary conditions have been fulfilled.

The dentist can use the methodology for treatment planning to a personally desired extent. However, he will not receive certification by the system for a case (as a type of proof) until all open questions to that case have been answered. Neutral medical experts must define which cases can be certified as "completely tested" based on the respective standing of dental research.

Boose and Gaines [88,89] place very high general demands on a comprehensive decision methodology:

Guideline 2: Demands placed on a decision methodology [88,89]

- The knowledge of many experts (all, if possible) must be integrated into the methodology.

- In case many expert opinions exist, all alternatives must be integrated and presented along side each other.
- These alternatives must be integrated even if they are contradictory.

These general demands shall be used. Rather than violating the integrity of the knowledge base by using contradictory arguments, all views and solutions are presented. In other words, a specific expert opinion is not preferred over another unless its quality has been proven to be superior.

4.1.4.2 Knowledge barriers to decision methodologies

, Mathematical and logical planning requires that responsibilities and boundaries are clearly defined, in contrast to intuitive treatment planning.

Only generally acknowledged and comprehensible solutions may be suggested during planning to assure quality. Intuitive treatment planning does not force the dentist to prove his decision in detail. This would not be very responsible in terms of effective and comprehensive treatment based on current decision foundations.

Each decision made by a generally acknowledged methodology for treatment planning must be verifiable and examinable. In principle, the methodology must allow every realistically occurring problem. It must, therefore, meet much stricter criteria than those of an individual decision. This shows why such immense effort is placed in describing the underlying foundation of the methodology presented here, and can go into detail in only a few exemplary cases. Since continual changes within dental medicine must be anticipated, the focus of this research lies in creating a basic, underlying methodology stable enough to allow a continual expansion.

Purposely, the currently acknowledged standard treatments have been included into the methodology first. These treatment measures are not expected to receive meaningful criticism. Difficulties will arise once controversial cases are included. On the one hand, they pose a challenge to an acknowledged reference system, since they allow doubt to come over the overall system. On the other hand, the controversial cases are of special interest, since they represent the current research. However, a medical decision methodology is of immense importance to allow a standardized and targeted discussion of the controversial decisions.

Hereby, it is conceivable and sensible, from a research perspective, to include unconventional research approaches in the decision structure (compare [90,91]). Until more practical alternatives can be shown, the competing models can be used to derive new research questions for a particular dental area from the methodology.

One way to solve this dilemma of practical decision structures on the one hand, and alternative views for research on the other, is to 'tag' uncertain facts and rules, as well as the conclusions derived from them. In other words, an alternative for which uncertain knowledge was used during treatment planning must be labeled as an uncertain, or research, alternative.

It must be either impossible, or bring about actual consequences (such as notification of, or possibly referral to, another expert) for the treating dentist to overstep the boundaries of his competencies.

The practicing dentist must generally be measured by the currency of his professional knowledge. A generalized decision methodology can help to make decision structures more transparent, and to reassure the dentist in his decision for a specific treatment.

Several planning options are conceivable: The practicing dentist, for example, will want to support his treatment with certain knowledge, since he is pressed upon by legal regulation to deliver conclusive treatment. The researching dentist will be more interested in uncertain knowledge that he and his colleagues can either prove or disprove.

This research work does not differentiate between certain and uncertain knowledge, since all knowledge is considered uncertain during the introduction of a decision model. However, this problem must be discussed to ensure the continued development of the methodology, especially if it is to be machine-based and open to criticism over a worldwide network.

It is practically conceivable to label every decision rule with the name of its author, the date of its initial formulation, and the committee and date of its initial acknowledgement. Similar procedures are currently underway, and have been implemented in part, in evidence-based medicine (EVM) and evidence-based dentistry (EBD). In this way, the evolution of the decision methodology can easily be reconstructed at a later time point. This may be necessary to examine its credibility. Also, an authorization concept should be attached to each rule.

Such a concept lays down who is allowed to make certain changes. Certain cases, for example in the area of prosthetics, should be examined by prosthetic experts.

Not only dental issues play a role during dental decision making. Medical and non-medical problems, for instance, can arise. Beside a need for a systematic maintenance for monitoring the currency of individual alternatives, the consistency of the overall system must be examined regularly to avoid an overall corruption caused by changes in details.

Figure 36: The "annual rings" of the conditional space of the knowledge base show the development of the domain. The condition of the system at any past time point (e.g. in case of legal disputes) can be determined by them.

A complex concept of rights and responsibilities results from these requirements that must be maintained. Such complexity can not be overseen by a single individual. Storage by version number is replaced by including the date and time. Due to legal requirements, all changes occurring after a certain date must be reproducible to provide proof.

Since every decision can be traced back to any past point in time since system operation began, obsolete facts and rules must remain in the system. This means obsolete facts and rules may not be deleted. Rather, such knowledge must be disabled, or barred, making its use in current decisions impossible. This constant growth of the methodology is seen in analogy to the annual growth rings of a tree.

4.1.4.3 Order of dental treatment planning

Now that planning has been broken down into therapy and reconstruction, the question arises how further division should take place. As described in Chapter

4.1.3.1, generating treatment alternatives should begin by defining the condition of the dental crowns and their "underlying" structures based on the dependencies found in the functional analysis.

As shown by the functional analysis, the essential preconditions for the dental roots result from the goal criteria defined for dental crowns. They, in turn, define the necessary preconditions for the periodontium, from which the requirements for the jaws result. The jaw joint and muscles must guide the jaw during mastication. The further approach and the order of dental treatment planning are defined by these dependencies.

Approach 2: Idealized order of dental treatment planning and important question raised[56]

1. Examine absolute, non-dental exclusion criteria. Is dental treatment impossible under the given conditions?
2. Examine acute exceptions. Do problems exist that do not allow comprehensive treatment planning and patient consultation?
3. Examine which teeth can be conserved. Plan conservation and periodontal support. Which measures can increase the value of the abutment? Which teeth must be extracted?
4. Examine the necessity of gap closure. A) Where is orthodontic gap closure required? B) Where can gap closure be realized using restorative crowns?
5. Examine the possible use of existing abutments. Where is an additional abutment required to fasten a crown?
6. Examine the remaining teeth and abutments. Which teeth or abutments must be treated?.(e.g. important: examine the value of a necrotic pulp)?
7. Examine the bone structure. Can the bone offer lasting support to the teeth?
8. Examine the jaw joint. Can the joint offer lasting masticatory support?
9. Examine masticatory musculature. Is the masticatory musculature strong enough to move the lower jaw to allow full masticatory functionality?

[56] The planning sequence presented here results from the innate incompleteness of diagnosis. Awareness should be tolled the fact that only recommendations can be given for the individual planning steps. Each next step can be seen as an examination of the last step.

10. Examine mucosa. Is it capable of protecting the dental structures against infections?
11. Examine the necessity of corrective (orthodontic) measures to position the teeth. Which teeth must be repositioned so that the dental crowns stand in a functional and aesthetic row?

The set of possible treatment alternatives can be reduced in each of these steps. "New" alternative can result from the view of an individual planning module. If, for instance, a bridge with 3 units is required, different alternatives are available to specify the material. In other words, new alternatives arise regarding bridge construction. From the view of overall planning, the set of alternatives is reduced, since only certain materials can be used. Therefore, from the perspective of the individual modules, the alternatives constantly vary. From a global perspective, however, the alternatives decrease with each planning step.

Iterations can occur during planning in special cases, as discussed in the following section.

4.1.4.4 Planning corrections in unexpected cases

As the previous section brought out, the planning process in Approach 2 can not solve all of the problems that may occur. The algorithm must be extended to meet such cases.

It can happen that a planning step changes the preconditions of a next step. This can be demonstrated by the example of dental extractions. If a bridge construction has been proposed, it must be examined if the available abutments can carry the construction. In special cases, such an examination may lead to the extraction of a weak tooth. This, in turn, may lead to a change in the preconditions of the planning step of the bridge construction itself. In such cases, a step back must be taken to repeat that particular planning step. This applies to all cases in which a criterion of a previous decision module has changed![57]

[57] Normally this does not pose a major problem, since the available information can be applied to the treatment. Ideally, the methodology does not require further information, and renewed planning can take place without requiring additional diagnostic measures. This step back is generally not felt if conducted with help of a computer.

4.1.5 Summary of the Basic Structure

Above, the basic structure of a dental decision model was derived. Herein, the types of knowledge generally used during treatment planning were described. Also, which limits are placed on current forms of knowledge representation, and in which form knowledge flows into treatment planning was discussed.

The overall question of planning was broken down into: (a) the preparatory measures outside of dental medicine, (b) the regeneration of natural structures (therapy), (c) the construction of artificial structures to meet the goal criteria described in Chapter 3 (Reconstruction).

Planning must not only adhere to the requirements of reproducibility. In addition, it must be possible to complete treatment planning using incomplete information, since the information is innately incomplete due to technical and time limitations. Therefore, a navigation system should be used for treatment planning. Such a system allows the dentist to specify treatment planning to the desired degree of detail. Navigation is defined as follows:

Definition 29: The navigation of planning (knowledge navigation)

- Navigation of planning (knowledge navigation) means that the planning methodology user is guided through the planning process from the beginning to end, even if the actual goal is prior to beginning the planning process.
- Practically, knowledge navigation is the step-wise focus on individual patient goals.

The problem of clearly separating certain from uncertain knowledge also arises while generating treatment alternatives during treatment planning. A clear separation is necessary to correctly estimate the competency limits for each past point in time within the methodology.

The functional analysis delivers evidence of how planning should be conducted in general. The dental crowns are central to dentition functionality and aesthetics. Therefore, their targeted state (state following treatment) is defined. The requirements for the abutments are derived from this definition. In turn, these requirements can then be transferred via the periodontium, to the

bones, joint and musculature of the jaw. Since the mucous membrane covers these structures, its boundary conditions can be derived from them.

The individual planning modules together make up the overall dental treatment planning system. Seen as a “black-box”, diagnostic information can be entered and individual treatment alternatives generated. The information pertaining to an individual patient must be complete before each planning step. The number of specific treatment alternatives may vary from step to step.

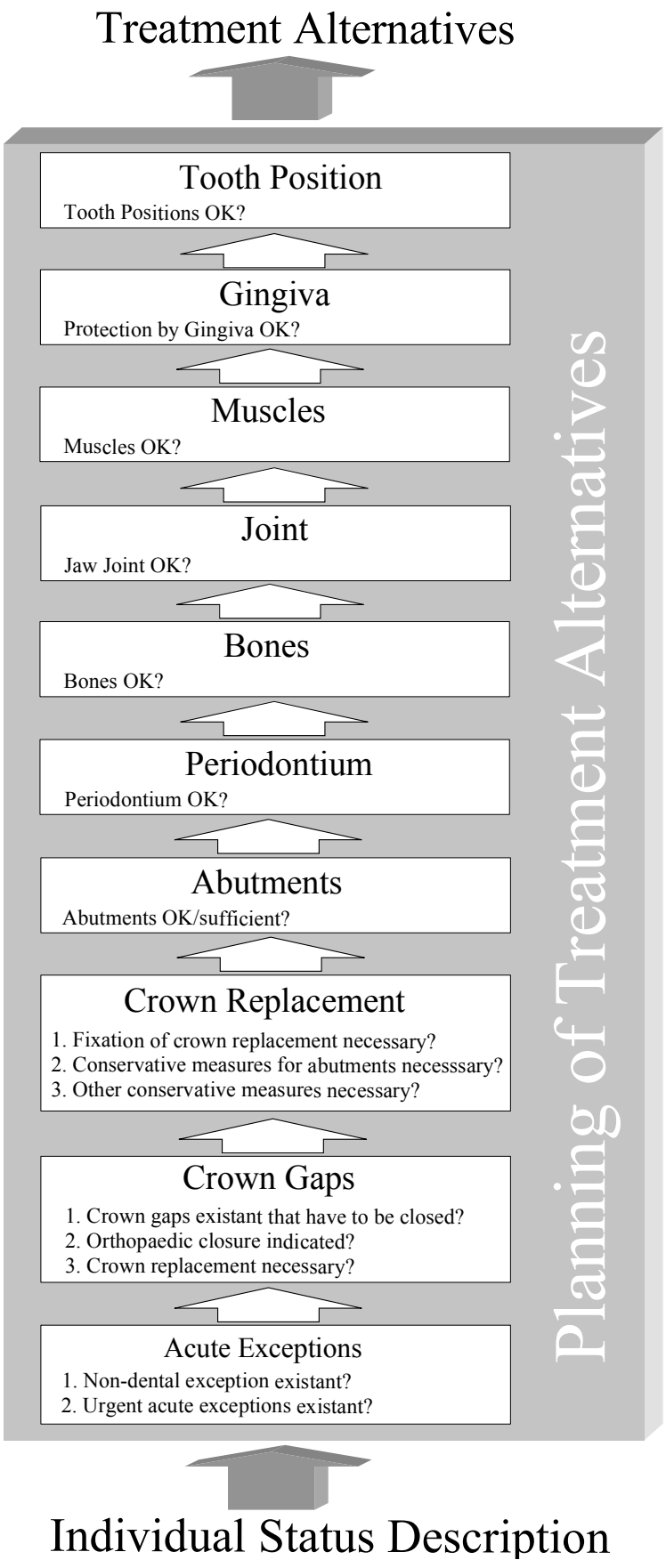

Figure 37: Idealized treatment planning – the number of alternatives passed on from module to module can vary. The number can either increase due to

additional treatment alternatives, or decrease due to absolute exclusion criteria. In complex cases, many planning iterations may be necessary. Important: This process does not contradict modern "preventive" dentistry, since the individual needs can be determined for each step.

4.2 A DETAILED LOOK INTO THE PLANNING MODULE[58] "DENTAL PROSTHETICS"

According to the dental treatment checklists, the goal of prosthetic reconstruction is to provide a healthy balance between functionality and desired aesthetics. The following principles apply specifically (compare [14]):[59]:

- The restoring or conserving periodontal structures is a basic requirement for the success of every reconstruction.
- Prosthetic reconstruction should be kept simple in cases of uncooperative patients, or such not willed to comply with necessary oral hygiene measures.
- A fully uncooperative, partially edentulous patient can be helped little with complicated and demanding prosthetic constructions.
- A careful conservation of existing teeth is more important than the complete replacement of missing teeth.
- Dental restoration can be considered satisfactory in many cases once a premolar occlusion has stabilized the situation of a shortened dental row.
- The optimal functionality of the individual dentition is the major criteria for extending restorative measures.
- Using extension bridges on abutments with a healthy periodontium and endodontium is an alternative to semi-prosthetic measures.
- Using abutments with a reduced, but healthy, periodontium for restorations shows a good long-term prognosis

[58] "Planning unit" in this case is a technical software agent. In this case, reference is being made to a part of the planning described in Chapter 4.1.3.1 "gap closure/incomplete dental crowns" is.

[59] The checklists are still a standard procedure used in dental education in Germany today.

- Minor restorations are preferred over extensive, splinted constructions. A restoration should never reduce or hinder a patient in his abilities to practice optimal oral hygiene.

These guidelines represent important boundary conditions for practicing dentists. The exact treatment planning procedure does not, however, emerge from them. A precise formulation is required within the context of a strict, algorithmic treatment plan. Therefore, in concluding the previous derivations, the following shall describe an approach that divides the decision methodology into a sequence of decision blocks.

The previous chapters have shown that before the actual dental planning can take place, the medical preconditions and exclusion criteria must be examined. Hereby, examining the risks involved is of primary importance. The methodology described here centers on dental aspects. Therefore, problems outside of dental medicine belong to a different medical domain and are not treated within the methodology. However, problems can occur that belong both to dental and other medical domains. These problems will be addressed. Hereby, it is not excluded that additional treatments may be required in the other domain.

According to the planning sequence, dental planning actually begins with the description of the necessary prosthetic construction. Therefore, this part of treatment planning been selected to demonstrate fine-tuning. While planning restoration measures, a distinction is made between the reconstruction of a single tooth and constructions effecting many teeth of the effected region. Planning the reconstruction of a single tooth is much less complicated. While many treatment alternatives exist, they contain relatively few possible treatment combinations. In contrast, constructions spanning entire regions allow a large number of combinations, which must be limited to a manageable number of possible alternatives. This is done with the help of the planning module.

A list of possible types of dental crown restorations is presented to demonstrate their diversity:

Table 1: Indications for dental crown restorations (completeness not guaranteed!)[60]

[60] Certain combinations of prosthetic measures are possible that have not been listed here.

Prosthetic	Possible treatment	Possible use
Crown restoration	• Restoration of lost tooth structure, which can no longer be regenerated.	• Replacement of incisal edge defects • Replacement of multiple fillings • Replacement of discolored, non-vital dental crowns • Replacement of abraded masticatory surfaces • Replacement of expanded, carious crown defects • Shape and positional corrections • Build-up of missing or lost supportive zones • Build-up of lost occlusal relief • Contact corrections
Protective crown	• Complete coverage of organic tooth substance and protection of dentin core against destructive influences within the oral cavity.	• In case substance lost through neuromuscular dysfunction (e.g. Bruxism) • As protection against abrasion and substance loss through retention clasps • In caries-endangered dentitions
Supportive or anchorage crown	• Anchorage of crown restoration on residual teeth	• Fixed and removable bridges • Combined restorations
Special crowning	• Bite raising, occlusal reconstruction, aesthetics,	• Restoration of orthogonal tooth relationship

Prosthetic	Possible treatment	Possible use
indications	Positional anomaly	
Restorative crown not possible[61]	• (Temporary) contraindication of restorative crown	• Pathological, apical processes • Incomplete and incorrect endodontic treatment • Marginal infection • Loose tooth • Periodontal and intra-bony pockets • Tooth tilt over 30° against masticatory surface[62] • Teeth lack antagonists, no splinting • Severe loss of substance, no guarantee of mechanical anchorage • Alveolar decomposition above apical third of the root.

Generally, the attempt to regenerate natural structures as far as possible should be made. Therefore, the goal of the planning module "prosthetics" is defined as the minimal amount of prosthetics required to achieve the overall dental planning goal[63].

4.2.1 Prosthetic Necessity

Part of the general goal criteria of dental medicine is directly relevant to prosthetic planning. The minimal criteria can be defined as follows:

[61] Special measures are required for children under 16 years of age. Special crowns are finished for children.

[62] A split bridge may be possible if orthopedic treatment is not required.

[63] This can expand during the course of treatment if the proposed solution can not be supported sufficiently by the abutments.

Guideline 3: Functional goal criteria of prosthetics[64]

- Interdental gaps should be closed[65], since an instable cut can cause a tooth to tilt.
- Antagonists should be present [66] to prevent elongation.
- Every crown should be supported sufficiently by an abutment and/or mucosa-born dentition.
- All surrounding structures, such as dental roots, jaws, mucous membrane, etc. should meet the set goals to allow full functionality of the dental crowns.

Prosthetic constructions should be developed based on the dental needs in order to make use of the technical possibilities for developing the required prosthetic measures. This planning should take place step-wise, whereby similarity criteria can be defined between constructions on each level.

4.2.1.1 Therapy limitations for dental crowns

Therapy is limited to the regeneration of natural structures. Bones and the mucous membrane can be regenerated successfully using modern techniques (transplantations, augmentation, etc.). Also, great advances have been made in repairing nervous defects. However, it is currently not possible to treat dental crown defects using natural, autologous materials.[67] Therefore, artificial materials are used to restore full functionality and aesthetics to the structures. Two types of artificial restorations exist, each requiring separate planning.

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[64] In this case, further goal criteria are required, but do not have a major influence on the following description of the decision structure. They can be seen as a fine-tuning of the methodology, but do not serve to describe of its basic structure. Pathological processes can not be covered by this definition of functional goal criteria. Since, however, this description represents a simplified, static view of the teeth, the processes can be disregarded in this first approach.

[65] An interdental gap is a gap between two dental crowns.

[66] An antagonist is the respective counterpart located in the opposite jaw.

[67] Autologous material: belonging to that person, body-owned material e.g. autologous donation.

Guideline 4: Approaches to reconstructing dental crowns

- Reconstruction of a part of a crown using artificial material.
- Reconstruction of a complete crown using artificial material.
  - Use of a natural root for anchorage.
  - Use of neighboring teeth as abutments.
  - Use of implants as abutments.

By using modern materials, a multitude of possibilities are available to today's dentists for reconstructing natural dentitions to meet the set functional and aesthetic goals, even in severe cases. Consequences result for treatment planning and the treatment sequence, because the constructions are attached to natural structures. Although the regeneration of natural structures should generally be preferred over reconstruction, the goal criteria of reconstruction must influence the goal criteria of therapy – for instance, when fastening constructions onto natural structures. Therefore, the minimal amount of prosthetics required must be defined first to estimate the effects on the natural structures.

4.2.1.2 Underlying questions surrounding the use of prosthetics

As described above, the dental crowns are central structures for mastication as well as aesthetics. Therefore, the following analysis focuses predominately on dental crowns. A missing tooth will be emphasized less strongly than a missing crown. This state will be named dental crown gap. Prosthetic constructions are primarily seen as crown restorations. In a next step, the anchorage of crown restorations will be discussed. The description of the occurring relationships is eased by formulating this aspect, since a distinction is made between causes (the need for a crown restoration) and effect (the need for one or more abutments).

As described in the previous section, conservation measures can not be planned comprehensively without considering the prosthetic needs, since, for instance, the need to include an abutment located near a gap into the construction depends on the given prosthetic possibilities. From the perspective of conservation dentistry, boundary conditions exist that can limit the use of prosthetic measures. The condition of the abutment, for example, can be of underlying importance to planning dental restorations. However, the condition can not be assessed without considering conservative measures. Since therapy and reconstruction depend strongly on one another, it does not make sense to

plan one without considering the other. Therefore, the prosthetic needs should be analyzed first, giving initial priority to examining the surrounding structures.

A wide spectrum of alternative solutions arise from the multitude of prosthetic possibilities for many practical situations. The feasibility of each alternative must then be examined from the perspective of conservation dentistry. *This does not limit conservation dentistry* considering the fact that "no prosthetic measure required" is also a valid solution. On the contrary, the need defines the achievement of the treatment goal. If, for example, a front tooth is missing, and gap closure is not possible, a prosthetic dental restoration should be suggested. If, however, all necessary dental crowns are present and worth keeping, no prosthetic treatment is suggested.

Prior to planning restorative gap closure, it must be examined whether problems actually result from the gap for the patient. If so, it must be examined whether the gap can be closed. *The valid demand exists to conserve and regenerate natural structures as far as possible before making use of prosthetic measures. However, the reverse is the case, in light of exact, redundant-free planning: Since the prosthetic is fastened to natural structures (abutments and/or mucosa-born), it would not be good to regenerate the natural structures to then invade upon them to fasten the prosthetic construction.*

Summary 20: Process of planning dental crown restorations

1. Determine which crown gap is to be closed.
2. Determine need for closure.
3. Determine need for prosthetic that includes neighboring dental regions.
4. Determine which preparatory measures are required for anchoring prosthetics that include neighboring dental regions.
5. Determine need for prosthetic and conservation measures within the effected dental regions (local to those regions).

Several treatment alternatives may result from these basic rules. The construction can be fastened onto natural abutments (dental roots) directly to the jaw via implants. The exclusion criteria must be analyzed for each alternative. The remaining solutions considered equal. Later it will be discussed how these

solution alternatives can be evaluated. The general goal criteria presented in will serve as the basis for further planning:

Guideline 5: Underlying goal criteria for prosthetic planning

- No interdental gaps (gap between two teeth) should exist (functionality).
- No missing antagonists (functionality).
- Each crown should be sufficiently supported by an abutment or mucosa-born dentition (functionality).
- At least the first five (visible) dental crown per quadrant should be present (functionality and aesthetics).

4.2.2 Planning Crown Restorations

Since a multitude of prosthetic constructions can be planned, often spanning several teeth and fastened to natural dental structures, a list of alternatives must be available beforehand. This, however, only makes sense if all possible alternatives are taken into consideration. This process can also be explained as follows: Although conservation planning could take place without considering the prosthetic needs, such planning would have to be repeated as soon as a prosthetic construction is to be fastened to a natural dental structure.

Therefore, a simpler approach is to first plan the restoration of the "underlying" support structures based on the general goal criteria, which are, in turn, defined by the dental crowns. Should, for instance, a natural tooth not be stable enough to carry a planned prosthetic construction, the whole solution becomes void, since an absolute exception criterion forbids its realization. In this particular case, the construction could be extended to provide better anchorage.

In respect to prosthetic planning, the methodology assumes that a present tooth is generally worth conserving. This initial assumption may be overthrown following a close examination of the possible conservation measures. If so, this changes the underlying base of the set goals, and, therefore, prosthetic planning must be repeated.

4.2.3 Prosthetic Constructions Spanning More Than One Dental Region

Several prosthetic treatment alternatives spanning more than one dental region are available for meeting the functional and aesthetic criteria. Each of these is referred to as a "mode" in the following.

Each mode of therapy has its own specific advantages and disadvantages. Therefore, a general evaluation can not be conducted to determine which alternative is best for a specific case. However, as long as these criteria can not be compared directly, they should at least be presented as equals. To avoid mixing their specific characteristics, they are treated in separate chapters. To provide a better overview, each mode belongs to a separate area for which solutions will be suggested.

Since it does not make sense to suggest a complete prosthesis if the patient still has 16 teeth, the area of complete, or full, prostheses will be limited to cases in with less teeth remaining. It may make sense to suggest a complete prosthesis if only two teeth are left, both with a poor prognosis. Since the value of a tooth or abutment can not be examined from the perspective of prosthetics alone, this planning step assumes the teeth are worthy of conservation. Later planning steps may show that one or more of the existing teeth are not suited for use as abutments. If the dentist decides to extract the teeth, prosthetic planning must be repeated, since an important assumption was refuted. The following, therefore, assumes that remaining teeth are to be conserved.

An example helps to show which aspects must be examined during prosthetic planning. If, for instance, a patient is missing several dental crowns, the following basic prosthetic solution alternatives are available:

- One tooth implant (Further examination: Is sufficient space available for the crown restoration? Is sufficient bone material available for the implant?)
- Fixed bridge (Further examination: Is sufficient space available for the crown restoration? Is the condition of the neighboring abutment sufficient? If not, include next neighbor.)
- Cantilever bridge (Further examination: Is sufficient space available for the crown restoration? Are two neighbors in sufficient condition available on one side?

- Adhesive bridge (Further examination: Is sufficient space available for the crown restoration? Is the condition of the available abutments sufficient?)
- Cone solution (Further examination: Is the condition of the available abutments sufficient?)
- Bar prosthesis (Further examination: Is the condition of the available abutments sufficient?)

The individual anchors can be subdivided further. However, this issue shall not be discussed here.

Conditional solutions can be proposed despite a small number of examination results, which eases preliminary decision making. The methods for fastening prostheses can be used in several different areas. The following table lists these areas according to the number of remaining teeth. Abutment reproduction using implants have been included.

Table 2: Types of "possible prosthetics" based on the "number of present dental roots"[68] (completeness noT guaranteed!)[69].

C	FR[70]	Cone prosthesis[71]	Bar prosthesis	Model cast prosthesis	Complete prosthesis
0	Possible	–	–	–	Possible
1	Possible	Possible	–	–	–
2	Possible	Possible	–	–	–
3	Possible	Possible	Possible	–	–
4	Possible	Possible	Possible	Possible	–
5	Possible	Possible	Possible	Possible	–
6	Possible	Possible	Possible	Possible	–
7	Possible	Possible	–	Possible	–
8	Possible	Possible	–	Possible	–
9	Possible	Possible	–	Possible	–

[68] Only 8 teeth per quadrant are considered. Also, due to this static view of dental medicine, prosthesis that are already present are not removed, unless their removal is expressly suggested or conducted.

[69] Careful: This table does not say that a solution is definitely possible in a given circumstance, just that it can occur.

[70] FR summarizes all "fixed restorations", including implants.

[71] Telescopic work may make sense.

C	FR[70]	Cone prosthesis[71]	Bar prosthesis	Model cast prosthesis	Complete prosthesis
10	Possible	Possible	–	Possible	–
11	Possible	Possible	–	Possible	–
12	Possible	Possible	–	Possible	–
13	Possible	–	–	–	–
14	Possible	–	–	–	–
15	Possible	–	–	–	–
16	Possible	–	–	–	–

(C= number of crowns present; "possible" = restoration possible, makes sense; – = not possible or does not make sense)

A new mode can be added without influencing the entire methodology in case of technical innovations and advancements. The new treatment alternatives arising from them must then, as before, be examined in terms of feasibility. The question must be ask for each mode: How can it be fastened onto the natural structures? Each mode strives to reach its overall goal using its own measures.

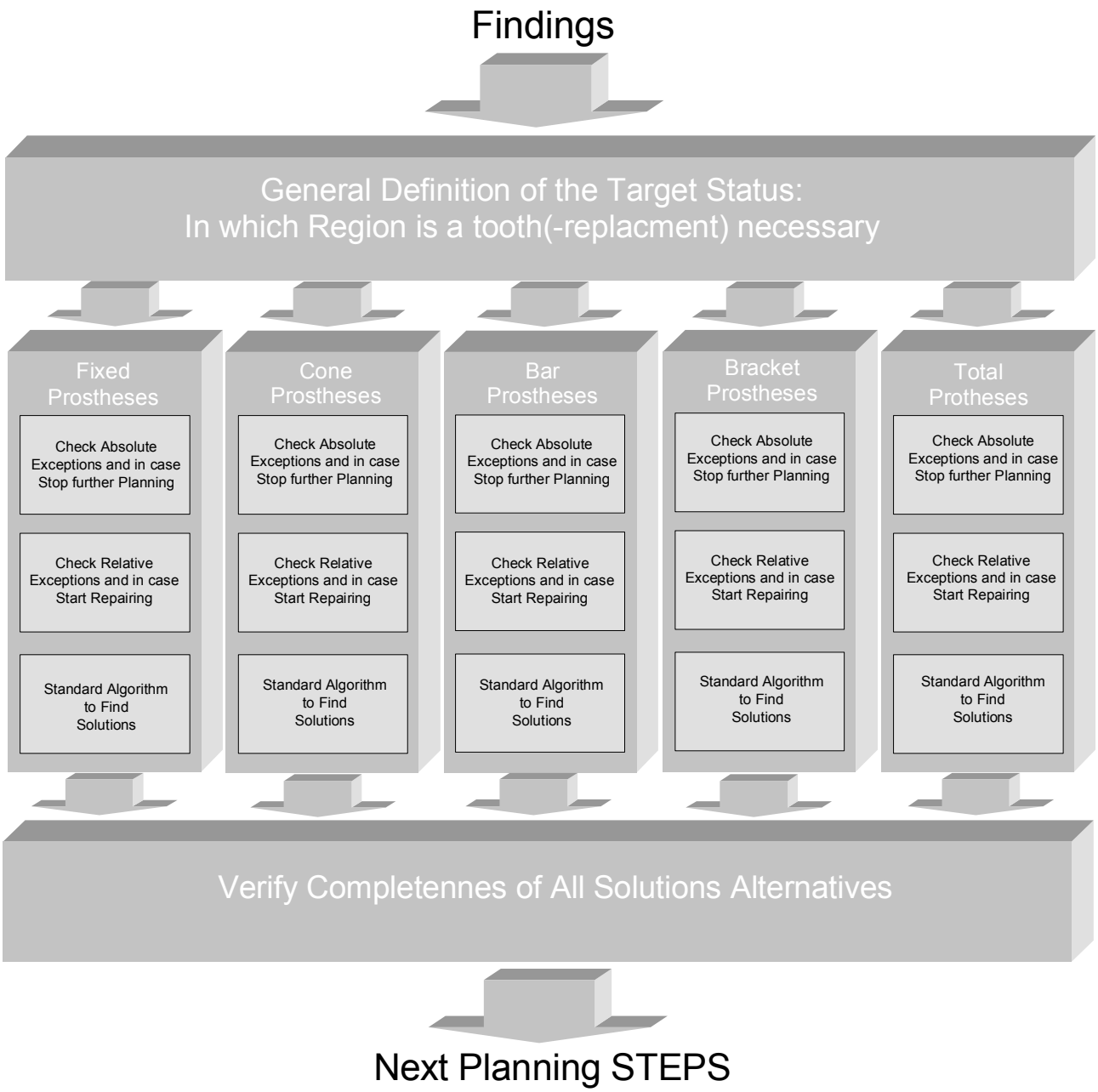

Figure 38: The prosthetic solutions are available independently, and can be presented as neutral alternatives to the user. Hereby, no solution is also a valid solution.

In few cases, complex prostheses can require combinations of different anchorages. In this work, focus is placed on cases in with one mode of anchorage. This focus also leads to a clear decision structure, whose advantages and disadvantages can easily be identified. Exceptions can be included at a later time point.

Before discussing the example mode „fixed restorations", the boundary conditions for fastening the crown restorations must be described.

The subdivision used in these modes could have been realized differently, and serve only as an option. All modes can be planned independently of one another and are considered equal. In making use of the information of advantages and disadvantages of each mode, the selection of a specific solutions should take place cooperatively between the dentist and the patient. (compare Chapter 0).

4.2.4 Prosthetics for Single Dental Regions

Within the methodology described in the previous chapters, one-tooth prosthetics are a special case of fixed prosthetics spanning more than one dental region. Since the construction is not attached to neighboring regions, it must have its own abutment. The boundary condition for abutments in this case basically remain unchanged, even though an individual case strongly limits the selection of treatment alternatives.

Two situations must be kept apart during planning. If the effected region already has an useable abutment, the dental crowns must be adjusted to it. If an abutment is not available, or the available one is in too poor condition, an implant must be planned. Both procedures must be examined closely in their preconditions determine their actual usefulness.

4.2.5 Planning Abutments and Abutment Reproduction Using Implants

Planning abutments generally involves functional aspects, even if aesthetic criteria can serve as boundary conditions in some cases. The initial question is which of the available abutments can be used in the construction. This generally depends on the condition of the abutment and on the selected mode. The neighboring abutments must be able to withstand the burden placed upon them to ensure full, lasting functionality. If this is not given, the next neighbor can be used. It is possible to bind the crown restoration to its neighbor using clasps and telescopic coping (bridge, cone, bar). Even if the basic characteristics of abutment planning are formulated similarly, the actual selection of an abutment depends strongly on the selected mode. A telescopic construction, for example, supports different characteristics than a bar constructions. An exact definition of the characteristics should be targeted to better serve abutment planning.

Fixed bridges can, for instance, be attached to their neighbors, who receive telescopic coping as a result. Another possibility is to attach the units of the bridge directly to the jaw using implants. In this case, the construction is tightly attached to the abutment, leading to specific hygienic requirements. This form of construction is carried solely by abutments. Cone and telescopic constructions, on the other hand, are removable. The cones and telescopes are generally attached to a natural root, but can be fastened to artificial abutments using implants. Bar constructions can also be attached to natural or artificial abutments. The bars attach one to the other. The bar is responsible for holding the removable crown restoration. In contrast to the previous constructions, the neighboring teeth must be filed to hold the clasp. However, implants are not necessary. Complete, or full, prostheses are, fastened to the jaw via the mucosa by the adhesive forces of the saliva. This aspect separates it from all other types of prostheses.

It may, however, be necessary, to stabilize large construction by fastening them to the jaw. Therefore, it must be possible to insert an additional abutment into the jaw, as an anchor for the prosthesis. Especially large constructions require an even distribution of the masticatory pressure over a number of available abutments. These additional abutments are not possible in small constructions due to spatial constraints. They are, however, recommendable for medium-sized constructions, and, possibly, essential in large constructions. The responsible criterion is the support polygon with which the appearing forces can be estimated. The question of an additional abutment must maximize the support polygon to guarantee the best possible hold. Accordingly, the rules should be defined exactly for the initial situation, the therapy used, and the intended location of the implant.

4.2.6 Examination and Specification of Prosthetic Alternatives

As described previously, an oversupply of alternative solutions is generated for each planning step. Each alternative is then examined it terms of feasibility. If a natural abutment is to be used, it must be made sure that it can lastingly withstand the forces acting upon it. If an implant is suggested, the bone supply must be examined. Relative and absolute exclusion criteria can apply. The

examination of these criteria for an alternative can lead to further measures, or even to the exclusion of an alternative all together.

Every mode must determine whether the current problem can be solved with the respective type of construction. In case of a hemophiliac patient, the implant alternative will probably lead to an exclusion. Certain constellations, for instance bridge constructions, may require artificial abutments. This treatment mode can, in turn, offer even more treatment alternatives, for example extending bridge constructions to neighboring abutments in case the effected abutment is in a too poor condition.

To keep an overview of treatment planning while going into the details, the dentist can concentrate on one mode at a time while examining the feasibility of an alternative. This strongly limits the amount of boundary conditions that must be examined.

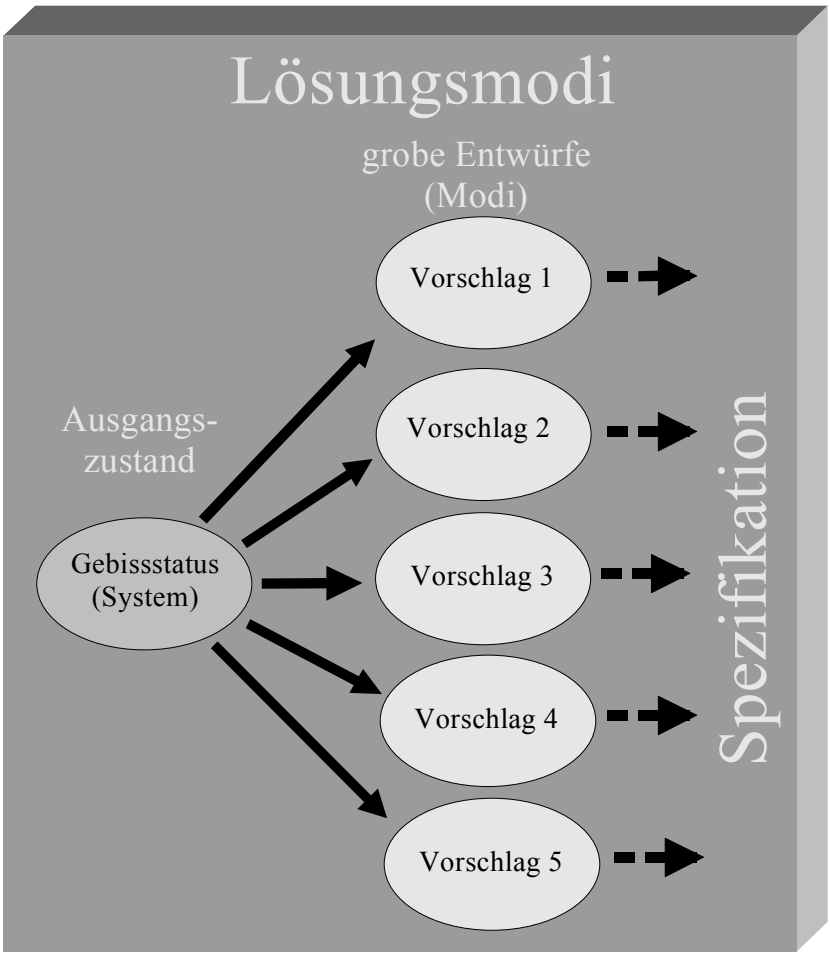

Figure 39: The rough alternative solutions are generated from the status of the dentition based on the decision methodology.

As mentioned for bridge constructions, each mode can propose its own alternatives through further specifications. A bridge can, for instance, include neighboring abutments if the condition of the effected abutment is too poor. Also, various materials can be used, leading to a large number of alternatives. Their individual specifications can be placed in a hierarchical order and, thereby, create a list of decision alternatives.

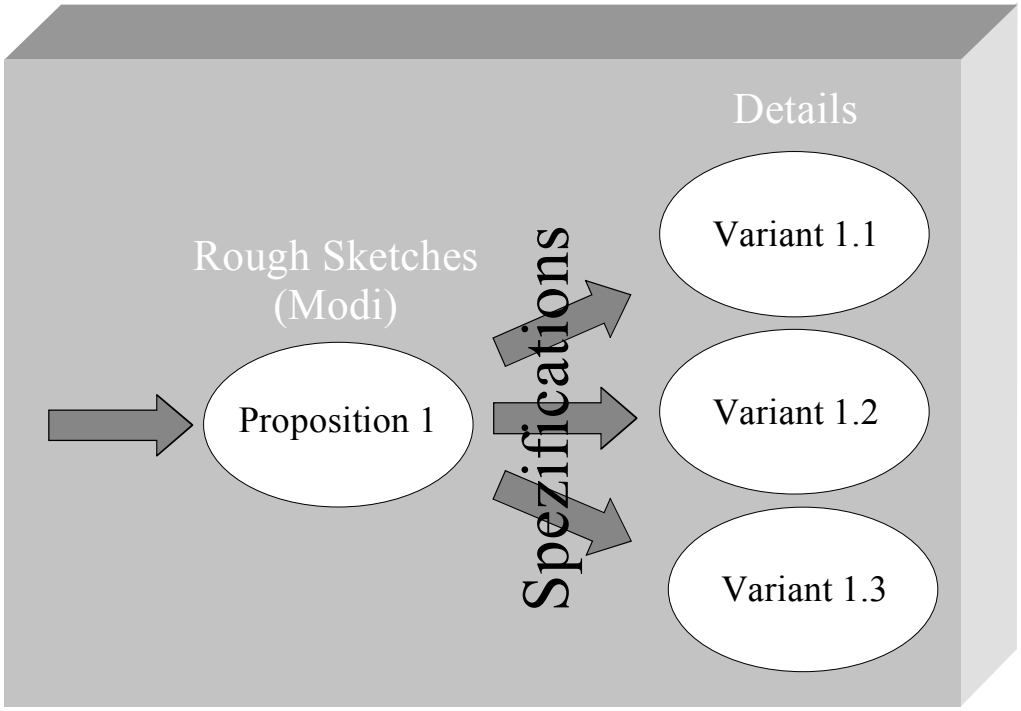

Figure 40: Each of these alternatives can be specified and examined in terms of feasibility. This can lead to further treatment alternatives.

During specification, seemingly possible alternatives may be excluded if an absolute exclusion criterion exists. In this way, based on the decision methodology, a type of proof is given for why a certain solution is not possible.

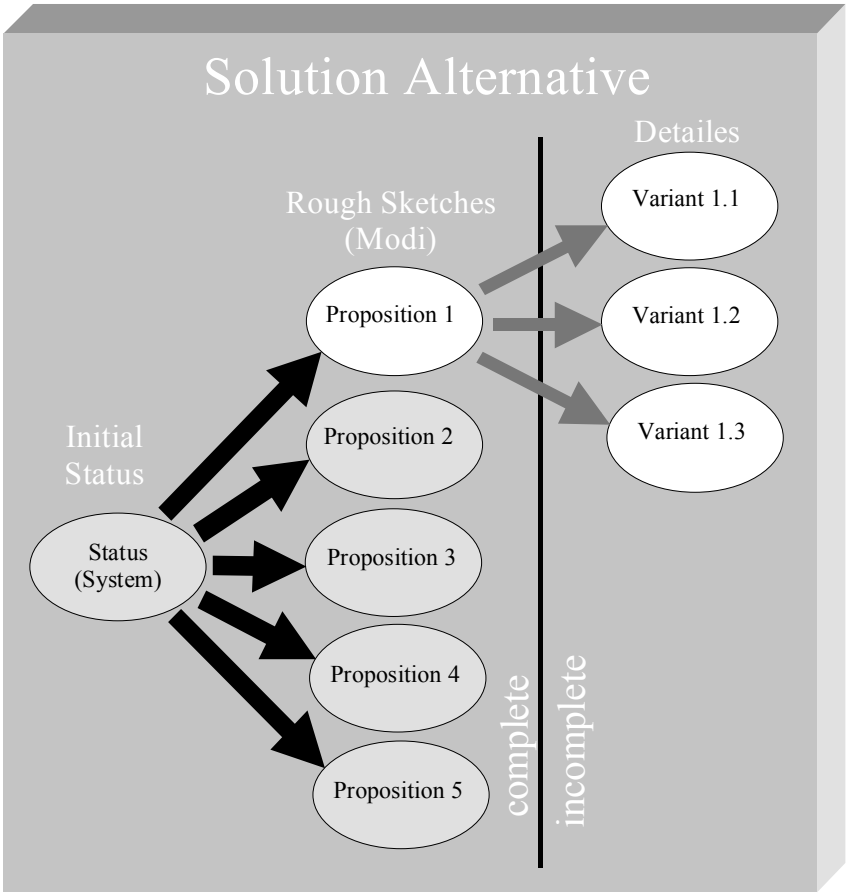

Figure 41: It is important to decision making that the set of decision alternatives is always complete. This helps the dentist keep an overview of the domain.

The planning dentist must always keep in mind which other alternatives are available. To keep an overview, a complete set of alternatives must be presented for each step (compare Figure 41). For the first step of detailing a prosthetic solution this means that all modes are relevant for a specific patient are presented. This overview allows building a preference, upon which the value of the chosen mode can be determined based on a specific specification. Should no version of the mode be specified, the entire mode is disregarded. If, for instance, all teeth show a very poor abutment prognosis, the idea of applying a bridge construction must be discarded following close examination.

4.3 PROSTHETIC SUB-MODEL: MODE "FIXED RESTORATIONS"

As an example, the previously developed rules for the mode „fixed restorations" are presented:

Guideline 6: Alternatives to planning abutments for bridges

(Developed within the AIDA project [92])

- Attachment of dental crown restorations onto a neighboring abutment; in case burden on abutment is too great, the next neighboring abutment can be included in the planning.
- Implants can be used on the outer crowns of the crown restoration, which serve as abutments for the construction (outer abutments). If two gaps are parted by an existing tooth, two neighboring bridge constructions exist, both using the same abutment. These bridges are then seen as one bridge with a central abutment.
- In case the span of the crown restoration is too large, implants can be set into the jaw to alleviate the bending force (new central abutment). In this case, the minimal number of abutments necessary for full functionality must be planned.

These rules are, of course, not a blank check for setting implants, but rather they help draw up possible alternatives that must then be examined in terms of feasibility for a specific case. The alternatives do not necessarily rule out one another. Rather, they can be combined, thereby creating new treatment alternatives, which can then be compared in specific cases by the dentist and the patient.

Planning the use of existing abutments does not pose much difficulty based on these rules. The rules for planning a central abutment remain to be specified, but the parameters have neither been determined nor proven. However, they have been formulated here as an example to help demonstrate the methodology:

Definition 30: Planning central abutments

- If a bridge spans more than 3 units, a new central abutment must be planned to reduce the bending force.
- The new central abutment should be located under the bridge in such a way as to equally distribute the forces.

In order to allow an uniform and strict decision, the following example presents an algorithm for planning fixed restorations:

Table 3: Algorithm for planning fixed restorations

Planning fixed restorations	
Description	Based on the diagnosis, a standard solution is planned for one or more fixed bridges.
Preconditions	Diagnoses have been made.
Results	Standard and special solutions for fixed restorations.
Process	
1.	**Gather examination results and check general plausibility**
2.	**Planning**
2.1	**Determine standard solutions**
2.1.1	Plan basic number of crowns required: a crown is planned for each gap within the first five[72] positions of each effected quadrant.
2.1.2	Neighboring crowns without 'underlying' supportive structures are combined to form a bridge construction.
2.1.4	Select abutments: Abutments are selected for each end of the bridge. 1. Solution with available abutments: Existing abutments are located. If both teeth of the location 0x1 are missing, the teeth in position 0x3 and position 2 are selected[73]. 2. Implant-only solution. Implants are used in place of abutments.
2.1.5	An additional abutment should be designated for each „3 consecutive gaps"[74],.
2.1.6	Connect bridge and abutments: Each crown is attached to an abutment, or to an abutment and a bridge unit, or to two bridge units. Each bridge unit is attached to an abutment, or to two abutments, or to an abutment and a bridge unit, or to two bridge units. Remark: Connections are made only between two bridge units.
2.2	**Determine special solutions**

[72] The area of visible crowns was set to five. This figure can vary in individual cases.

[73] Remark: If the gaps are in position 0x5, a cantilever bridge may be an alternative.

[74] The number 3 was chosen as an example, since it represents the most frequent form. This figure can be varied for special cases.

2.2.1	Check for Maryland bridge: If the upper jaw has gaps in positions 1 and 2, the Maryland bridge (adhesive bridge) may be an alternative and should be examined.
2.2.2	Check splinting: If an open gap results due to a missing antagonist in the opposite jaw, splinting may be an alternative and should be examined.
3.	**Output the result.**

The process of planning a fixed restoration is presented in a way that it can be interpreted clearly by the dentist. However, it can not be processed directly, because it is not based on a strict language definition. Therefore, the following describes how such a definition can be made to create a strict standard beyond that of natural language.

4.3.1 Conceptual Model: Planning "Fixed Crown Restorations"

Prior to completing the planning mode "fixed crown restorations", all acute case must have been resolved. Also, any gap closures must have been identified. If a gap can not be closed, prosthetic measures should be used. The following examines the rules for planning bridges and full crowns (mode "fixed crown restorations").[75]

4.3.1.1 Planning crown restorations

A comparison of the current state and the target state can help determine the need for crown restorations. No decision regarding the type of restoration is made at this point. Upon completing this mode, therefore, the question of whether, and if so where, – in which dental region – artificial crowns are required can be answered. The first part of this question is an exclusion criterion for the remaining planning steps within the mode. In other words, should no crown restorations be planned within this mode, prosthetic treatment is not indicated.

[75] The planning rules of the methodology were tested with hundreds of cases. In resulting research, a part of the model was visualized in an object-oriented design model and then implemented (compare Section 6.3.2.1).

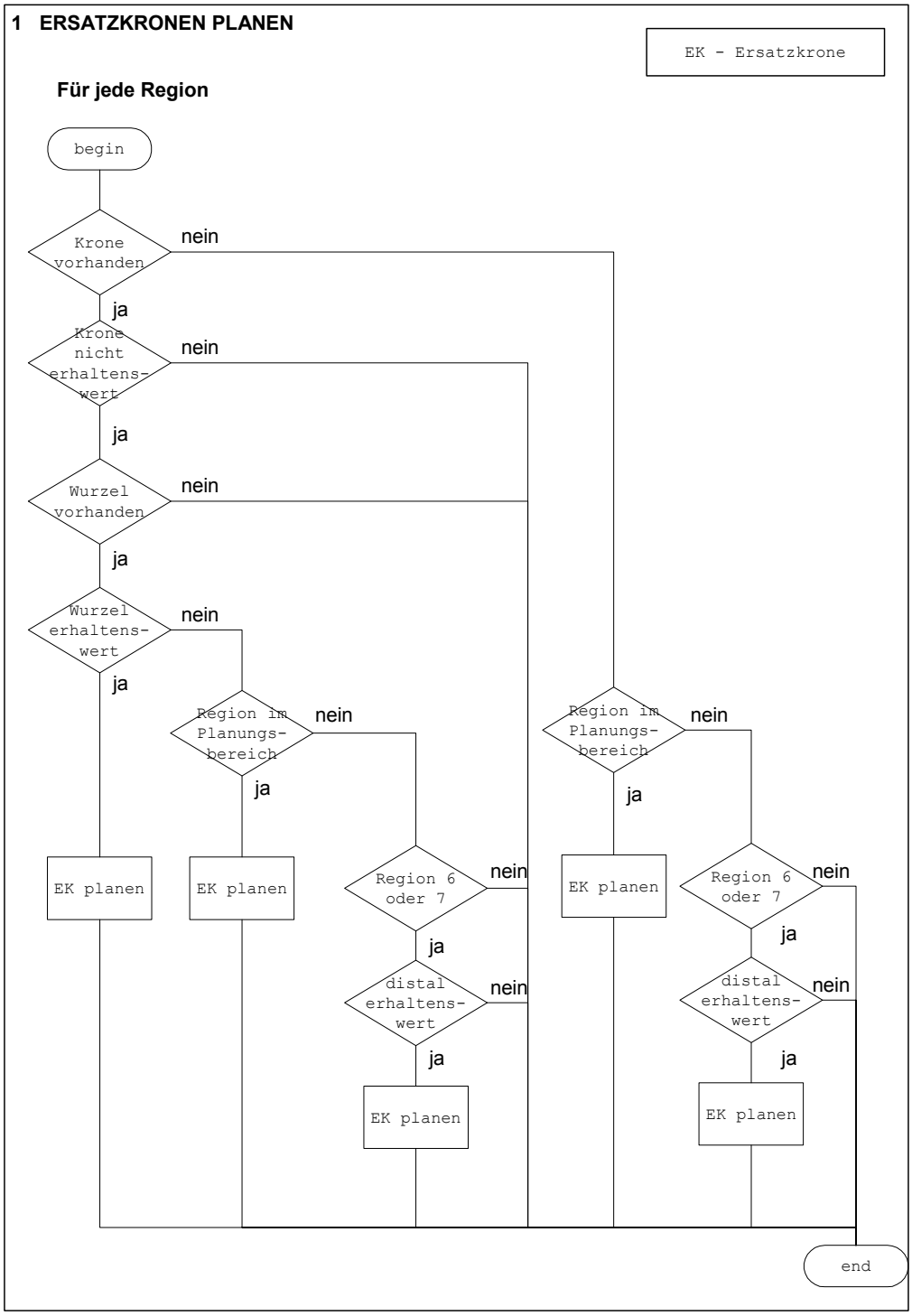

Figure 42: Activities for planning crown restorations. The regions 0x1 to 0x5 have been defined as the visible region of the dental crowns This may vary in individual cases.

4.3.1.2 Planning bridge units

The possibility apical attachment to an available abutment is examined for each crown restoration within the bridge planning mode. If this is not possible, the

possibility of an inclusion in a bridge construction as a unit of the bridge is examined. This unit can be specified further to form a bridge anchor, providing it receives its "own" abutment. This is realized through abutment reproduction using an implant. Alternatively, the bridge unit can be attached to a neighboring crown.

If a bridge unit can be fastened to a natural abutment, the later must, at least in part, be prepared and furnished with retention elements. After finishing the mode "plan bridge units", the crown restorations that are to be included into a bridge construction have been identified.

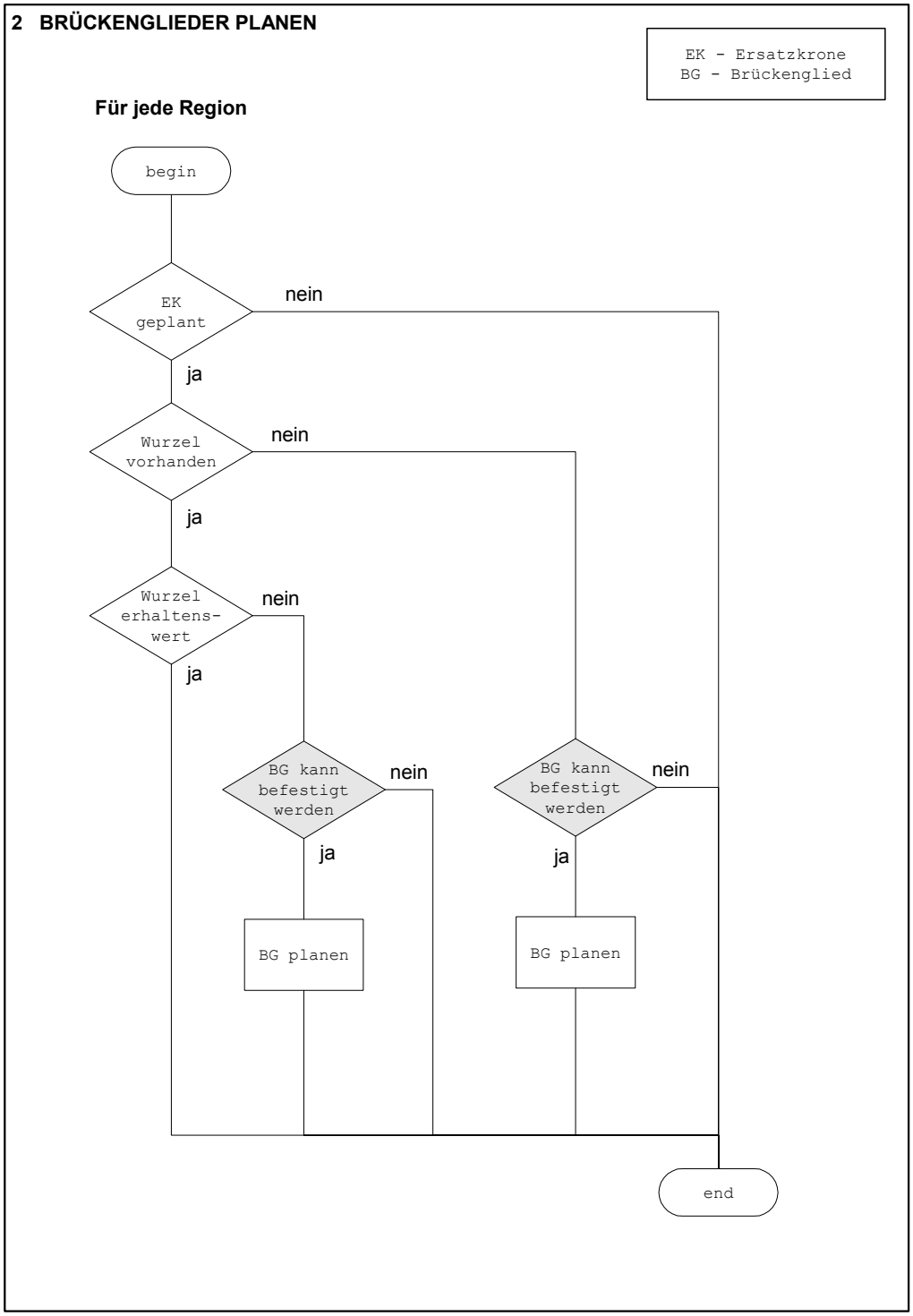

Figure 43: Activities for planning bridge units. The possibility of using neighboring crowns/abutments necessary to fasten bridge units is examined.

After completing the mode “plan crown restorations” and “plan bridge units”, it is clear whether – and in which regions – crown restorations are needed, and if they will be part of a bridge construction. Planning the crown restorations is then complete. The next mode is “plan abutments”.

4.3.2 Conceptual Model: Planning Abutments for "Fixed Restorations"

Building upon the planning of fixed restorations explained in the previous section, abutment planning will now be discussed. The bridge units can either be attached to neighboring abutments, or an implant must be set in the appropriate location. In the first case, further crown restorations must be included into the bridge construction as retention elements. In the second case, it must be examined if the preconditions for an implant have been met.

The "abutment planning" mode examines the possibility of fastening the end units of the bridge to the jaw (the end units are located on either end of the a row of bridge units). Three alternatives exist:

1. The bridge unit is fastened to a neighboring crown restoration, which, in turn, is fastened to either a natural or artificial root (core module "use available abutment").
2. The end units of the bridge are fastened to an implant (core module "plan terminal implant").
3. In case large areas must be spanned, additional implants must be set (core module "plan abutment reproduction").

It should be noted that planning implants, as described in steps 2 and 3 above, is used in various problems.

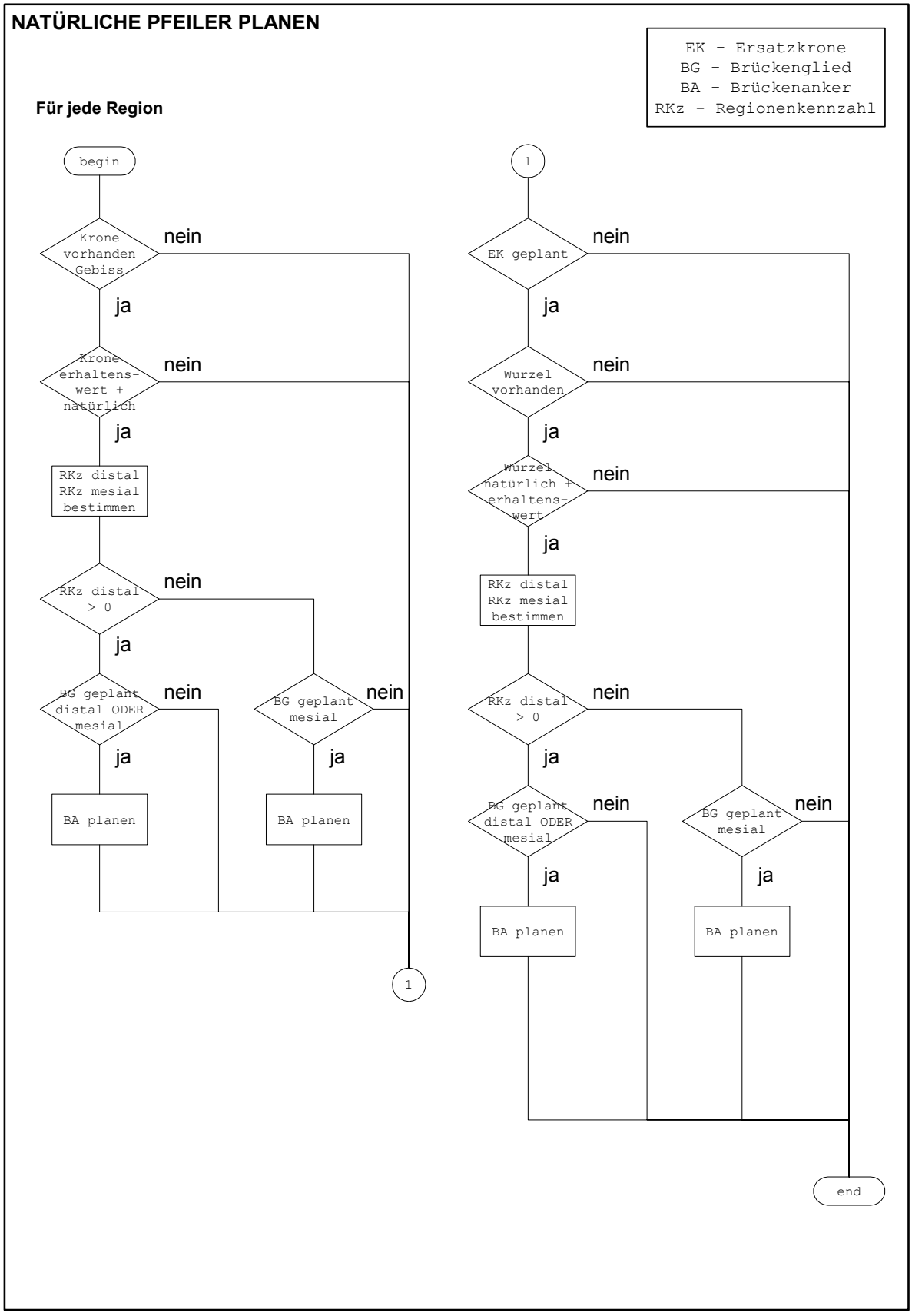

Figure 44: Activities for planning natural abutments. Which natural abutments can and should be used for fastening a prosthetic construction is examined.

4.3.2.1 Using available abutments

All natural roots that can be used to fasten a specific bridge construction are identified during natural abutment planning. The anchors for the bridge in the effected region of the dentition are also planned. A natural root can only serve as an abutment for a bridge if it possesses a sufficient quality. Whether a previously prepared crown or a quality crown is used as an abutment depends on the respective conditions and the dentist's preferences. Both alternatives can be planned and suggested.

This form of planning includes all suited natural abutments into the construction. The number of new implants is kept at a minimum.

4.3.2.2 Planning terminal implants

It may be desired to leave natural dental structures undamaged. Therefore, in addition to the mode "use available abutments" implant solutions are also suggested as terminal abutments at the ends of the construction. This can prevent the need for telescopic coping. The teeth effected by this measure would otherwise be included in the bridge construction.

A certain degree of invasiveness can not be avoided when using implants. Hereby, one or more implants are set into the jaw. In some cases, however, a preparation of the jaw is the preferred option. In this case, the jaw may require reconstruction using augmentation.

4.3.2.3 Planning additional abutments

The distance spanned by the terminal abutments of a bridge may not surpass a certain length. A maximal length is set in the decision model for bridges with three or more units. The module examines the length of the span and, in case of exceeding lengths, recommends the use of additional abutments to support the bridge construction.

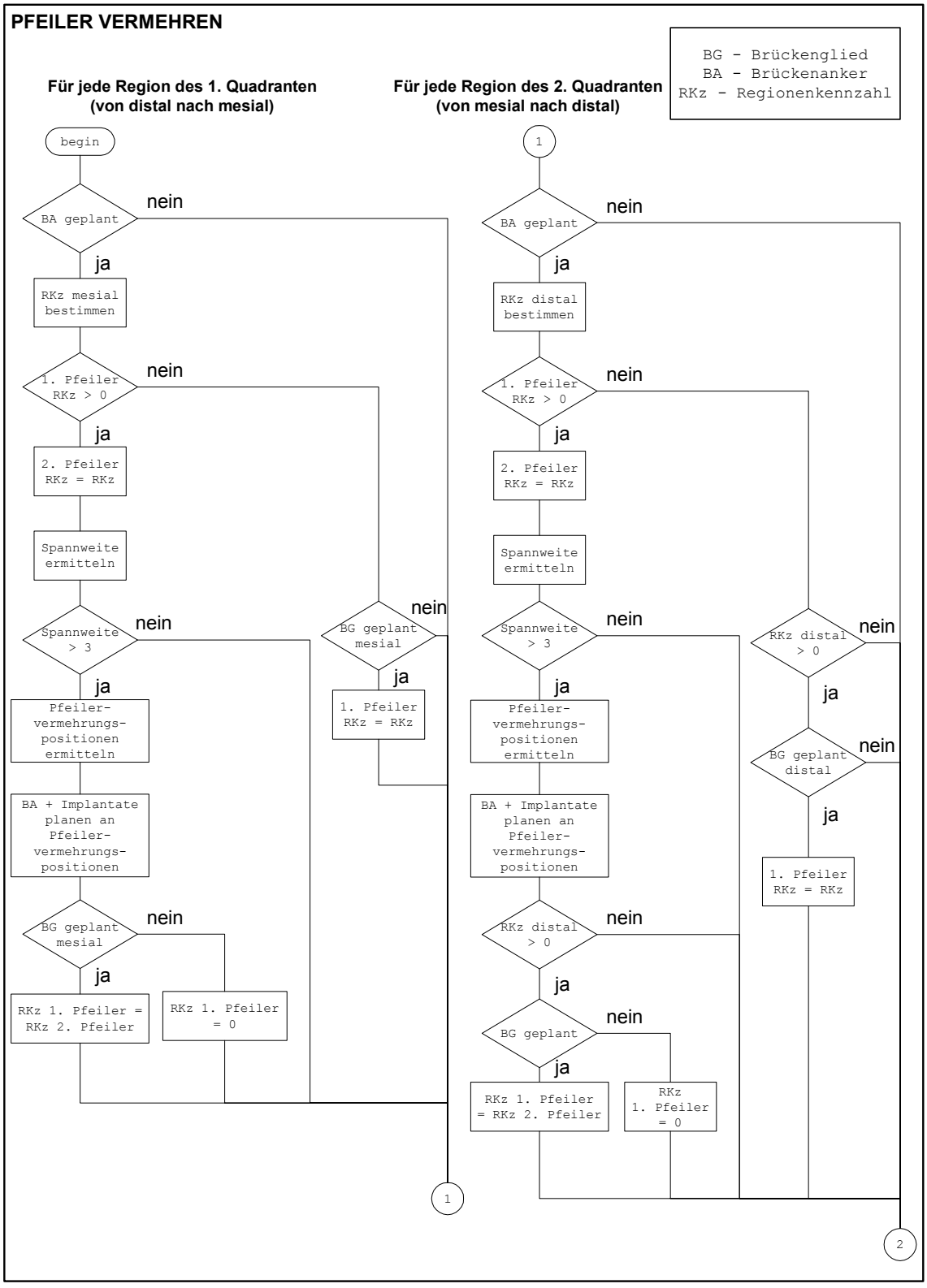

Figure 45: Activities for planning the insertion of additional abutments (upper jaw). It is examined whether a sufficient number of abutments are available for a prosthetic construction. If not, additional abutments are planned. The diagram is specified for the upper jaw.

If additional abutments are required, but can not be placed, an absolute exception criterion comes into effect for that particular alternative.

4.3.2.4 Integration of the three planning modules

The core modules of the construction process are now to be combined to allow their processing in as few planning steps as possible. Hereby, a recommendation is for planning one tooth crown restorations given if bridge units can not be planned, or restorations could not be used in a bridge construction.

If, however, bridge units could be planned, two planning recommendations are made. For one, the possibility of using natural roots to fasten the bridge construction is recommended wherever possible. If natural structures are not available, a second recommendation is given to use implants to fasten the bridge. If natural structures not available from the beginning, only the second implant-supported recommendation is made. The order in which the core modules are used can be seen in Figure 46.

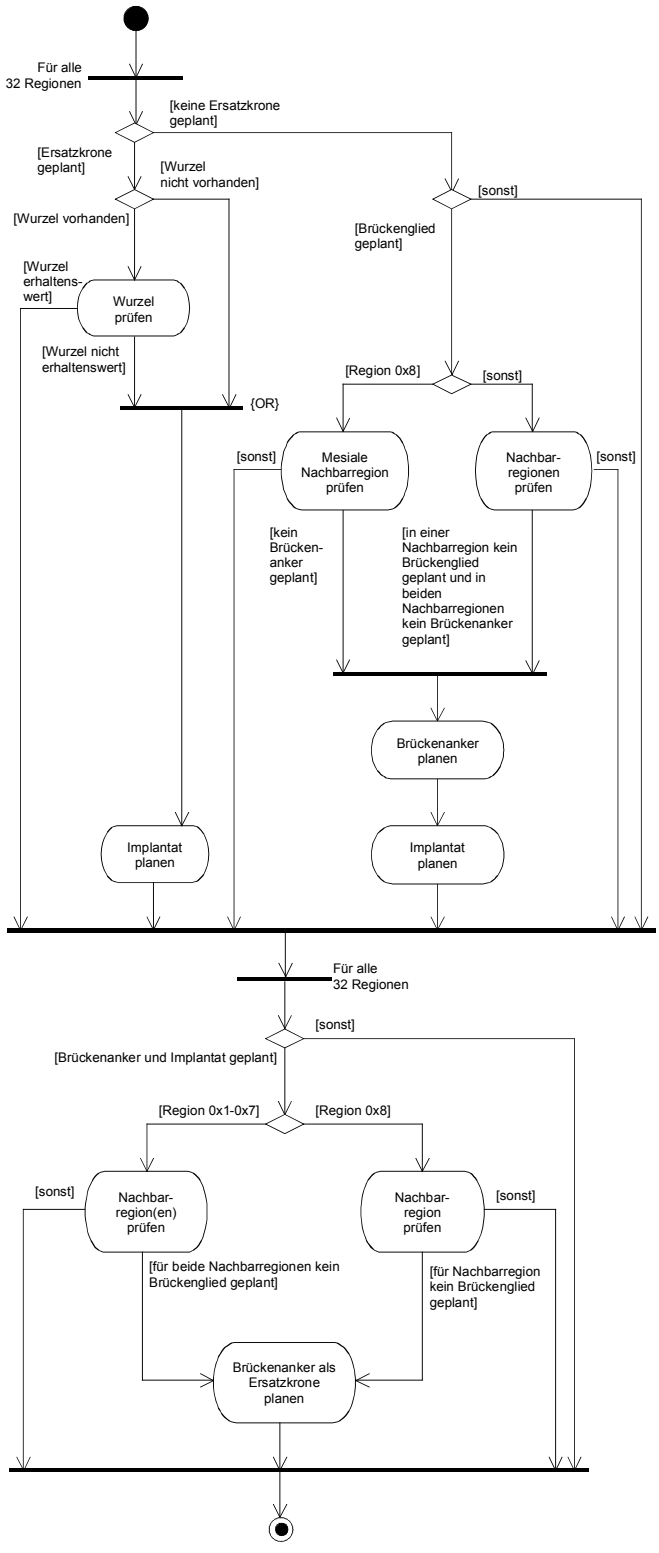

Figure 46: Activities for planning abutments in cases of "fixed restorations"

The prosthetic constructions recommended on this basis represent the minimal solutions. They can be expanded upon if necessary, for instance, in cases of instability. Hereby, a more stable solution is recommended, which either uses additional abutments or implants.

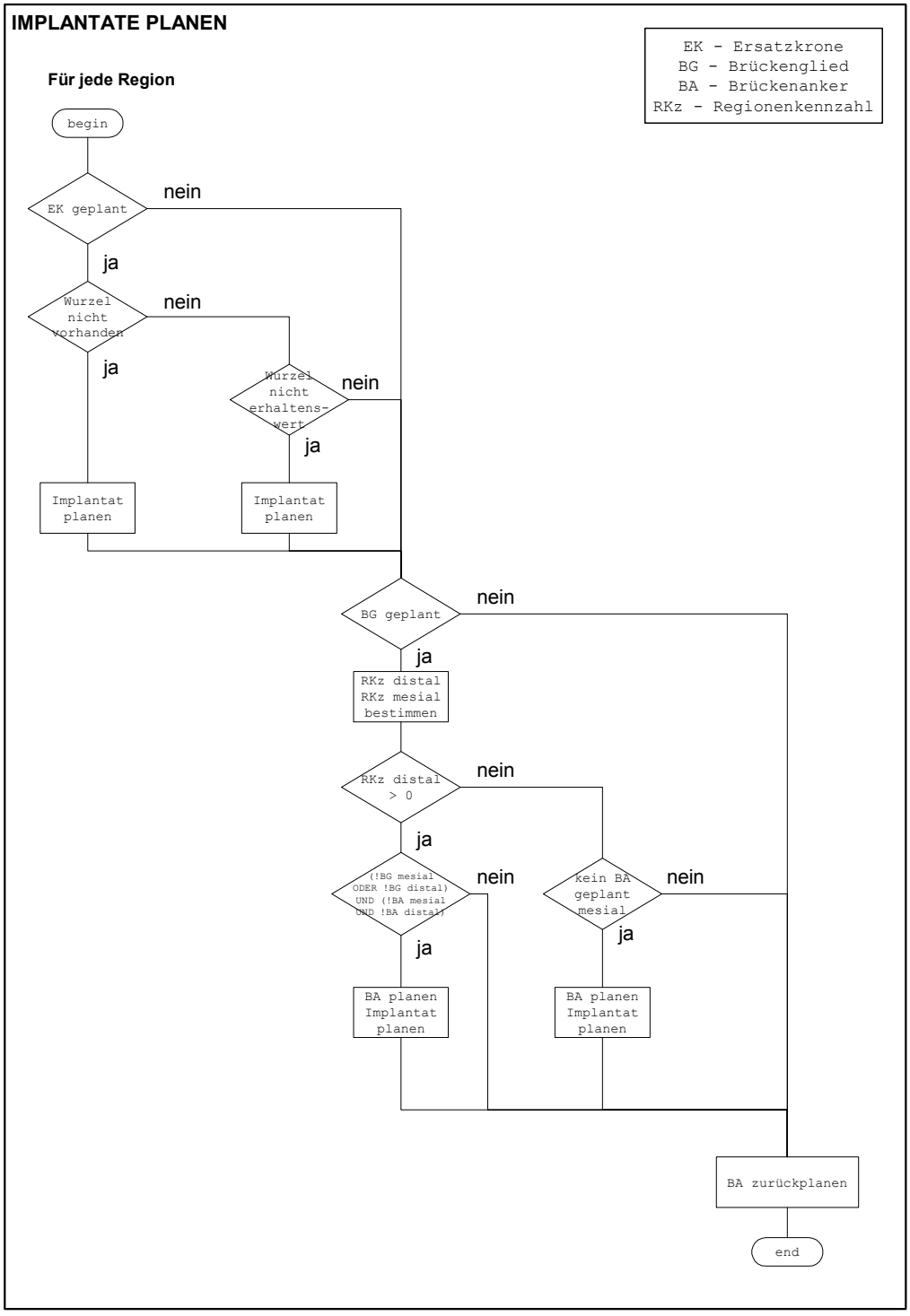

Figure 47: Activities required for planning implants.

4.4 PLANNING THE TREATMENT PROCESS

The necessity of a treatment process was derived from the functional analysis, which lead to the measures required for prosthetic construction. After describing the general goal criteria and the derived patient-specific solution alternatives, the

question posing now is how the respective alternatives can be realized practically. The treatment process is not a strict result of the descriptions of the treatment alternatives, even though many relationships exist.

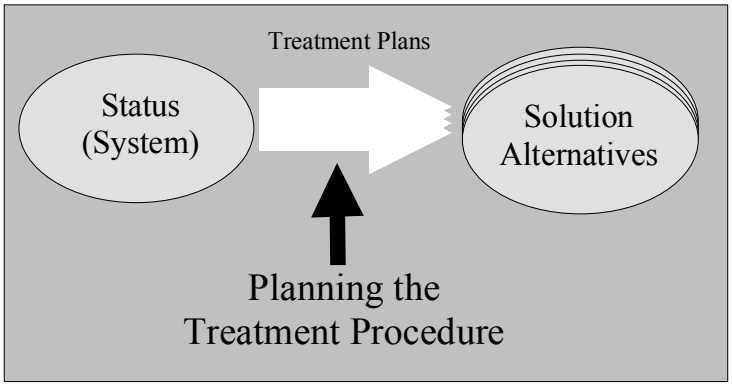

Figure 48: If, for a specific patient status, the anamnesis and the results are combined at a certain time point t, the treatment can be idealized as a transformation of conditions (compare Chapter 0).

Goal criteria must be defined for the treatment process in order to find an optimal treatment:

Definition 31: Goal criteria of the treatment process
Treatment should occur in such a way that as little effort as possible is required to reach the treatment goal. If quality structures are endangered by the treatment goal, protective measures must be integrated into the goal criteria.

Intermediate steps are required to reach the treatment goal. Such steps must be able to examine the proposed treatment measures. Dental treatment includes preparatory and non-dental measures, as well as the realization of the treatment (compare Chapter 3.3.1). The following will only briefly discuss the preparatory measures, since they are an indirect part of the dental domain. In addition, the actual treatment plan presented here covers only direct dental treatment measures.

4.4.1 Preparatory, Non-dental Measures

As discussed previously, a dentist may also be confronted with non-dental treatment measures. Most such measures are independent of dental treatment. Some, however, have effects on dental treatment measures, such as value limits or other limitations.

The reasons must be vital if an absolute exclusion criterion makes dental treatment, or its planning, impossible. Or if a required general medical treatment destroys stomatognathic structures. Only an improvements of the overall condition of the organism can justify relativizing the goal criteria of dental medicine. In such cases, the focus of discussion lies beyond the scope of the dental goals. Therefore, they shall not be discussed further.

'Normal' dental treatment planning begins once these measures have been determined, or cured.

4.4.2 Planning the Dental Process

While planning the treatment goals, it became clear that the individual treatment measures build upon each other and can be seen as the preparatory measures for the overall result. Since relationships exist between them, certain boundary conditions result for the treatment process. Treatment should generally be conducted backward if goal-oriented planning – starting from the goal and going back from there – is used. Additional evidence for this is provided by the functional dependencies of the dental structures, such as that the jaw (joint), gingiva, periodontium, dental roots, dental cervix and crown are all connected to one another.

In an architectural sense, the "underlying" structures build a foundation for the "overlying" structures based on the functional dependencies. Treatment should begin at the foundation, since static, or functional, problems must be expected otherwise. The treatment process can, therefore, be derived from the previous chapter.

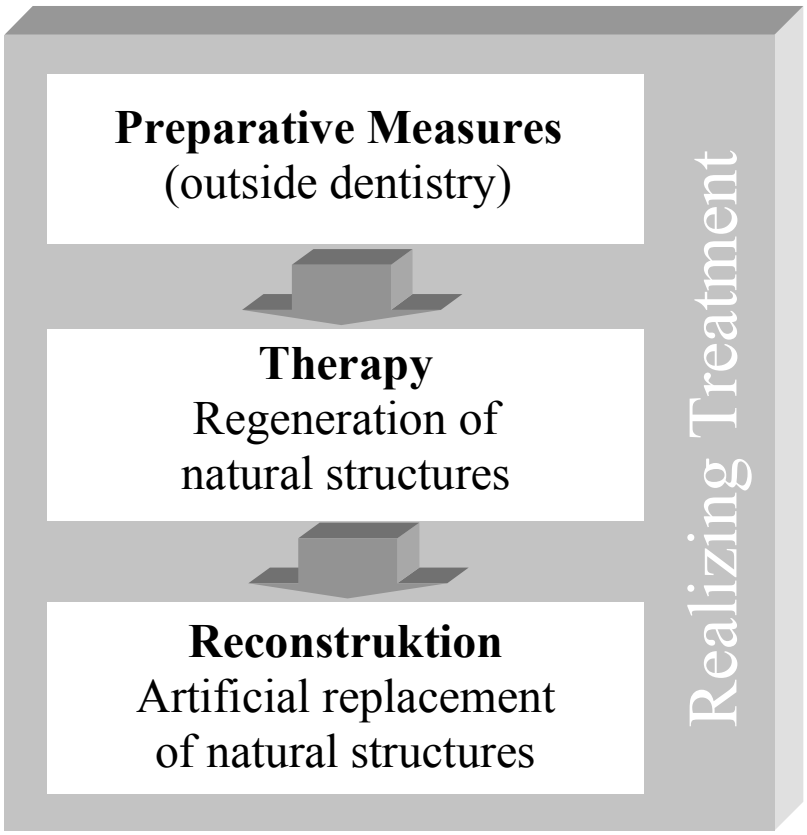

Figure 49: Treatment is the realization of the treatment plan. It can be broken down roughly in preparatory measures, therapy, and reconstruction. Some types of reconstruction require an separate steps.

Generally, whenever possible, natural structures should be regenerated before using artificial materials[76]. Between the natural and artificial structures, healing processes are required that may effect a treatment beyond its mere realization.

However, there is an important exception: Since orthodontic measures generally require a long period of time, conservation measures should not be put off too long if possible. These measures serve the regeneration and conservation of healthy structures and should be carried through quickly. The treatment process, therefore, is:

Summary 21: Idealized dental treatment process[77]

[76] This statement refers to the detailed anatomical analysis above

[77] If, e.g., endodontic or periodontic measures require an extraction, the status of the patient changes to such a degree that prosthetic planning must be conducted redone.

(In the following sequence, parallel occurrences can arise between steps 5 and 7).

1. Anamnesis; physician consultation.
2. Interpretation of the results, including documentation.
3. Diagnosis and planning of acute, mid and long-term treatment; information, consultation and informing; decision structure for goals; treatment plan.
4. Conduct acute measures.
5. Extraction therapy; implantology; pre-prosthetic surgery.
6. Tooth conservation via endodontics, health advancement and preventive dentistry; periodontics; pediatric and juvenile dentistry; restorative dentistry.
7. Orthodontic measures.
8. Application of fixed or removable prosthetics.
9. Measures of health advancement (good nutrition, adequate oral hygiene) and prevention (reduce risks of disease).
10. Follow-up care; follow-up treatment.

This process can be presented in greater detail to determine specific treatment measures. It does not make sense here to specify the demanded strict processes for the individual modules. The interactions between the modules must be described in a finer granularity.

In order to complete the process, an accounting module is included. The recall module is limited to scheduling. From there, the planning cycle begins again.

4.4.3 Control Structures during Treatment

Mechanisms that guarantee the success of the overall treatment in accordance with the decision methodology are required to verify the success of individual

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This means, a step back must be taken into the module responsible for planning prosthetic treatment. Such a deviation of the treatment plan becomes necessary once a treatment module reaches into the planning area of a previous module. The jump back is made only for a specific treatment alternative, leaving the other alternatives untouched by the jump.

measures during treatment. Therefore, it must be clearly defined when the criteria must be checked.

Definition 32: Control structures during treatment

- Every treatment step, large and small, verifies the fulfillment of its treatment goal.
- Once the treatment goal is reached, the next module is called.
- If the treatment goal is not reached, a step back is taken to the responsible module.
- In addition, each module can verify the fulfillment of its own preconditions prior to beginning with its actual tasks (planning or treatment). This way, mistakes can be avoided before they push their way through the entire methodology. The overall treatment goal should have been fulfilled after completing a treatment, from the perspective of the methodology. However, this does not necessarily mean that all dental goal criteria were fulfilled.

The following diagram shows this relationship:

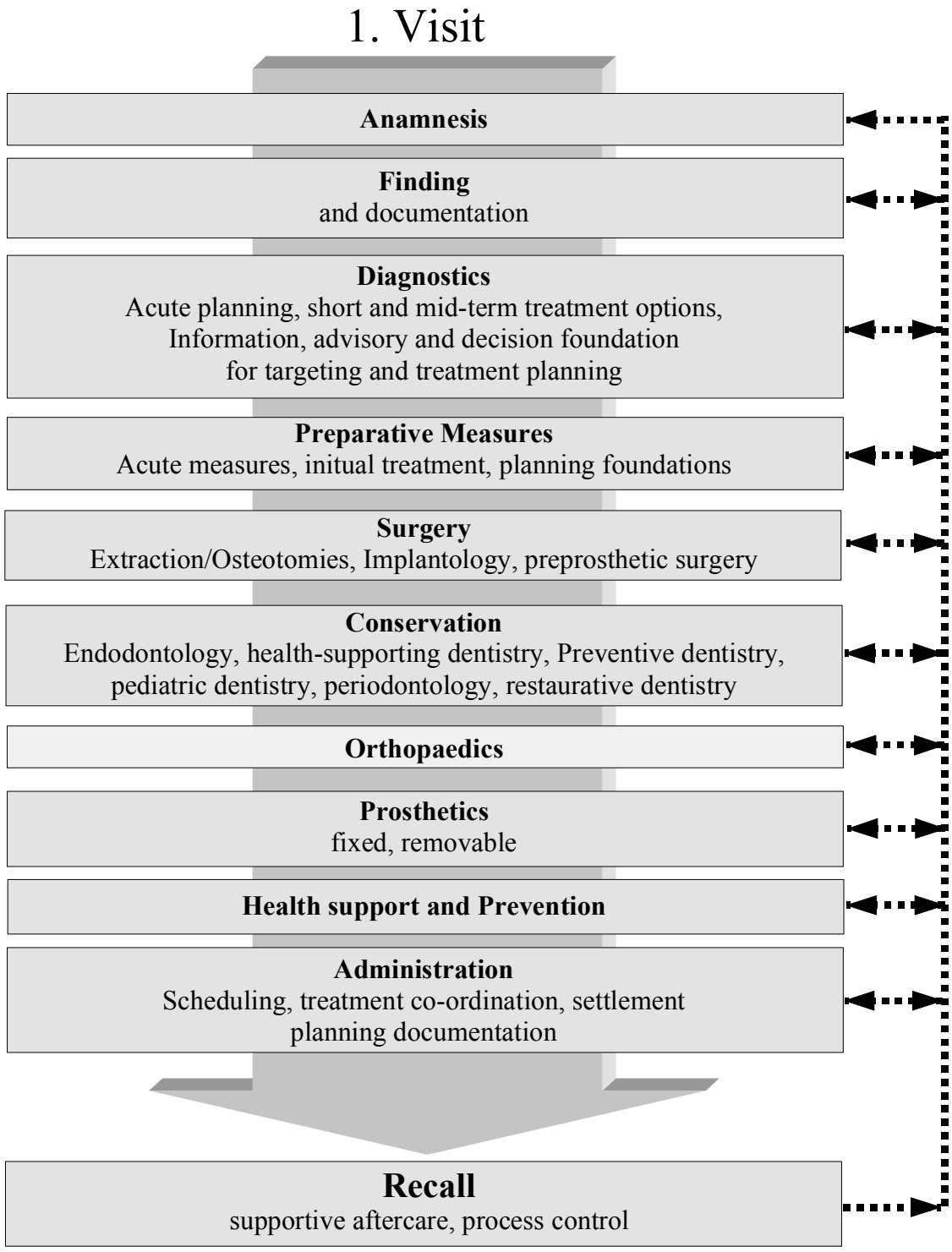

Figure 50: Basic dental process plan: The planning steps are conducted consecutively, whereby each step verifies the fulfillment of its goal. Should problems arise, a step back must be taken to the previous. Treatment iterations can occur during this process.

4.5 SUMMARY: GENERATION OF TREATMENT ALTERNATIVES

The most important results of Chapter 4 are summarized briefly:

Summary 22: Necessary foundation for generating treatment alternatives

- Acknowledged decision structures are required to generate treatment alternatives.
- A strict representation of the decision structure in form of an algorithm is required.
- Problem areas are broken down to determine the necessary planning rules. These rules should be comprehensible, acknowledged, and complete.
- Anamnesis and the diagnosis deliver information about the patient status.

Definition 33: Procedure for generating treatment alternatives

1. Determine target conditions for the dentition from the goal criteria (Where is a natural or an artificial dental crown needed?).
2. Backward planning of the possible treatment alternatives is conducted for each dentition.
3. Develop a treatment plan for concretion of the treatment process.
4. Make a list of the required materials.
5. Cost-performance lists can be used to determine the costs based on the treatment plan and the list of required materials - as is commonly offered by software today.

The dentist and the patient require information from all of these areas to select a treatment, in accordance to decision theory. Each of these points can be an essential criterion for or against selecting an alternative. The ability to compare all of the relevant factors supports patient maturity and helps to improves their understanding of the individual problem. The patient can better identify with the problem and actively support the success of his treatment. A neutral basis for communication between dentists and patients can help prevent misunderstandings and improve further cooperation, which has a direct effect on treatment success.

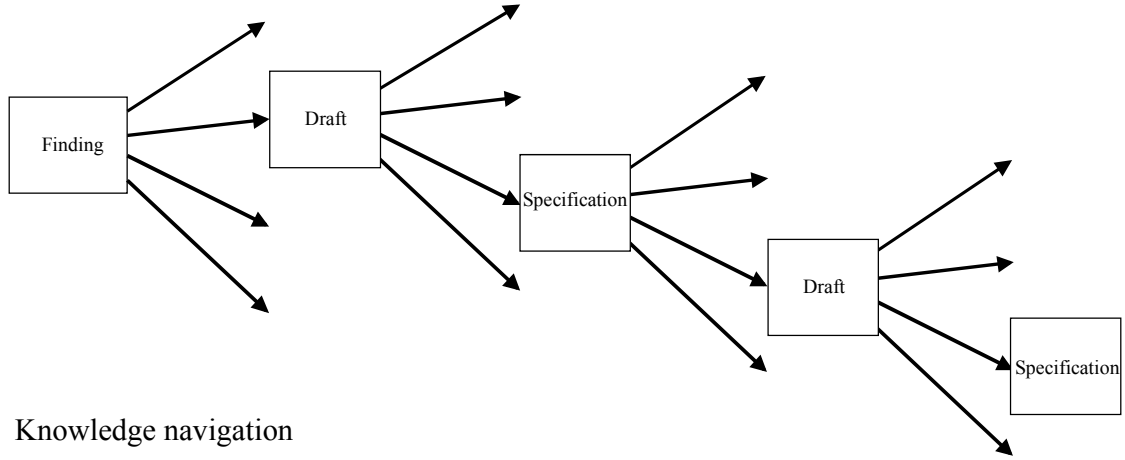

Figure 51: Due to the innate incompleteness of the diagnoses, planning must be fine-tuned using additional information. Since an under-supply of alternatives could mean leaving out a suitable alternative, an over-supply must be offered

The following chapter shows how the selection of a treatment alternative can be supported. Despite the fact that the presented methods do not allow a strict decision.

5 SELECTING A TREATMENT ALTERNATIVE

Decision making can generally be seen as a part of planning. However, a separate chapter will be dedicated to this topic, since it surpasses the mere purpose of being a scientific, comprehensive methodology to generate treatment alternatives.

The previous chapters described how, using hard criteria, a fixed decision structure can result from goals and the functional analysis. Treatment alternatives are the result of these and the individual diagnoses. The alternatives contain the descriptions of the alternatives and the respective treatment plans, including their individual material and cost specifications.

In accordance to decision theory, the dentist and the patient should be able to select a suitable alternative based on the above. However, the dentist and the patient do not receive a comparison of the proposed treatment alternatives. Therefore, this chapter will present methods and show ways to ease the selection process. Ideally, the selection of the treatment goal should result directly from the delivered information.

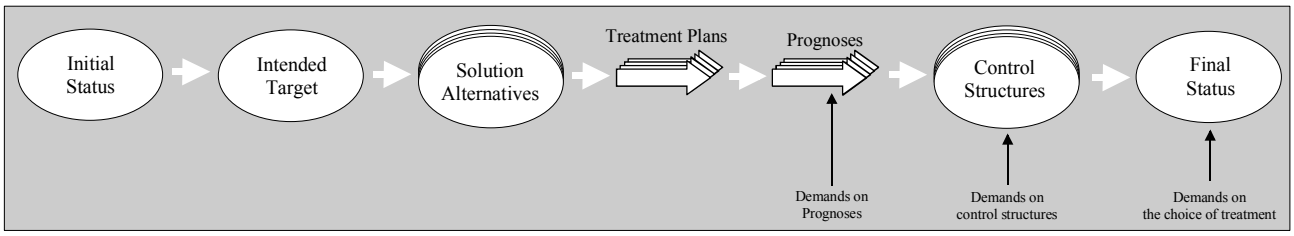

Figure 52: In previous sections, the treatment alternatives were derived from the goal criteria. Chapter 5 describes the criteria required to compare the proposed alternatives, and, thereby, the criteria needed to select a specific treatment.

As shown in previous sections, planning does not result in *one* solution, but rather a set of alternative solutions. These alternatives must be considered equal alternatives if decision criteria is not available to limit the solution set.

Therefore, a separate step is now introduced that also has criteria for or against an individual alternative to help find an optimal treatment for the patient.

Definition 34: Decision
A decision is the selection of one from a set of several, not simultaneously conductible, alternatives. The predominant characteristics of this definition are selecting and naming the alternatives. In contrast to, for instance, a legal judgment (ex-post), planning targets future-oriented decision making (compare [76]).

Since the additional information required to make a decision has no further effect on the already described decision methodology itself, control structures are described to support comprehension of the decision structure. This should lead to a comprehensive decision foundation for the dentist and the patient. Prognoses can be made for each treatment alternative to help give the patient a clearer picture of the expected solution. In addition, information can be gathered and presented that, although not mathematical or logical, can support the decision making process.

Selection is supported by various types of criteria:

- Practical aspects of a solution, e.g. the duration of treatment.
- Progress studies fortify predictions.
- Prognoses gained through controlled studies.

5.1 PROGNOSTIC PROBABILITY STATEMENTS

After proposing and explaining each treatment alternative, evaluation criteria must be determined for each. These criteria should allow a comparison of the individual alternatives. Generally, the functional, aesthetic, and financial prognoses are combined to form one prognosis for the overall evaluation, from which a stringent decision can be made. This, however, goes far beyond the scope of today's scientific knowledge and, is an ethical issue. Therefore, this type of additional information should be presented to the dentist and the patient neutrally, to simplify the individual selection.

In addition, it should be noted that the evaluation of the targeted goals and their prognoses must be brought in unison with the patients' emotion during the

actual decision making process. For example, the fear of surgery can not be compared to and evaluated with differences in costs. This would, however, be required in a scientifically acknowledged selection of a treatment for an individual patient.

Statistics relating to a specific group of people do not allow definite conclusions over the prognosis of a specific patient. Therefore, they can not automatically be included in the decision for a specific case. However, they can serve as additional information and, therefore, as decision-support in the selection process. The dentist and the patient can, knowing the probability of a certain risk, evaluate the risk potential and make it part of their case-based decision. Therefore, the following will describe different types of prognoses existing within dental medicine.

The following will focus on the technical prognoses according to Popper ([95]). Herein, constructive measures aimed at achieving certain results (e.g. healing) are presented (compare also [42]).

5.1.1 Life-Span of Prognoses

A differentiation is made between short, middle and long-term prognoses [82,97]. Short-term prognoses cover the time during treatment, while mid-term prognoses focus on reaching the targeted state. Long-term prognoses cover the time period following treatment.

Functional and aesthetic prognoses are generally mid and long-term, since short-term prognoses are covered by the treatment plan.

5.1.1.1 Short-term prognoses

A short-term prognosis describes the development of each treatment phase. In dental medicine, this applies, for example, to an individual visitation. Primary interest is placed on the realization of the treatment. The short-term prognosis is contained within the treatment plan.

5.1.1.2 Mid-term prognoses

The mid-term prognosis describes the time period between the first use of a specific solution and recovery from a specific treatment. Treatment is completed once the patient has fully integrated the chosen solution. This type of prognosis is concerned with the usefulness of the solution following treatment. No

complaints may arise due to the selected treatment. From the patient perspective, all acute dentition-related problems must have been resolved.

5.1.1.3 Long-term prognoses

The long-term durability of a solution is described by the long-term prognosis. The regeneration of natural structures, hygienic development, the extension of restorations in cases of instable dentitions[78], as well as long-term cost strategies are the focus of long-term prognoses.

This type of prognosis is often neglected in treatment today, since it is a critical topic during patient consultation. The strong influence of probabilities makes giving specific answers difficult, and, therefore, complicates the communication between the dentist and the patient. However, the long-term prognosis is an important part of treatment planning, because a treatment is also an investment.

A long-term prognosis can be given, for instance, for a 5, 10, 20 or 50 year period to provide better answers pertaining to the development of a treatment alternative[79].

5.1.2 Types of Prognoses in Dental Medicine

Different types of prognoses exist according to the subject matter [96]. The consequences resulting from these prognoses create the "space" of expected events[74]. The general types of prognoses will now be presented in terms of functionality, aesthetics, costs, and the various time frames.

Beforehand, it should be repeated that there is no direct relationship between the static view chosen for this analysis and the length of the prognosis. Moreover, in contrast to a dynamic view, the static view reflects an estimation of a given future point in time. However, this does not take into consideration that new information arises over the course of time, which may lead to a different estimation or, in some cases, require new planning.

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[78] For example, risk of caries and periodontal diseases.

[79] For an 80 year old patient, for instance, the question arises whether a 50-year durability should be targeted?

5.1.2.1 Functionality prognosis

The expected functionality of a solution must be described in great detail, with all its advantages and disadvantages, Especially in terms of handling, hygiene, and the need for follow-up care. the patient is able to estimate the consequences of a certain treatment on his own only after receiving a detailed description. Whereby, verbal, textual and graphical presentations can help.

More emphasis should be placed on providing a *neutral description* of the functionality and the required measures, rather than on an *evaluation* of the functional aspects. It is not yet clear how this can be modeled scientifically.

The functional prognosis should present the natural and artificial structures that are to be use. Changes to tooth substance, bone loss, gum contraction, as well as abrasion of prosthetic constructions or fillings playing an important role.

The functional prognosis can, for example, be based on a biomechanical simulation. A respective mathematical model has been developed within the AIDA project, and is currently being tested. The model is composed of three sub-models, which calculate the forces acting on the prosthetic and the dental crowns, the burden placed on the roots and implants, as well as an approximation of the effects the construction would have on the periodontium.

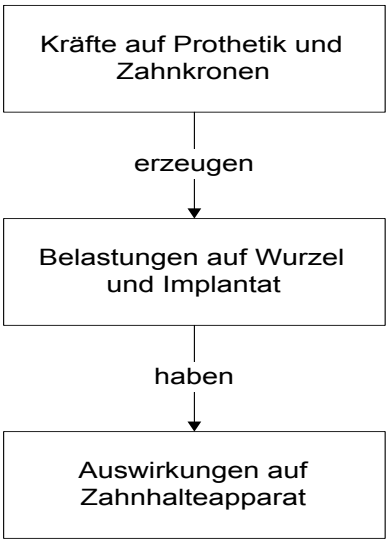


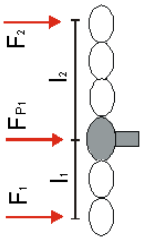
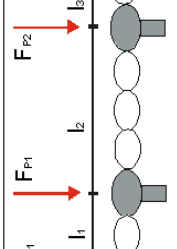
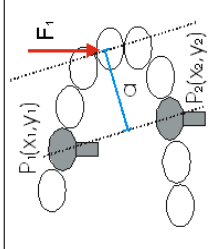
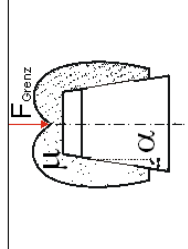
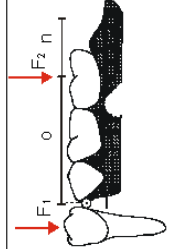
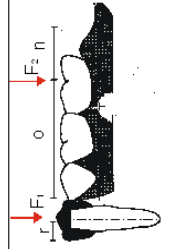
Figure 53: Procedure for determining the effects of a prosthesis on natural structures.

Masticatory forces as measured by [Lenz, 1992 #334].

- Dry meat: approximately 35 N
- Gum drops: approximately 30 N
- Small nuts: approximately 17 N
- Pudding: approximately 3 N

The effects all force patterns have on the prosthetic can be using these approximations of the maximal dental force load. Mathematical models are needed to calculate the masticatory forces acting on the abutments carrying the prosthetic constructions. A comprehensive collection of respective models is presented by Lenz in [96]. Calculations for constructions requiring more than two abutments are quite complex, because the bending forces of the prosthetic must be taken into consideration (compare Table 4).

Table 4: An overview of the models presented in [Lenz, 1992 #334].

Modell für	zu berechnende Werte	Modellparameter	Herkunft der Modellparameter	Lösungsformeln
einen Pfeiler, mit oder ohne Extensionsbrücke			**F_1, F_2, F_{P1}** sind aus Kräftemodell, **l_1, l_2** werden errechnet aus Eingabeparametern für Brückenspanne, **c** ist Federkonstante des Pfeilers.	$i_{max} = \frac{F_{max}}{c}$ $F_{max} = \max(F_1, F_2, F_{P1})$ $M_{max} = \max(F_1 l_1, F_2 l_2)$
zwei Pfeiler, Brücke mit oder ohne freies Ende			**F_1, F_2, F_{P1}** und **F_{P2}** sind aus Kräftemodell, **l_1, l_2** und **l_3** werden errechnet aus Eingabeparametern für Brückenspanne und Pfeilerpositionen.	für den linken Pfeiler: $F_{max} = \max(\frac{F_1(l_1+l_2)}{l_2}, F_{P1})$ $i_{max} = \frac{F_{max}}{c}$ $F_{emax} = \frac{F_2 \cdot l_3}{a}$, $e_{max} = \frac{F_{max}}{c}$
Drehmomente bei zwei Pfeilern			**F_1** ist aus Kräftemodell, **a** errechnet sich aus Parabelgleichung und Position der Pfeiler, **P_1** und **P_2** errechnen sich aus Pfeilerposition. Angriffspunkt von **F_1** wird aus der Parabelgleichung gewonnen.	Die Gleichungen werden im Anschluß an die Tabelle hergeleitet.
Konuskrone			**F_{Grenz}** ist die maximal auftretende Kraft auf die Krone; diese ist abhängig von der Prothesenart. **μ** ist Eingabeparameter der Materialkonstanten, **α** ist Eingabewert des Konuswinkels.	$F_{Grenz} = F_{emax}$ wenn zwei Pfeiler. $F_{Grenz} = F_{max}$,wenn ein Pfeiler. $L = \frac{F_{Grenz}(\mu - \tan\alpha)}{\mu + \tan(\alpha)}$
gelenkige Gingivalprothese			**F_1** und **F_2** sind aus Kräftemodell, **o** und **n** errechnen sich aus den Eingabewerten für okkludierten und nicht-okkludierten Bereich. **E** ist die Elastizität der Gingiva. **t_{ret}** = 1,4s (Retardationszeit)	$W(t) = 3F_2 \frac{o}{E \cdot (o+n)}[1 - \exp(-\frac{t}{t_{ret}})]$ $i_{max} = \frac{F_1}{c}$, $F_{emax} = \frac{o \cdot F_2}{2(n+o)}$, $e_{max} = \frac{F_{emax}}{c}$ F_{emax} =0, wenn $1 - \frac{3}{2} \cdot \frac{o}{n+o} < 0$
fest verankerte Gingivalprothese			**F_1, F_2, o, n, E** und **t_{ret}** wie bei gelenkiger Verbindung. **r** ist der Kronenradius und wird gleich dem Zahnradius gesetzt. **k** ist die Drehfederkonstante des Pfeilers.	$W(t) = 3F_2 \frac{o+r}{E \cdot (o+n) + \frac{3k}{(o+n)}} \cdot$ $[1 - \exp(-\frac{t}{t_{ret}} \cdot (1 + \frac{3k}{(o+n)^2})]$

Before beginning with the simulation of the prognosis, the necessary patient information must be collected and examined in terms of plausibility.

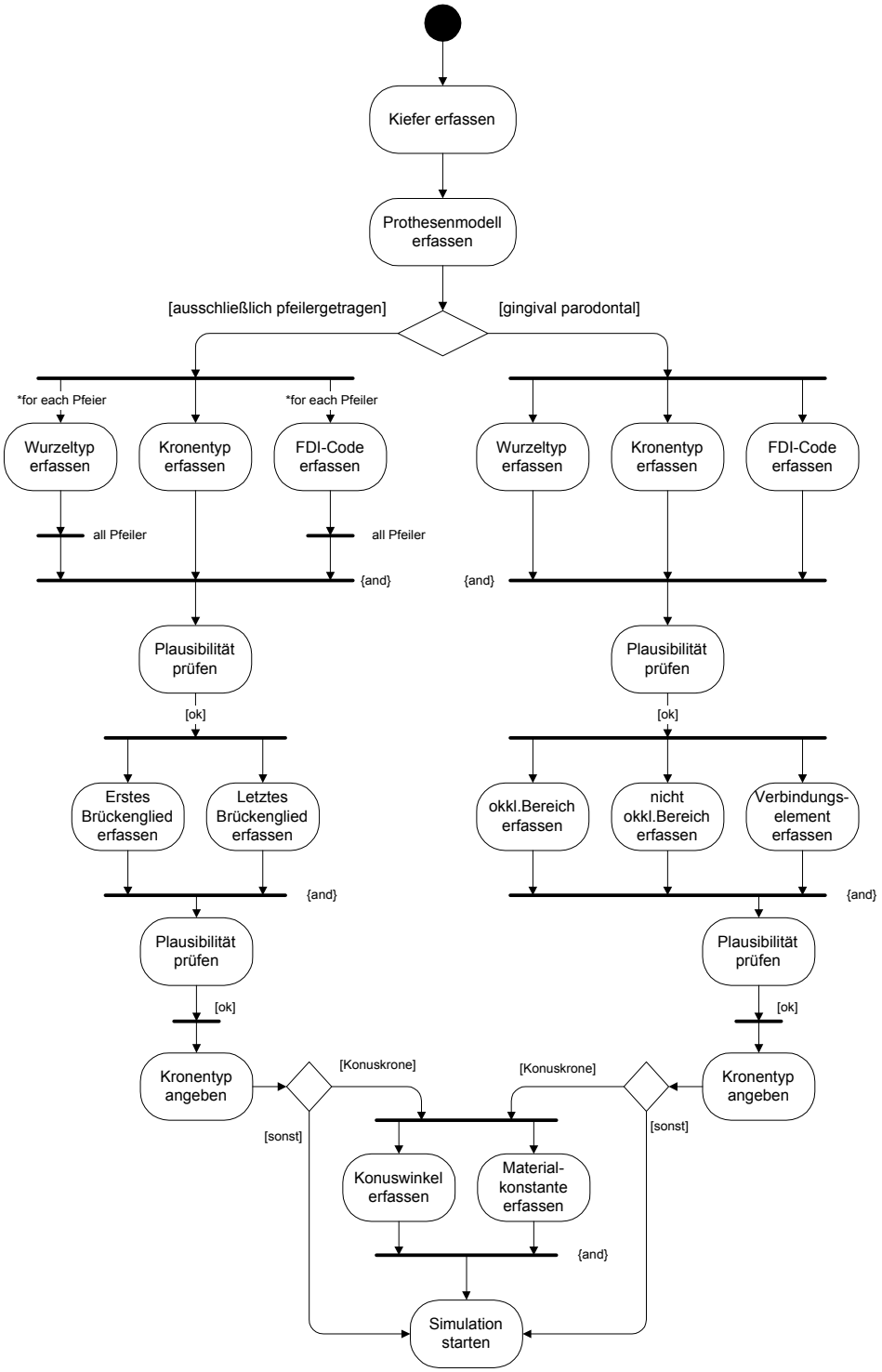


Figure 54: Overview of the activities in case "preparing the simulation of the prognosis".

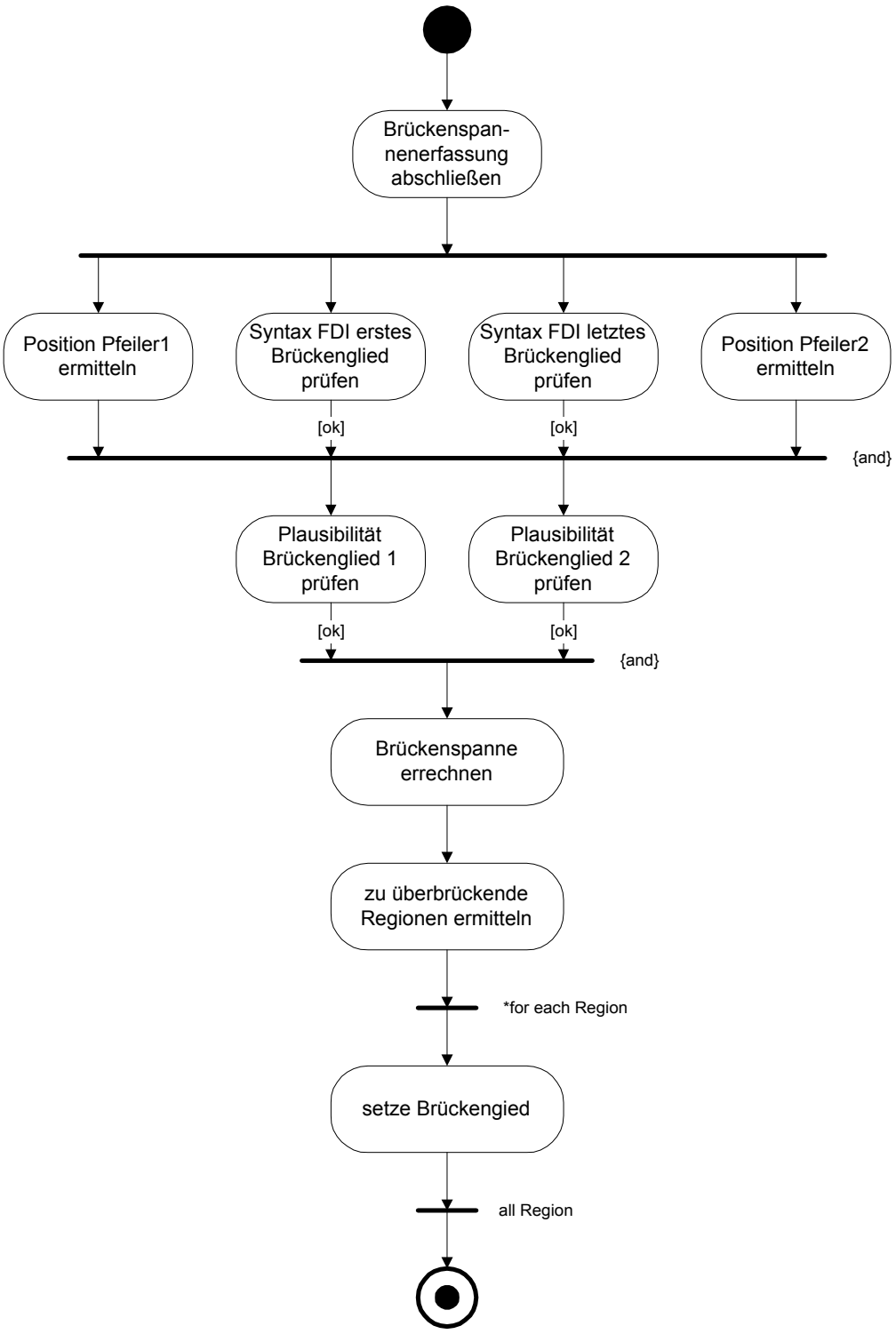


Figure 55: Activity diagram of the plausibility examination.

As soon as the plausibility examination has been completed, the actual simulation phase can begin.

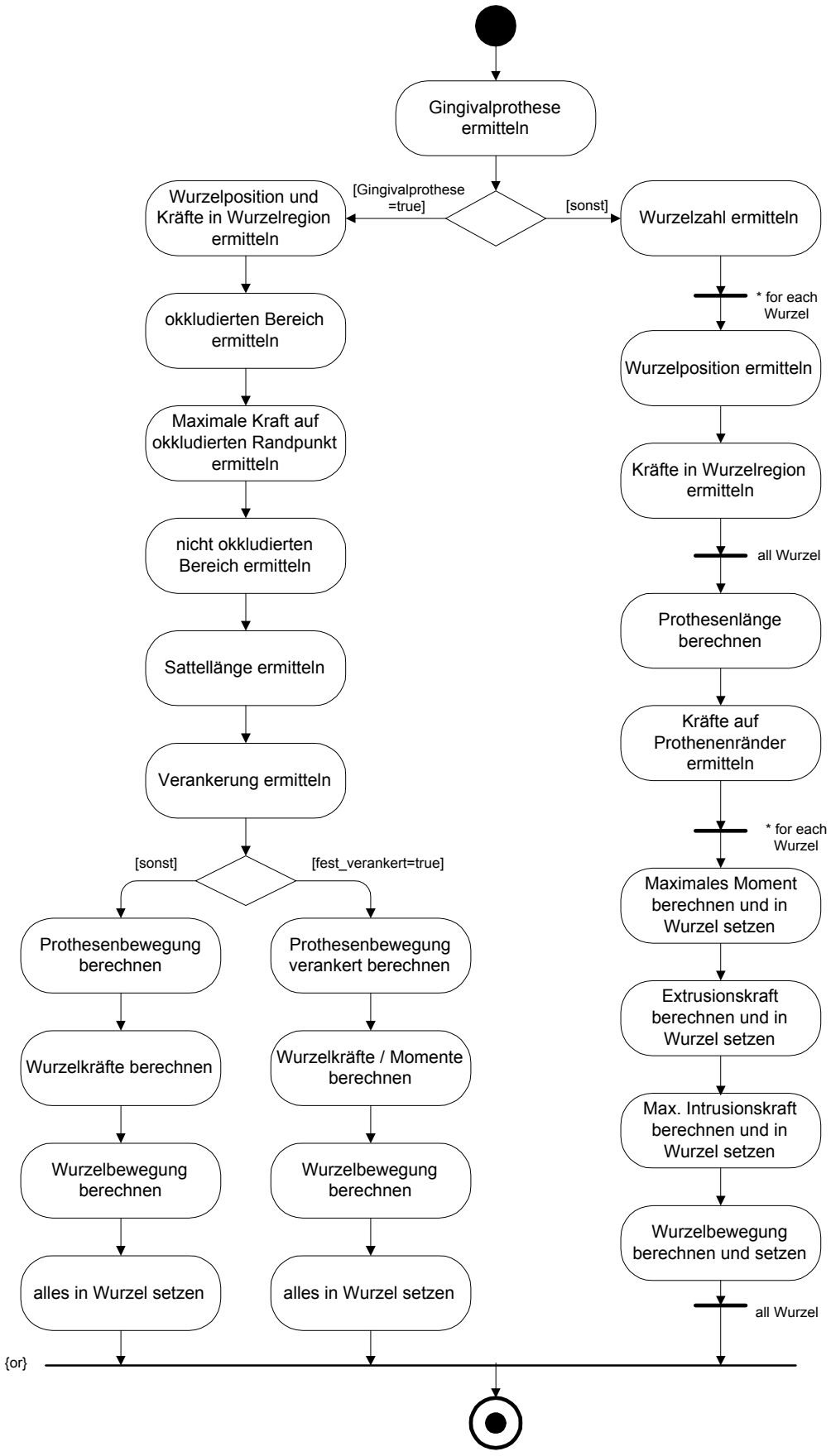


Figure 56: Activity diagram of the data calculations of the limits for the selected reconstruction.

The maximal forces for extrusion, intrusion, and displacement are calculated during the simulation. Also, the required freedom of movement for extrusion, intrusion and gingival movement, as well as the maximal occurring torsional forces are determined. Should one of these figures surpass the recommended limits, an extension of the reconstruction, as well as the resulting consequences, must be considered (e.g. an additional abutment may be required, etc.).

5.1.2.2 Aesthetic prognoses

The aesthetic development of a solution must also be evaluated. The development of the natural structures (bones, etc.) play an important role, just as do changes to artificial materials (discolorations, etc.). The respective information can generally be taken form experience and data collections.

The short and mid-term aesthetic prognosis are pretty well covered by the dental goal criteria. Therefore, aesthetic prognoses usually focus on estimating the long-term development of a treatment alternative.

5.1.2.3 Financial prognoses

The expected costs can easily be taken from the treatment and cost plan. Also, estimates can be taken from the functional and aesthetic prognoses. The required material and average work time can be estimated, and the cost of treatment returned automatically.

The functional and aesthetic prognoses show which treatment measures will probably be required. From this, the expected long-term costs can be estimated. Therefore, the life-span of each of these prognoses should also be analyzed.

5.2 ADDITIONAL INFORMATION USING CONTROL STRUCTURES

The following structures are referred to as control structures, because they can be used to help control decision making in everyday use. They comment the decision process in a user-adjusted manner.

The possibilities of an evaluation of the treatment alternatives can be shown as an example for the prosthetic reconstruction modes (compare Table 4).

Table 5: This table matches individual aspects of different types of constructions with their usage areas. Mixed forms are not shown here.

Erklärung	Konus-/Teleskop-prothese	Stegprothese	Brücke	Einzelzahn-implantat	Totale Prothese	Modellguss-prothese
Medizinisch	Verankerung der Prothese am Restgebiss/Implantate, bei günstiger Verteilung ist mit wenigen Pfeilern (2) eine gute Abstützung erreichbar	Besonders im UK bei Restzahnbestand von 2-4 Zähnen	Ersatz eines oder mehrerer verlorener Zähne – Präparation gesunder Zähne erforderlich – Inaktivitätsatrophie[82]	Erhalt der Nachbarzähne, Vermeiden der Inaktivitätsatrophie	Nur gingival getragen, häufig ungenügender Halt (UK), Fortschreitender Knochenabbau nicht vermeidbar	Verankerung der Prothese an Restgebiss, bei günstiger Verteilung ist mit wenigen Pfeilern eine gute Abstützung erreichbar
Technisch	Standard	Standard	Schwierig im OK FZB und UK bei großer Spannweite	Technisch aufwendig	Standard	Standard
Finanziell	2 Konusse von der Kasse übernommen, sollten nur 3 Zähne im Kiefer vorhanden sein werden 3 Konusse übernommen, 60% Kostenübernahme	Vergleichbar mit Konus	Kostenübernahme bis zu 60% durch die Kasse	I. d. R. kein Kassenzuschuss; pro Implantat muss mit 2500-3000 DM gerechnet werden.	60% Kostenübernahme	60% Kostenübernahme
Zeitlich	Verhältnismäßig kurzer Behandlungszeitraum	Verhältnismäßig kurzer Behandlungszeitraum	Kurzer Behandlungszeitraum	Großer Zeitaufwand	Kurzer Behandlungszeitraum	Kurzer Behandlungszeitraum
Qualitativ[83]						
Dauer-haftigkeit	Abh. Von Mundhygiene, Pfeilern, usw.	Abh. Von Mund-hygiene, Pfeilern	Abh. Von Mund-hygiene, Pfeilern	Abh. Von Mund-hygiene, Knochenqualität	I. d. R. 4 Jahre	Abhängig von Mund-hygiene und Pfeilern

Every decision within the decision structure is assigned an explanation. These explanations are pieced together during the course of decision making to create an individual overall explanation. The overall explanation for a specific treatment alternative can, therefore, be generated automatically during the decision making process. Therefore, each explanation must be formulated in such a way that it fulfills the expectations of realistic decision making constellations.

This can be demonstrated by the example of abutment planning: The decision structure demands that a bridge spanning more than three units requires the an additional abutment. A corresponding explanation in case of surpassing the limit could be: “An additional abutment must be included, since the bridge spans more than three bridge units.” This explanation will seem reasonable and acceptable to the dentist. It may be necessary to include an additional explanation for the patient referring to the type of additional abutment required, such as “This will require including an implant. …”

The explanations must be presented in an individually customized manner, since a variety of groups, each with different specialty knowledge, are involved in the decision making process. Therefore, the following will distinguish between user groups without, however, going into their different knowledge standings.

5.2.1 Explanations for Dentists

The dentist is the only person involved in the dental decision making process that must have a general overview of all the decision instances. Therefore, he is responsible for coordinating and planning the treatment, even if he does not actually carry out each step himself[80]. The following general methods for presenting knowledge are available to the dentist:

Definition 35: Knowledge presentation for dentists

- Student textbooks
- Books for further education and extended learning
- Practice guidelines
- Visualizing decision structures during treatment planning
- Diagnosis and planning sheets

The formulation of the contents can be very technical, since a high degree of basic understanding of the problem area is expected from the dentist. Decision support must be based strongly on the amount of previous user knowledge available, because the knowledge cleft between beginning students and experienced experts is very large.

5.2.2 Explanations for Patients

Patient consultations will continue to increase in importance in the future [93]. Simple explanations and concrete treatment alternatives are required to achieve a consensus in selecting the form of treatment, because it can not be expected of the patient to possess specialty knowledge. Cognitive psychological studies must be conducted to determine which information is most important to the patients.

[80] Prosthetic constructions are usually made by dental technicians.

Definition 36: Knowledge presentation for patients

- Present actual patient pictures.
- Present the remaining dental structures in a simplified, schematic manner.
- Explain the individual treatment alternatives, the treatment process, and the efforts or burdens of each alternative in commonly understandable language.
- Explain the prognoses expected for each treatment alternatives.
- Present example solutions.

It must be expected that the span of comprehension is lower among patients, since they generally do not possess extensive dental knowledge. The patients will most probably not be interested in how the decision making process takes place in detail. More so, they will need basic descriptions of the solutions and the important limitations of each. A rough summary of the contents is of primary importance for the patient. However, if the patient so desires, it should be possible for him to obtain more detailed information regarding specific aspects.

5.2.3 Explanations for Sponsors

The sponsors will continue to support their decisions on the most important features of a case to receive a clear decision structure. The detailed description of the initial condition is of immense importance, because, from this, the sponsors can determine the need for dental care provision themselves. A rough description of the targeted condition is usually enough for the sponsors for making their decision to finance the solution or not.

Definition 37: Knowledge presentation for sponsors

- Coded, standardized description of the patient status
- Therapy and cost plan (HKP)
- Further comments

Justifications for special treatment alternatives are generally required in specific cases only. Generally, the need for treatment results from the diagnosis.

5.2.4 Explanations for Legal Entities

Presentation of the case regarding legal coverage generally requires a medical explanation of the relationships as well as a complete status documentation. The dentist is legally covered as long as the treatment is conducted according to the current medical standing [94]. However, all acknowledged positions must be taken into consideration.

Definition 38: Knowledge presentation for legal entities

- Visualization of the decision structure
- Treatment plan
- Therapy and cost plan
- Further comments

5.3 INTEGRATION OF EVIDENCE-BASED DENTISTRY (EBD)

Evidence-based dentistry (EBD) is increasingly becoming an important quality assurance concept in dental medicine [49]. However, neither the term evidence-based dentistry, nor its scientific methods have been clearly defined to date [98]. EBD is, however, used most often in connection with the evaluation of dental treatment alternatives or concepts.

An integration should be considered once a closer definition of the means needed to conduct an evaluation has been determined. Including the results of EBD in the planning concept for generating treatment alternatives is possible without great difficulty. Once a specific treatment concept has been identified as basically possible, but can not be used due to reasons of outcome quality, the generation of this alternative can then be blocked within the planning module.

With other words, the general approach of representing the correlations of dental decision-making can serve as a basis to determine future research projects. Accordingly, the overall approach rather is a research program than a research project, since it can be refined endlessly and cannot be finished within a period of time.

This insight plays an important role in understanding the nature of evidence-based knowledge generation. In contrast to the widely acknowledged point of view, trials – which are supposed to gather information for the comparison of

two or more decision alternatives – do not represent the initial point of scientific knowledge generation but the final assessment of a decision-structure (e.g. mutual assessing the treatment with or without a specific drug). Currently, this decision structure is not objectified within the discussion among scientists. During the definition of clinical trials, the decision alternatives (formulated in the hypothesis) are defined and verified by a small experts group. This tasks could be enhanced by publishing the decisions structure and including a larger community before defining research projects.

With other words, the information resulting from trials can be used to initiate a revision of the modeling process described above. A trial can – in best case – prioritize one treatment alternative before the others. In this case, the others are no longer treatment alternatives. This takes effect on the decision structure.

5.4 FURTHER INFORMATION FOR DECISION SUPPORT

Visual and sound information can also be used to clarify and support the previously presented information. They can not, however, be used to directly generate treatment processes or probabilities. Here, explicit knowledge comes to play that can not be integrated into the decision making process until after the user has interpreted it. Therefore, this information can not be presented in a formal, scientific manner. Simple search and filter mechanisms can, however, help to sort this information for purposes of better presentation and availability to the decision makers.

5.5 COMPARATIVE EVALUATIONS OF THE TREATMENT ALTERNATIVES

To allow a definitive selection among the proposed alternatives, each treatment alternative must fulfill its goal criteria. The evaluation of each alternative must be lead to an overall evaluation, thus allowing a direct comparison of the individual alternatives.

However, the actual decision must be left to the patient-dentist consultation, because a neutral approach for evaluating treatment alternatives is not available to date.

Figure 57: An evaluation of the alternatives is necessary based on the diagnosis.

Therefore, absolute values are not required for a systematic evaluation. Rather, it can only be ascertained that a treatment alternative leads to a sound result and avoids over-treatment.

5.6 SUMMARY OF THE EVALUATION AND SELECTION OF TREATMENT ALTERNATIVES

The use of a decision structure based on patient status – as presented above – is not the only way to generate treatment alternatives. It is also possible to provide each alternative with additional information regarding current and future features, thereby, supporting the decision making process during the dentist-patient consultation. Decision theory requires that the prognoses must be known for each alternative to estimate the timely development during and after the selected treatment measure. The respective area can be limited to permissible medical treatments by using suited goal criteria, as shown in previous chapters.

Even if biometrical methods do not allow drawing direct conclusions over a particular patient, they do offer evidence on how decision making can be made easier. Functional and aesthetic prognoses can be conducted with the help of biometry. Criteria can be improved practically by considering their technical specifications (e.g., abrasion, aging processes, discoloration). Financial prognoses can also be generated for the treatment alternatives and their respective treatment plans, because the required time and materials can be directly taken from them.

It can be expected that evidence-based dentistry will play an important future role in the selection of suitable treatment alternatives. A strict decision methodology – as the one presented here – and EBD can complement one another ideally. The first generates the alternative solutions, while the second is used to compare them.

Example cases can serve to better evaluate and present the treatment goal. They make it easier for the patient to imagine the final result. The available information should be presented in a structured way to provide a better overview. Additional knowledge is included with each treatment alternative. The information is based on estimations that have been calculated for each treatment alternative. This additional information can not be used by the treatment methodology to make a strict selection of a treatment alternative, but it can be useful in supporting the individual selection process.

6 MACHINE SUPPORT IN DENTAL DECISION-MAKING

Generally speaking, it is possible to develop machine-based decision support for dental professionals by using a patient-oriented planning methodology. Such support should serve to offer a neutral representation of the decision making process. Also, the decision made should be realized using a suitable sequence of treatment measures. The quality of the outcome can be expected to increase as long as a constant fine-tuning and verification of the methodology takes place.

Automation can only be realized based on neutrally represented knowledge. Regarding machine-supported decision processing, it must be clear which part of the decision process can be standardized and transferred to a computer system. This is an important issue of human-machine interface ergonomics, and not merely a question of processing [100-102]. The interface is the eye of a needle in many cases. User acceptance depends on friction-free communication, and, therefore, is a major key to the success of the methodology.

In the previous chapters, it was shown that not the use of computer technology demands a strict representation of the decision process, but, primarily, dental medicine itself. The following will analyze the basic differences between information processing by humans and machines in order to show the strengths and weaknesses of both in terms of a neutral representation for a decision methodology . Cooperative ways to reinforce the strengths and eliminate the weaknesses of both options can result from the analysis.

Using the example of fixed crown restorations, the following will show how the dental decision model can be transferred to a computer system, while giving consideration to the set boundary conditions. A future outlook for decision support in dental medicine is then presented based on the results.

6.1 GENERAL HANDLING OF STRUCTURED DECISION KNOWLEDGE

Today's state of modeling knowledge in a practical environment is presented, before discussing the various aspects of dental knowledge processing.

6.1.1 Human versus Machine Knowledge Processing

The computer was developed based on demands for neutral information representation and processing. A comparison of human and machine characteristics is presented in the following table to show the strengths and weakness of each.

Table 6: Comparison of human and machine information processing (compare [41]**):**

Humans	Machines
Model	
• Humans attempt to harmonize their perception of the world and reality. Therefore, by nature, they are used to modeling (mental modeling in this case).	• The rules of interpreting information must be entered into the system. The actual mechanisms for processing the information, therefore, come from outside the machine environment.
Diagnosis	
• Humans have a manifold of finely tuned sensors for diagnosing (eyes, ears, tactile senses, heat sensors, etc.). • The human brain is able to interpret this information as a diagnosis.	• A normal computer does not posses adequate sensors to conduct medical diagnosis (key board, microphone, possibly simple measuring devices) . • Measuring devices can record values, but these must then be structurally interpreted, or modeled, by a human.

Humans	Machines
Information processing	
• Humans can process information sequentially (1000 steps being quite many). • Humans can only process few parallel requests. • Human information processing is influenced by emotions, experience, prejudices, ignorance of the subject matter, etc. → are not objective .	• Generally machines use (= von Neumann architecture) and work strongly sequential (a normal computer processes up to 1 billion commands per second). Such machines are well-suited for representing sequentially processed deterministic methodologies (algorithms). • Modern computers are constructed to handle a high degree of parallel processing. • Machines can represent facts and rule-based knowledge on a long-term basis.
Decision making	
• Humans must make decisions (decision theory: planning is the anticipation of decisions to limit uncertainties (compare [82,94]). • Humans use hard and soft facts to make decisions. Decisions made by humans must not be fully comprehensible in a mathematical, logical sense → Humans use intuition.	• A machine can only process hard knowledge (facts and rules) (computability). • Since not all medical knowledge can be formulated in hard facts and rules, a computer model is always incomplete in terms of the current knowledge standing.
Information storage	
• Humans find it hard to store their thoughts over a long period of time. • Storage is not exactly reproducible in each case, since humans do not use clear rules to formulate their thoughts.	• It is possible to store data over a long period of time. • The stored data can be reproduced exactly.

Humans	Machines
Communication	
• Humans take a long time to present their thoughts (visualization, written form, verbalization) → communication barrier. • Humans communicate slowly, describe and recall decisions inefficiently. • Humans can not offer access to their knowledge over a 24 hour period (sleep, breaks required) • Humans can process only few parallel requests.	• Multi-medial presentation of the processed knowledge is possible. • Machines can transfer data worldwide quickly. • Server standing time can span several years (availability approximately 99.99% depending on the design). • Multi-user abilities are well developed.
Information retrieval	
• Retrieval is erroneous and depends on the particular situation.	• Retrieval is deterministic: certain queries always lead to the same answer, others are always unsuccessful.

This comparison quickly shows that the underlying differences do not really allow a direct comparison of human and machine information processing. Since a machine can not be authorized to make decisions, due to the innate incompleteness of a diagnosis, it must focus on processing acknowledged decision schemas. The machine is, therefore, reduced to a communication medium, and responsibility can not be given to, or taken by, it. Machines are much better equipped to perform such communication tasks than humans, since they work strictly deterministic, faster and more reliably. Humans and machines should complement each other optimally to provide the best possible patient treatment.

Second opinions are already being given by humans, but the quality of the outcome should be improved further. Therefore, the following focuses on a machine-based decision methodology and its interactions with its human users.

The basic handling of a neutral decision model will be described from a modeling perspective. Based on these general, technical aspects, the prosthetic

planning model discussed in previous chapters has been implemented as an example.

6.1.2 Knowledge Acquisition and Modeling

A “knowledge base” is of central importance to machine-based dental knowledge representation [103], All of the acknowledged knowledge is stored in this knowledge base. However, such a dental knowledge base does not yet exist [104]. Therefore, an implementation-near design model has been developed based on general modeling foundations and the dental decision model described in the previous chapters, and is presented as an example. However, the general aspects of modeling knowledge are discussed first.

General approaches for developing knowledge structures, and, therefore, knowledge bases, have matured over recent years, for example the CommonKADS method [50] and its formal representation (e.g. [105,106]). Beside a methodological process for modeling knowledge, CommonKADS also includes libraries containing wide-spread problem solving methods, as well as important elements of comprehensive process models for continued software development.

From the view of software development, it can be of essential importance not to generate a design model for the purpose of implementing code directly from reality. Such a procedure could lead to communication problems, e.g. between dentists and developers, since the language used by both may strongly differ. Using a conceptual model as an intermediate communication platform to which all groups involved have direct access is, therefore, recommended. (compare Figure 58).

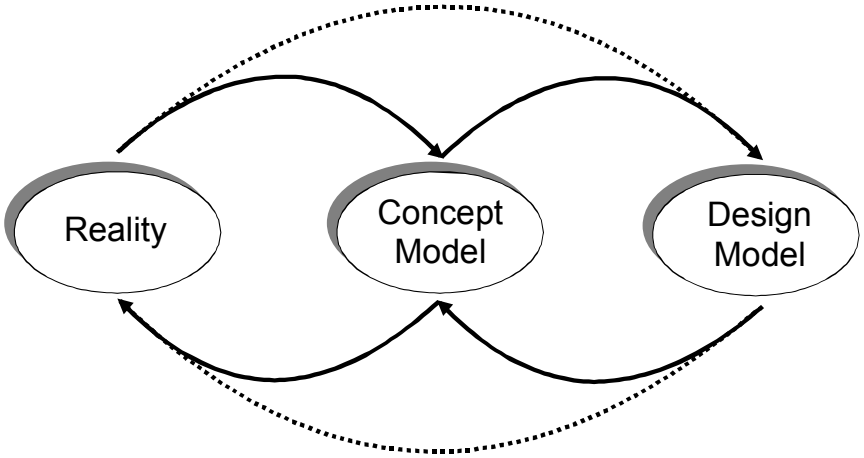


Figure 58: Concept and design model. The developed decision methodology was not directly implemented as a formal design model, but rather as an informal concept model. This allowed identifying which parts of the decision making process could be formalized and which must be left to human intuition. Also, a critique of the design model is only possible based on the conceptual model.

An advantage of the conceptual model is that a model is available for presenting primary overlying structures without getting lost in the details of the initial structuring process. Within this context, the decision model presented in the previous chapters can be seen as a conceptual model from which a design model can be developed.

As an example, it will now be shown that "hard" coding is possible for some aspects of this approach. The object-oriented paradigm was used, because it offers a good overview based on its modularization of structures. Beforehand, however, the representation, processing and presentation of medical decision structures must be explained in more detail.

6.1.3 Knowledge Representation, Processing, and Presentation

The basic development of a reference system for dental decision making must begin with the basic structure of the domain, as described in previous chapters. Thereupon, specialized knowledge can be added, such as exceptions and special cases.

The actual decision structure can be stored in form of facts and rules, from which a machine can independently draw conclusions. The implemented model

is stored on a central, machine structure (a computer) for this purpose. The methodology can be then be networked world-wide, with all its positive and negative effects.

The overall methodology serves the individual users roles its special contexts by offering different 'views'. This emphasizes the aspects currently important for the dentist, the patients, and other users. Therefore, an overlying knowledge structure must know which aspects may be presented to whom and when. Based on this, it is conceivable that guidelines, reference and text books, educational material, hypertext pages, case studies, etc. can be generated directly from the formal decision model.

In addition, external sources can extend the formal decision structure. Such sources could be: available guidelines, reference and text books, educational material, hypertext pages, and case studies. A machine can not interpret these sources, because a formal relationship between their respective representations does not exist upon which conclusion can be drawn. Therefore, interpretation is left to the user.

Via formally stored links, this explicitly stored knowledge (e.g. audio and video sequences, or texts) can be accessed. The following presents the differences between formal decision knowledge and explicitly stored information.

Basically, a synergy between formal knowledge in form of facts and rules and explicit knowledge in documents should be aimed for the purpose of presenting explanations and example documents for each aspect of the decision making process. In turn, it should also provide the respective decision sequence for each document[81].

The decision support methodology can profit from multimedia documents if it presents additional explanations together with each solution. In this way, a clear presentation can be given of how the solution can be realized.

[81] A video sequence can, for instance, be complemented with links to allow explanation of the occurring processes at any time. Or, using an intelligent reference system, documents containing further information can be accessed.

6.1.4 Dental Information Model and Controlled Terminology

Medical informaticists would expect the discussion of a dental information model at the beginning of this book. But such a model is one type of representation for the dental domain resulting from the dental points of view. It is supposed to represent the prior statements on dental planning in an unambiguous manner to manifest a basis for the communication among the dental community. Accordingly, the information model has to vary over time – according to the life-cycle for dental decision models – and adapt to respective refinements.

To avoid that the whole discussion on dental decision making starts from the point the informational view – and perhaps looses its dynamic to early – it has been set at this position by purpose. Nevertheless, a dental information model will become one of the most important factors in dental research in the future. Though current information models in medicine are restricted on static (instantaneous) aspects, they can – in general – be seen as meta-models for dentistry in the future. With other words, they provide a well-defined theoretical foundation for dentistry and, therefore, can be called "theoretical dentistry" and be surrounded by a respective "theoretical medicine" in the future.

A information model, on the other hand, is crucial for the definition of a well-defined and controlled terminology. It is true that such vocabularies are necessary for the exchange among the dental community and like that are put in front position during modeling most of the times. Nevertheless, they *result* from the requirements in dental decision making and are an integral part of the informational design model.

6.2 MEDICAL DEMANDS PLACED ON MACHINE-BASED PLANNING

As shown in Chapter 4.1.4, a planning methodology can not generally cover all special cases. The practicing dentist should, therefore, be given the opportunity to understand the decision making process in detail by using a computer system. This allows the methodology to quickly recognize possible deviations between individual cases.

Therefore, the following will discuss the collection of patient-specific data before going into the presentation of information. Finally, additional quality

management control mechanisms will be described for dentists for use in individual treatment planning cases.

Questions pertaining to the technical infrastructure and data transfer (carrier, services, security concepts) will not be discussed in this work.

6.2.1 Ergonomic Data Collection and Documentation

A fast and easy to use system is of underlying importance to the success of a knowledge-based decision structure [102]. Despite the multitude of help the system may offer, a practicing dentist will not accept it if treatment planning costs more time than before (compare [101,107]).

Computer-generated interfaces offer totally new possibilities for displaying results. Rather than using pre-printed black and white paper forms, a computer can optimize the presentation of each result using multimedia elements [41]. The actual problem can be emphasized clearly by the system, and concrete solutions shown to lead the dentist through the decision making process [108].

Input and other manipulation of objects can be realized using Drag&Drop. The dental assistants can, for example, drag already prepared preliminary examination results into the tooth diagram, while the dentist dictates the diagnosis (compare [100]). Certain diagnoses are increasingly being taken directly from photographic case material and can be offered to the decision support system directly for processing.

The collected patient data should be stored in such a way that they can be reconstructed in detail at any time (compare [19]). For this purpose, not only the patient-related data, but also the general facts and rules must be stored in the decision methodology.

Two general types of data are accrued: the knowledge of the decision making process itself, which is stored in actual knowledge base. The knowledge base contains the entire model of generally acknowledged relationships of dental medicine. The second type of data is the patient-specific data, which is stored in a database.

6.2.1.1 Automatic data collection using measuring devices

A direct connection to the measuring devices should be available for direct transmission of the results to the system in order to write the information into the knowledge-based system as conveniently as possible. Additional information

regarding the decision structure is required to interpret the data. Generally, a type of driver architecture is conceivable, based upon which the device manufacturers define the interpretation of the measured values so that they can be integrated into the decision methodology.

However, the data can also be translated into knowledge within the individual devices – for this version, the measuring system must receive specific information about the problem and which information is required for the solution.[82]

Standardized interfaces are required to adjust the different technical subsystems to one another in both cases. The advantage of a direct connection to the measuring devices is faster and less complicated communication with less transmission errors.

6.2.1.2 Data input using automatic speech recognition

Verbal diagnosing can be conducted ergonomically using speech recognition. The dentist dictates the results and diagnosis in the usual manner. A speech recognition machine then translates the speech into machine commands. Commercial software is already available for this procedure [109,110]. This software uses a "Speech Application Program Interface" (SAPI) for this purpose. Examination results and preliminary diagnoses can be immediately displayed on a screen or confirmed via head set. The dentist can, therefore, always reassure himself that the input was correct.

Proof exists that such standard systems are efficient for medical applications [111]. The complete knowledge of the knowledge base is available for use to further increase the chances of recognition. The vocabulary can, for example, be limited to suit the diagnostic environment, since only certain sensible answers are possible for certain questions. If the vocabulary is limited, for example, from approximately 20,000 word forms of a general dental vocabulary, to the 20

[82] Example 1: Should a dentist want to set an implant, he will want to know the distance to the nervous channel, based on x-rays he has taken. It is conceivable that the answer can be taken directly from the x-ray and presented separately. The decision system can then directly process this data.

Example 2: Panorama x-ray in case of gap. Question: Is their sufficient space for an implant?

possible forms required for periodontal diagnoses, the chance of recognition climbs to nearly 100% [112]. Such limiting boundary parameters also have a positive effect on the recognition speed [109].

The knowledge of permissible input must be stored in relationship to the respective diagnostic situation in order to optimize speech recognition. Such concepts are not yet available within the dental domain, but are available in some non-dental domains [113].

6.2.1.3 Knowledge-based focus on diagnostic needs

The demand for easy handling includes that the diagnostic effort not be greater than with conventional methods. This demands that the diagnostic process itself is performed ergonomically and simply. Also, meaningful conclusions must be possible even if based on only a few basic diagnoses. For detailed diagnostics, the designs must lead to clear conclusions.

As described earlier, optimizing the ergonomics of diagnosing is a matter of the inner decision structure, and not a mere human-machine interaction issue (compare Chapter 4.1.1).

6.2.2 General Demands Placed on Knowledge Processing

The rules of computer-supported decision making must, generally, be formulated very precisely to allow computer interpretation. A medical text book, for instance, does not require this precision, since the practicing dentist can add missing information and interpret the drawn conclusions.

A comprehendible decision methodology must secure the decision making process. Hereby, a type of proof system, based on the axiomatically defined goal criteria, is of great importance. The argumentation must be based on verified conclusion rules. Since computer programs generally work in a clearly comprehensible manner, the following assumes that an implemented decision model indirectly brings about the proof of comprehensibility. In addition, diagnoses, treatment plans and measures can be examined to find inner planning conflicts or contradictions.

A ‘space-saving’ representation of the decision model is desired to increase the clarity of the system. This means, storing redundant facts should be avoided. This is why the design model of the prototype was developed using the object-oriented modeling paradigm. The object-oriented analysis targets an optimal

presentation of the stored knowledge without redundant storage of information required at different locations (compare [58]).

Multiple data entry can be prevented by allowing communication of the decision model with other information systems. This also leads to a more comfortable handling of the system within the practice or the clinic. Therefore, compatible information exchange between the subsystems must be provided. This requires a comprehensive break down of the methodology into clear partial solutions, for which the accepted input has been standardized. Concretely, this means that an acknowledged diagnosing language must serve as the basis for the communication between the dentist and the decision support system.

6.2.2.1 Limiting the competency of computer-based treatment planning

The user of a dental treatment planning system should be able to recognize which tasks the computer carries out and how it made the decisions it did. In other words, clear limits must be staked regarding the competencies of the decision support methodology. It must be apparent how cases are to be dealt with in which the system oversteps its set competency limits.

Since the correctness of the decision model is not yet proven, a transparent model must be created. This opens it to the world-wide criticism of researchers and practicing dentists. The methodology can only ‘grow’, and, thereby, increase its reliability, if it remains open to criticism. A different perspective shows that the decision methodology can also be used as a communication medium between the parties of the dental community involved. The methodology offers the generally acknowledged structures and an open basis for discussion between scientists and practicing dentists.

Generally speaking, the decision system has no competencies, because it is merely a representation of an overall view of the domain. If the dentists allot certain rights and privileges to change decision rules to certain groups of authors, this should be recorded within the methodology and clearly brought out at the respective locations when presenting the decision alternatives.

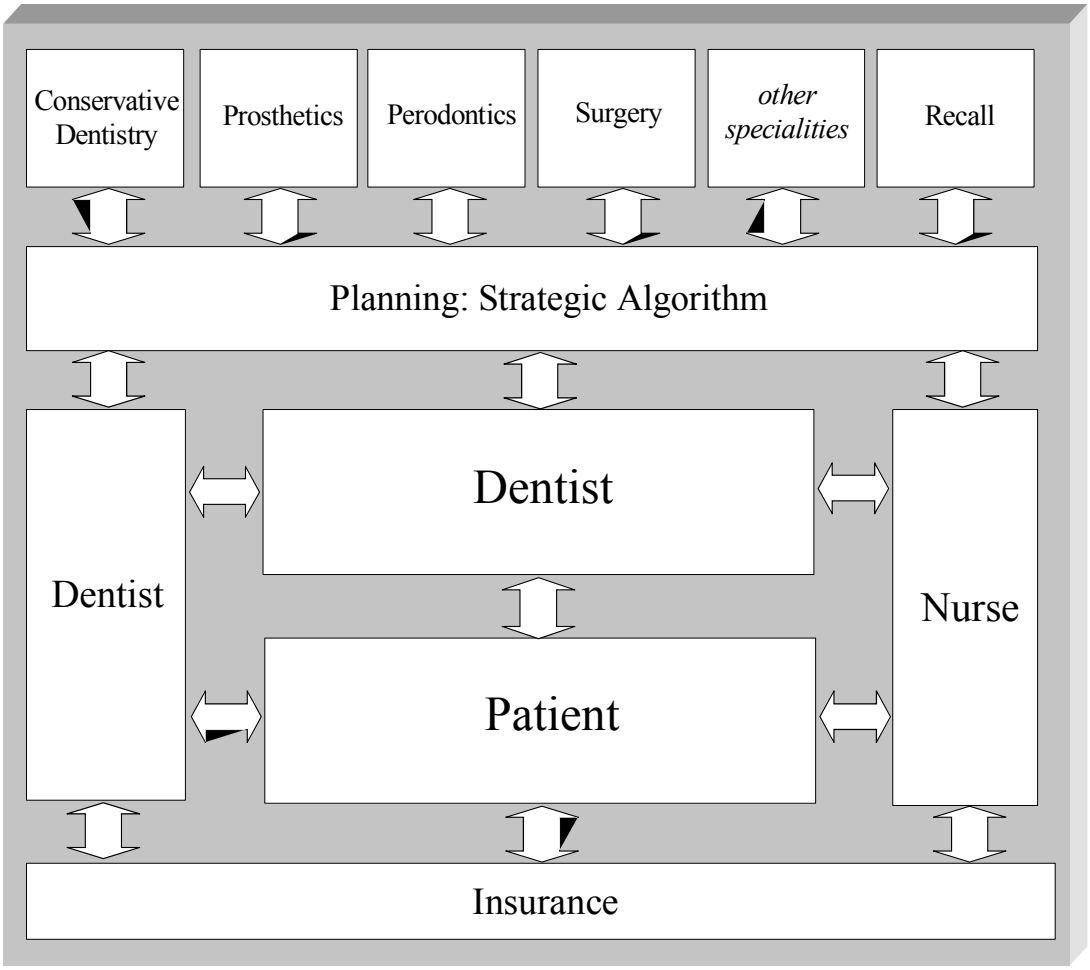


Figure 58: Abstracted view of the interactions of dental practice. Although many interactions exist between the parties, planning is actually limited to the dentist, because he lays down the treatment strategy for each treatment alternative, and, as a result, carries the most responsibility.

It must be made very clear which user groups within dental medicine are allowed to make changes to the methodology. Generally, a concept of rights and privileges on many levels is conceivable, for which individual dental specialty groups are responsible.

The actual allotment of privileges has not been conducted here, since it does not rest solely on dental criteria. Moreover, social, economic, and hierarchical issues also play a role.

6.2.2.2 Ergonomic presentation of information

The ergonomic presentation of medical information holds a central position in decision making. It involves not only the question of what is presented when and for whom, but also which information can and is collected with which amount of

precision. As explained in Chapter 4.1.1, a methodology must be able to offer solution alternatives based on easily acquired information. The alternatives can then specified more closely in further steps. The overall process of decision making, therefore, also depends on the methods of measurement used and their precision. Offering opportunities for communication between humans and machines also plays a role in this case.

Room for much discussion remains for the issue of presenting decision structures using modern computer technology despite the work conducted by the Orquest project [114]. This work has limited itself to translating classical media, such as photographs, texts and standard diagnosis forms into electronic media. However, a greater need exists for navigating the dentist and the patient through the treatment process [108]. Presentation methods must be adjusted to suit the central role held by the decision structure. New and improved presentation methods[83] are needed to clearly present the decision structure.

6.2.2.3 Control structures and decision explanations

The control structures for regulating reading and writing privileges, as well as the explanations of the decisions made, can easily be attached to the decision structure technically by storing respective privileges and explanations for each decision alternative.

A decision alternative is only visible to those groups of users having the reading privileges to see them (e.g. scientists or treating dentist). Accordingly, changes to the decision structure can only be made by those users owning the corresponding writing privileges.

If a treatment alternative appears during the course of the decision making process, its explanation is automatically added to a list of explanations. Since decision making is goal-oriented, the sum of the explanations results in the overall explanation for selecting a specific treatment. A hierarchical concept should be introduced to keep an overview of the various explanations. The concept should allow views in various levels of detail for a specific dental case. Upon request, the explanations can be broken down into detailed individual explanations.

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[83] For example, a 3-D presentation of a virtual impression of a dentition.

6.2.2.4 Informing patients and long-term verification of outcome

Most offers of informing the patient are not customized to the patient. The patient receives photographs and sketches that were not created based on his specific case. Graphical presentation of the individual problems could be improved by using modern computer visualization technology [114].

It is possible today to photograph the situation of a patient's dentition without great effort, and to store these pictures on a computer. The individual case and ist possible solutions can be presented clearly by using x-rays and examination results from other areas such as cariology, endodontics, periodontics, etc. Combing the diagnoses with the individual treatment plan can lead to the following effects.

6.2.2.5 Obtaining study designs from treatment alternatives

As described above, treatment alternatives can result during treatment planning that must be considered as equal. It is close at hand to compare these alternatives by using randomized studies. Such studies would strictly follow the standing decision methodology and extend it.

Summary 23: Advantages of a comprehensively documented planning process

- Diagnoses, plans and measures defined by the dentist can be examined in terms of plausibility, uncovering contradictions or unclear data.
- It is possible to make use of patient data during patient consultation.
- Personalized patient consultation is supported.
- Informing sponsors is made possible.
- The patient and the follow-up dentist can later evaluate whether the chosen treatment was successful. The same applies for involved third parties (sponsors, appraisers, etc.).
- In case of legal disputes, the high degree of transparency offers an equal initial position for the patient, the dentist and, possibly, third parties-
- Long-term verification of the results is possible for treatments planned and conducted in a standardized manner.
- Since several equal treatment alternatives may be proposed, a selection can be made automatically based on randomized studies, and, therefore,

support comparative studies.

The patient should identify with his personal case, since patient compliance and cooperation are important for treatment success. A clear, personalized presentation of the possible solutions and their selection process must be given to support the identification process. The results should not only be presented graphically-geometrically, but, rather, in the context of the dental preconditions and their consequences. The presentation of the results must comply with the competency level of the respective user. Approaches to this topic within the medical field of neurology can be found in [115]. Comprehensive approaches to recipient-oriented presentation are not yet available for dental medicine.

6.3 DATA PROCESSING APPROACHES

The decision methodology presented in Chapters 3-5 only apply to dental decision making. After having described the requirements of computer-based decision support from the information technology and the dental perspective, the possible services of knowledge-based decision support are described. Thereupon, an example of an implementation approach is presented.

6.3.1 Tasks of a Dental Information System

Computers have established themselves in dental practices as organizational aides within the past 10 years. However, they are primarily used to simplify the billing process (compare [116]). Although there are some computer applications available to graphically plan treatment measures, the current solutions only take a part of all possible treatment alternatives into account. Graphical solutions also only represent a specific perspective of the overall dental domain. Therefore, the basic possibilities for using computer-support are presented first.

6.3.1.1 Sub-goals of a dental information system

Different types of systems can be used for frictionless, computer-supported decision making, as Bürsner [115,117] describes in detail.

Beside standard input media, speech recognition is newly available. Speech recognition could help to ease human-machine communication, especially in the dental field, because hygienic standards demand contact-free communication.

The communication with billing software is important to avoid multiple data entry. A connection to measuring devices and databases could allow direct data collection. The information presented on electronic diagnosis sheets should be stored in an electronic patient record, and, thereby, be available for further use. Should neither the dentist, nor the computer system be able to find a satisfactory solution, video conferencing could provide access to a professional second opinion.

In the following, the possibilities of computer-based decision support are discussed in more detail.

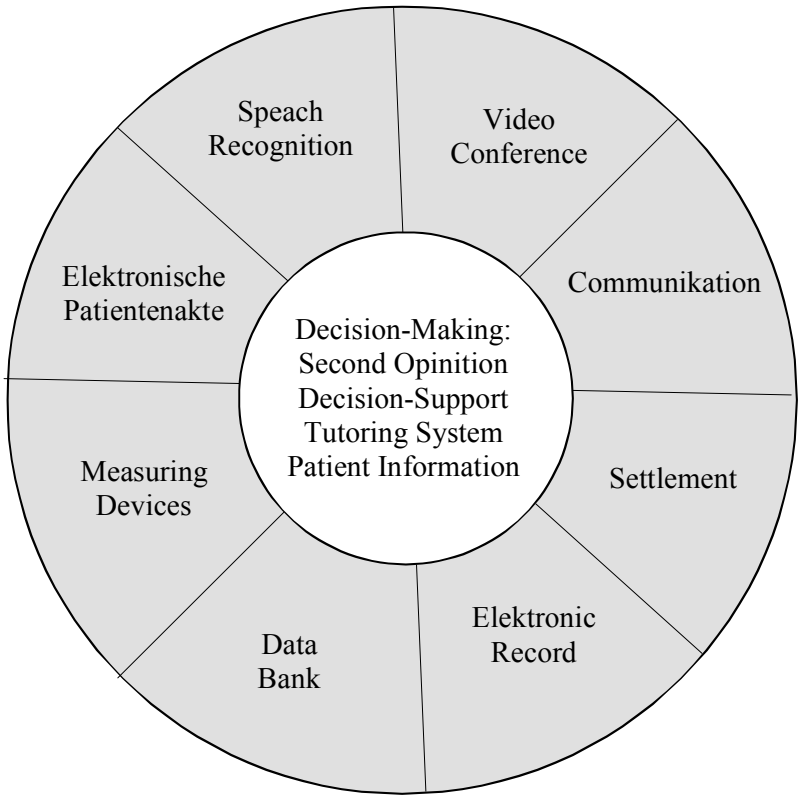

Figure 59: Subsystems of computer-based decision support [114].

6.3.1.2 Possible tasks of computer-based decision making

The solutions discussed in the previous section are now mapped to services. These services show the potential of a fully developed computer solution. It is not intended, however, to impart the idea that all of the following services must be realized, or be realized in the near future. The solutions may cover several components and offer help in specific problem areas.

Table 7: Possible tasks of computer-based decision making

Task	Question	Service
Speech input	How could contact-free documentation be realized?	All system functions are speech-driven, including diagnosing.
Treatment planning	How is a treatment selected from the offered alternatives?	Input: diagnosis Output: treatment alternatives
Treatment process	How is the treatment plan derived for a selected treatment alternative?	Support the dentist during the treatment process.
Help function	How are general questions answered?	Answer general questions by using a search function, including a topic index.
Medical information media	How can an overview of the medical information be obtained?	Use of external information sources, such as CD-ROMs, etc.
Search for example cases	How can similar cases be found?	Automatic search for example cases by symptoms.
Patient information	From where can the patient receive understandable information to his case?	Prepared or dynamically generated forms can be given to the patient for important decisions. Or, individualized information sheets can be printed.
Second opinion via email	How can the dentist obtain a professional second opinion?	Communication via email system. The file is sent to the specialist via an automatic distribution system. The expert appraises the case and sends back the results.
Verification of the diagnosis	How can the diagnosis and differential diagnosis be verified?	Input: diagnosis, Output: queries, differential diagnosis.
Verification of the treatment	How can treatment conduction be verified?	All required preconditions must be fulfilled and are examined by the system .

Task	Question	Service
Scheduler	When is what decided or treated?	The system takes over scheduling completely. This occurs practice, dentist and patient-oriented.
Electronic patient record	Which data must be stored where?	All patient data must be stored in the system and can be searched by various criteria.
Video conference	How can the dentist obtain a professional second opinion?	Communication between the dentist and the expert using picture and sound media→ they can work with the same file simultaneously.
Forensic examination	Which legal boundary conditions must be considered?	For each case, individual and special help is available in acute cases. Use of external information sources concerning forensic questions.
Protocol system	Which information should be recorded and when? Does record-keeping make sense?	Automatic protocol of patient treatment records in case of legal concerns → Legal safeguard for dentist and patient.
External protocol	Which information should be recorded and when? Does record-keeping make sense?	External protocol of patient treatment records in case of legal concerns; legal safeguard for dentist and patient → stored on server belonging to a neutral entity.
Billing	How is billing conducted and how can optimal billing be ensured?	The system takes over the entire production of the therapy and cost plan (HKP), and automatically processes invoices with health insurance companies.
Ordering / Purchasing	Which materials are missing and where can they be ordered?	Automatic ordering of technical material before it is required.

6.3.2 Approach to Machine-Based Support in Dental Medicine

The medical requirements placed on decision making, and the expectations of computer-based decision support were discussed in detail in the previous chapters. Now the realization of a computer-based decision support will be discussed using examples.

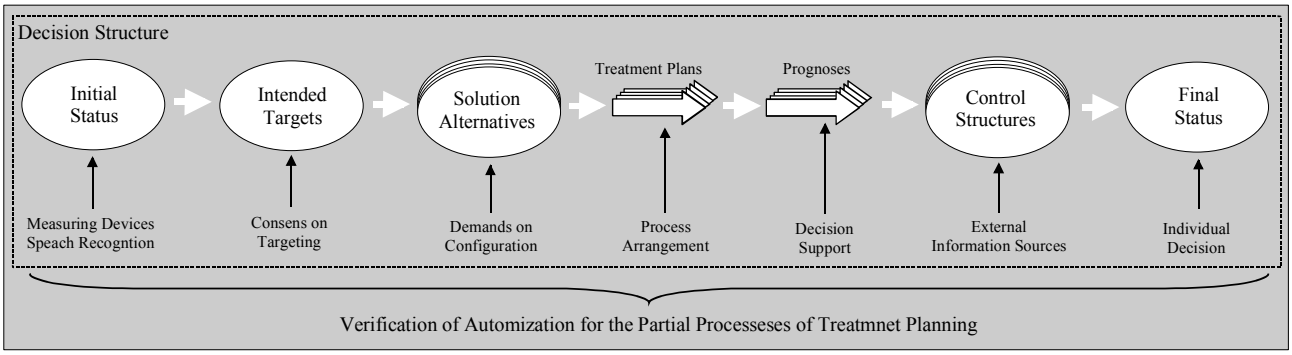

Figure 60: All aspects of dental treatment planning are examined in terms of suitability for automation or machine support.

Beforehand, in analogy to the decision methodology presented Chapters 3-5, it the parts of the methodology suited for computer support are discussed.

Summary 24: Development of computer-based support for dental medicine

Which areas of dental decision making (compare Chapter 3-5) are suited for computer support?

- **Collecting patient information**: Collecting information using measuring devices is largely possible, but not always efficient. Inputting information by the dentist using speech recognition is largely possible, but still involves a great deal of effort.
- **Defining the treatment goals**: The general treatment goals are poorly suited for computer-based support, because the goal criteria serves as the foundation for the derivation of the decision structure – little need for automation. The patient-specific treatment goals are well-suited for automation, since they result stringently from the goal criteria; necessary precondition: goal criteria must be uniquely formulated, and a sufficient basis for diagnosing must be given.

- **Generation of treatment alternatives**: Well-suited for computer-based support, since based on the patient-specific treatment goals. Since diagnosis is innately inexact/incomplete (due to timely and spatial limitations), it is not absolutely certain whether the proposed solutions can all actually be realized (oversupply of solutions necessary).
- **Planning the treatment process**: Generation of the treatment plan for the individual treatment alternatives is well-suited for computer-based support.
- **Developing prognosis**: It is basically possible to generate prognosis with the help of a computer. However, this is difficult for long-term prognoses, because they are strongly influenced by outside factors such as dental hygiene.
- **Pointing out control structures**: Due to multimedia functionality, computer well-suited for offering supportive media (graphics, sound, texts, etc.)
- **Selecting a suited treatment alternative**: The final decision for a suited treatment alternative is difficult, because no uniform measure exists for comparing the function and aesthetics to the costs.
- **Administration (scheduling and billing)**: Is already available in practice and has proven itself well.

6.3.2.1 Design model for the "fixed restoration" mode [84]

An inference prototype is a software application in which the facts, or decision rules, are stored. An inference engine then draws conclusions based upon the facts. The AIDA[85] inference prototype can, therefore, generate a treatment plan based on patient-specific diagnoses.

An example structure of the inference prototype for the mode "fixed restoration" is presented to better describe the capacity of the concept. The

[84] Compare conceptual model in Chapter 4.3.

[85] The design model and the object-oriented prototype were implemented by Ralf Weber, Irmela Stamm and Mirjam Müssig at the Institute of Medical Biometry and Informatics, Department Medical Informatics, of the University of Heidelberg under the direct guidance of the author [118].

example serves to brings out that the structures described in the previous chapters not only serve scientific discussion. They can also be used practically in decision support systems.

The modeling method UML was used to develop the implementation-near model. This allows a graphical presentation of the relationships based on an international standard.

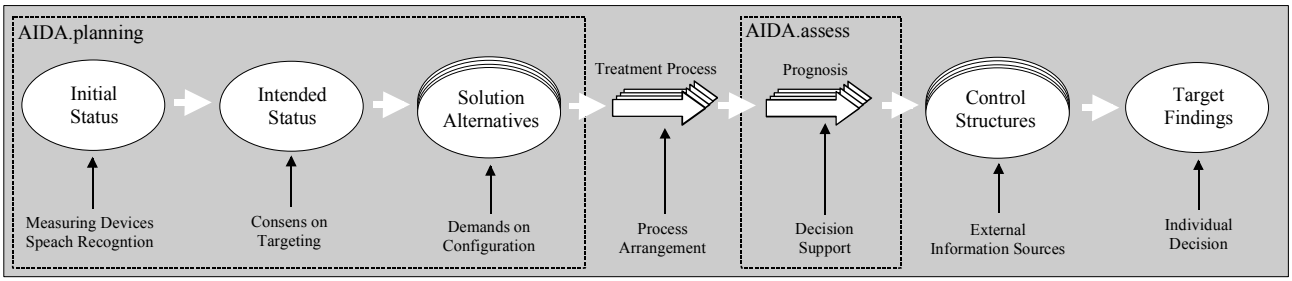

Figure 61: Basic structure of dental decision making [119]. The sub-tasks of dental decision making have been defined in accordance to general decision theory [120].

Since the UML notation is understood intuitively and has been described precisely in other sources [56,121], we make use of the method without further introduction.

The design model describes the decision process in a unique and comprehendible manner. The treatment processes are depicted as sequence diagrams, which building upon the class model of the dentition. The prototype was later implemented upon this basis.

The class model can be derived (compare Figure 62) based on the functional analysis. All possible constellations of the dentition model generated during a particular time frame are described. Figure 62 shows that a dentition is made up of 32 regions, each composed of 0 or 1 root and 0 or 1 dental crown.

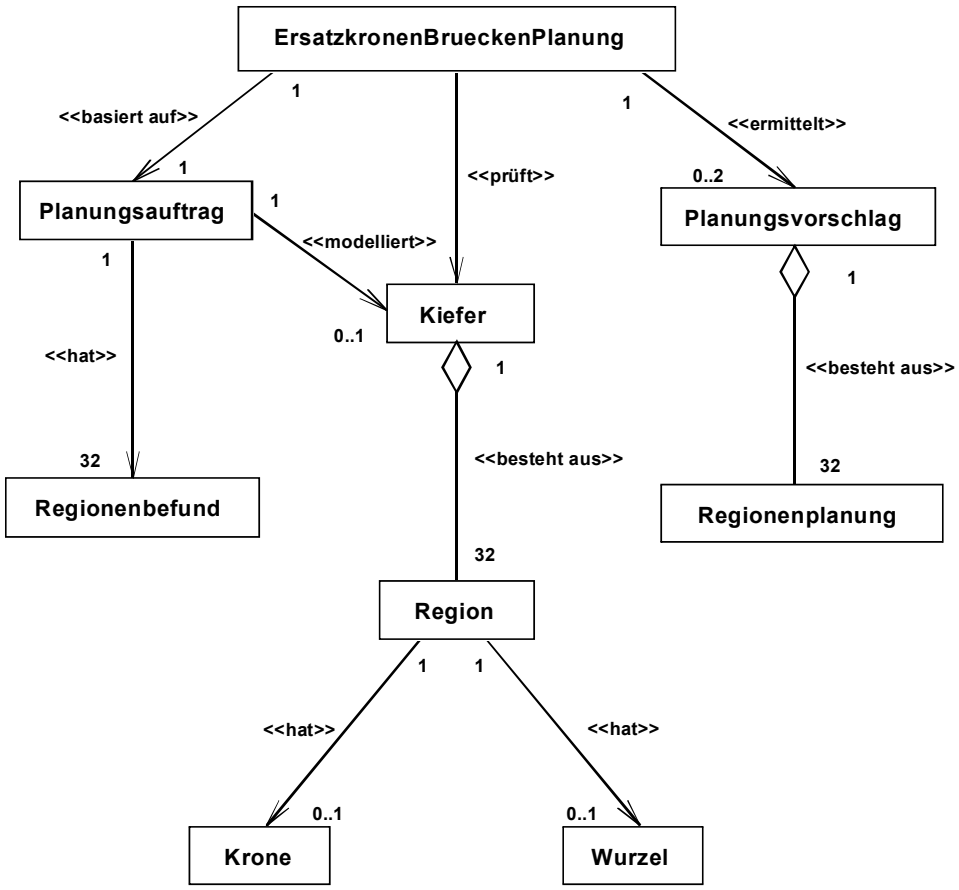

Figure 62: Class relationship model. Different classes are required for treatment planning and are instantiated at run time. This object model, in combination with the patient-specific examination results, shows the condition of the individual dentition.

The rules[86] of the dentition model can be formulated uniquely using propositional logic:

- (Verblockung ∨ Brückenglied ∨ Karies ∨ ersetzter Zahn ∨ Füllung ∨ Halteelement ∨ Initialkaries ∨ Inlay ∨ Zahnkrone ∨ Keramikverblendung ∨ Geschiebe ∨ Zahn in Ordnung ∨ Schlifffacette ∨ Teleskop/Konus ∨ Teilkrone ∨ Teilretention ∨ überstehender_Füllungs-/Zahnkronenrand ∨ Kunststoffverblendung ∨ Versiegelung ∨ zerstörter_erhaltungswürdiger Zahn ∨

[86] "∨" refers to the logic operator "or". While "¬" represents the complement of the following set.

nichterhaltungswürdiger Zahn ∨ Zahnstein) ⇒
Zahnkrone ist vorhanden.

- (Verblockung ∨ Brückenglied ∨ ersetzter Zahn ∨ Füllung ∨ Inlay ∨ Zahnkrone ∨ Keramikverblendung ∨ Geschiebe ∨ Teleskop/Konus ∨ Teilkrone ∨ überstehender_Füllungs-/Zahnkronenrand ∨ Kunststoffverblendung) ⇒
  Zahnkrone_ist_nicht_natürlich.
- (zerstörter_erhaltungswürdiger_Zahn ∨ nicht_erhaltungswürdiger_Zahn)⇒
  Zahnkrone_ist_nicht_erhaltenswert.
- (¬fehlender_Zahn ∧ ¬Brückenglied)⇒
  Wurzel_ist_vorhanden.
- (ersetzter_Zahn ∨ Implantat)⇒
  Wurzel_ist_nicht_natürlich.
- (nicht_erhaltungswürdiger_Zahn)⇒
  Wurzel_ist_nicht_erhaltenswert.

Sequence diagrams are required to determine the sequence of the program. They are used to break down the overall process into smaller, logical steps, according to problem areas. The following presents the sequence diagrams for data input, treatment planning, and data output:

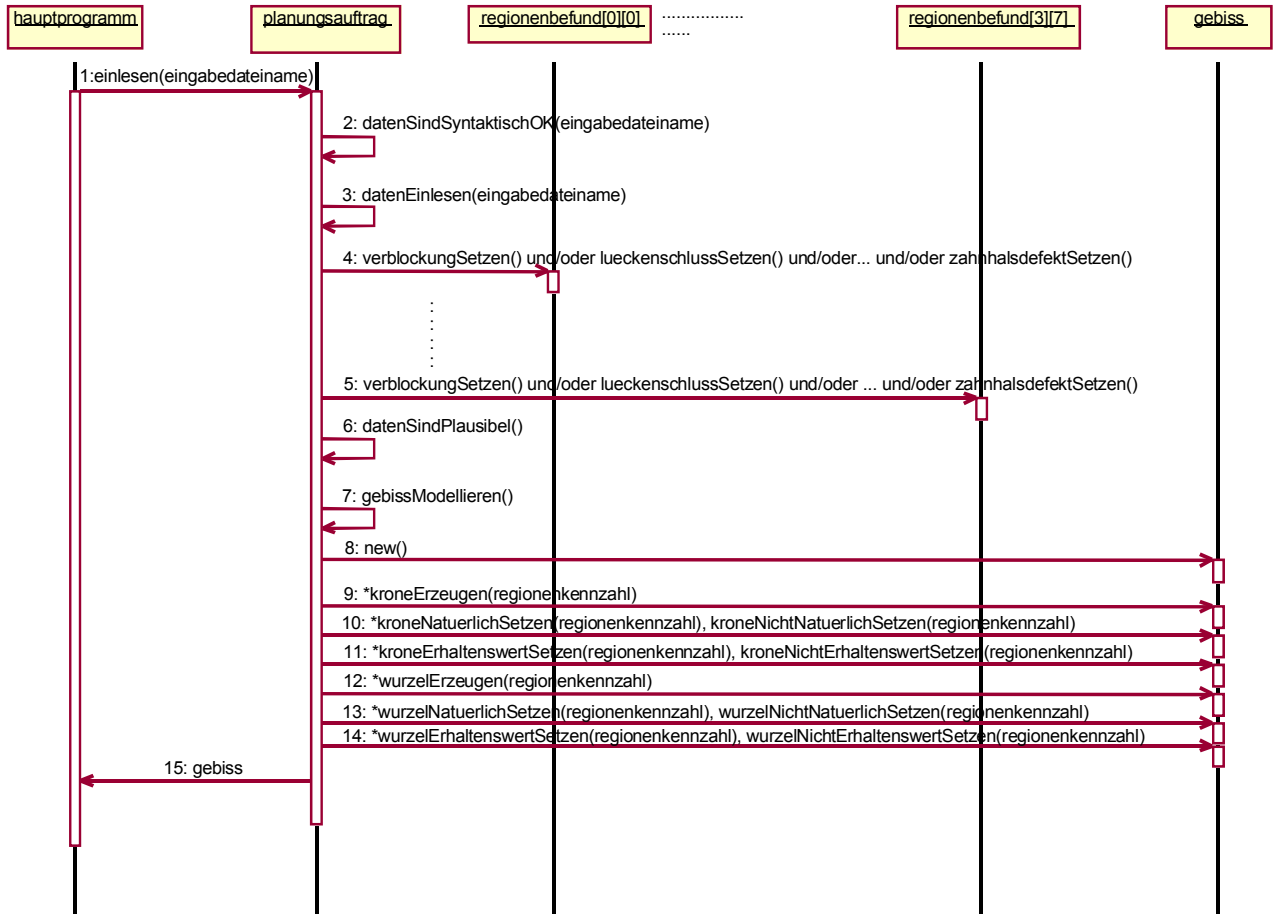

Figure 63: Sequence diagram for data input. Plausibility checks can already be conducted while coding the diagnosis. The columns represent those parts of the program forming a sequence, as defined by the process arrows. The sequence processing order is from top to bottom according to the numeration.

Figure 64: A rough presentation of the sequence diagram for treatment planning. The crown restorations are planned before the necessary abutments, in accordance to the decision model in Chapter 4.

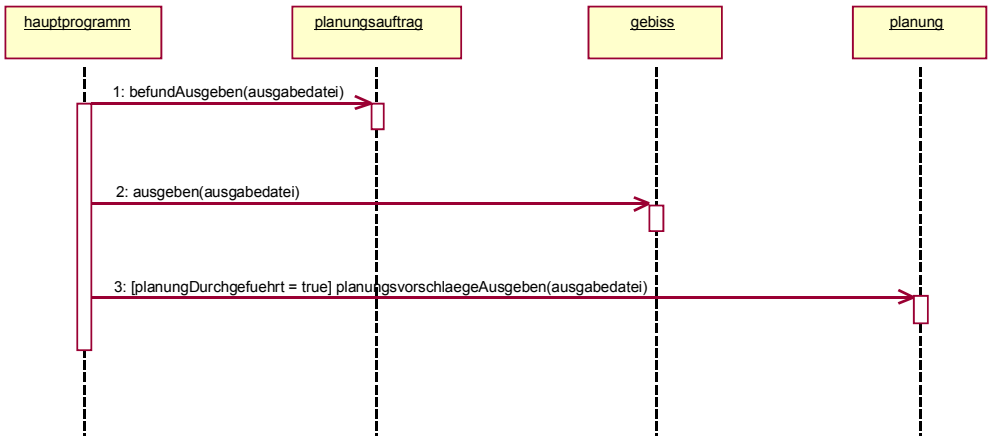

Figure 65: Sequence diagram for developing the result file. The finished plan is presented in a way understandable to the dentist, and is then written to an output file.

Using special tools, the code structure can be generated based on the class relationships, the extended dependency rules, and the sequence diagrams. Other methods can be introduced for treatment planning. A detailed implementation

model is not presented at this point, because the decision foundation was already described in the previous chapters.

6.3.2.2 Evaluation des AIDA prototype version 1.1

This section describes the evaluation of the AIDA prototype 1.1 for treatment planning and the generation of treatment alternatives for fixed crown restorations.

The decision structure was implemented in such a way that the decision model can be integrated into available software applications using so-called suggestion agents for treatment planning. The prototype was developed, implemented, and evaluated for computer-based treatment planning using the Unified Modeling Language (UML, compare [56]) and the Rational® Rose®[87] software package [121]. Although the module for initially planning fixed prosthetic restorations is not yet able to take over planning completely, it can suggest possible fixed prosthetic measures based on the given diagnosis (compare [92]). In addition, the procedure for planning fixed prostheses can help to identify ways in which the decision structure can be used to further extend the methodology.

A step-wise realization of the planning aid was achieved using separate software agents to allow the step-wise evaluation of the integrity of the overall methodology. A decision support system must not demand too much additional input, or it will not be accepted in everyday use (compare [101,107]).

The current version of the AIDA prototype has not yet been integrated in practice systems or billing applications. An interface was programmed that can be downloaded via the Internet in order to conduct the evaluation of the prototype. The interface makes it possible to send the coded diagnoses to the planning system located at the Heidelberg Kopfklinik via e-mail. The information then enters the system, and integrity checks are conducted using plausibility rules before planning actually begins.

[87] Rose® is a registered trademark of the Rational Software Corporation.

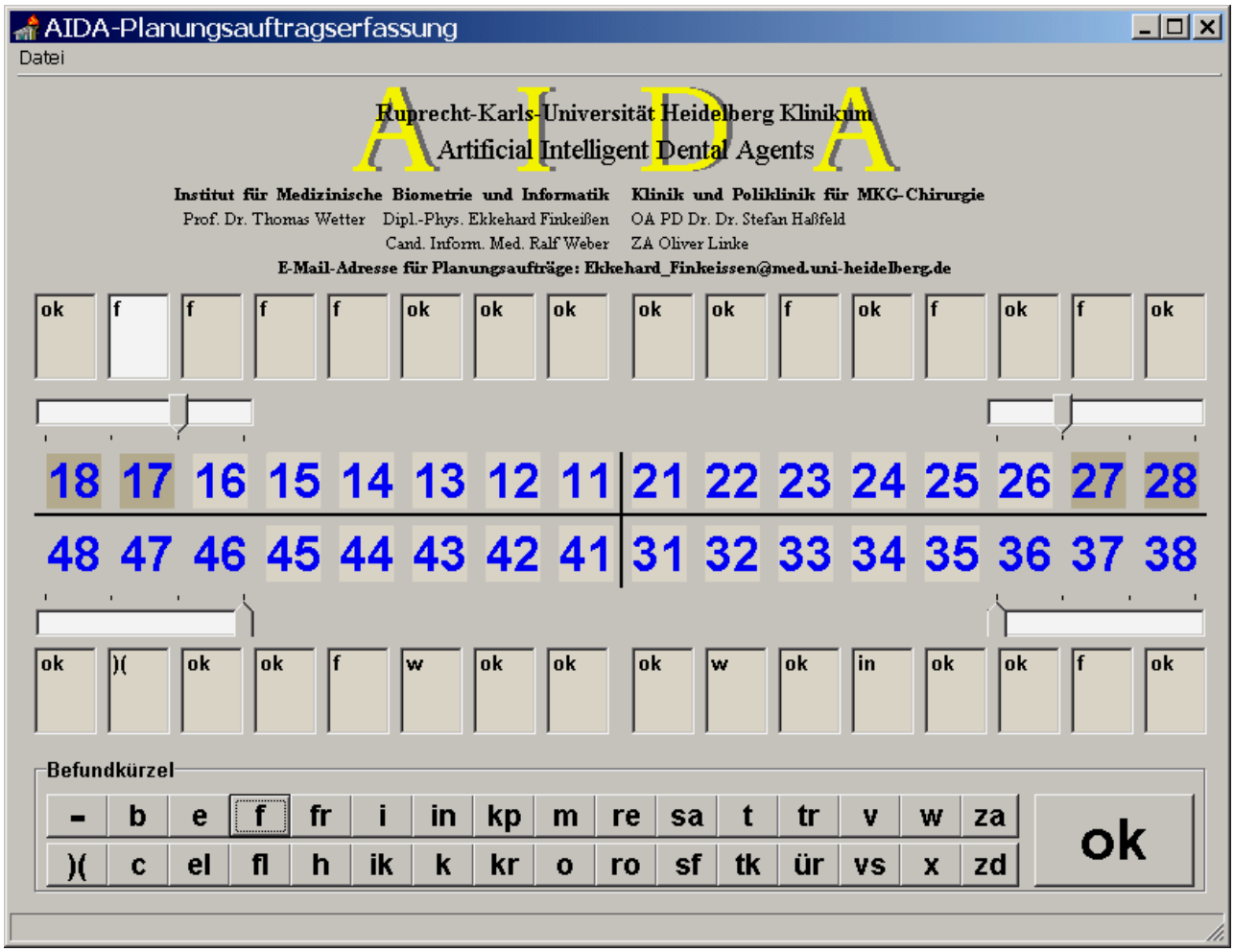

Figure 66: The input template is detached from the actual planning machine and can be downloaded from the Web (http://aida.uni-hd.de). It supports the anonymous coding of diagnoses, which can be sent back to the Heidelberg Kopfklinik. AIDA then generates the treatment alternatives and outputs them in a text file.

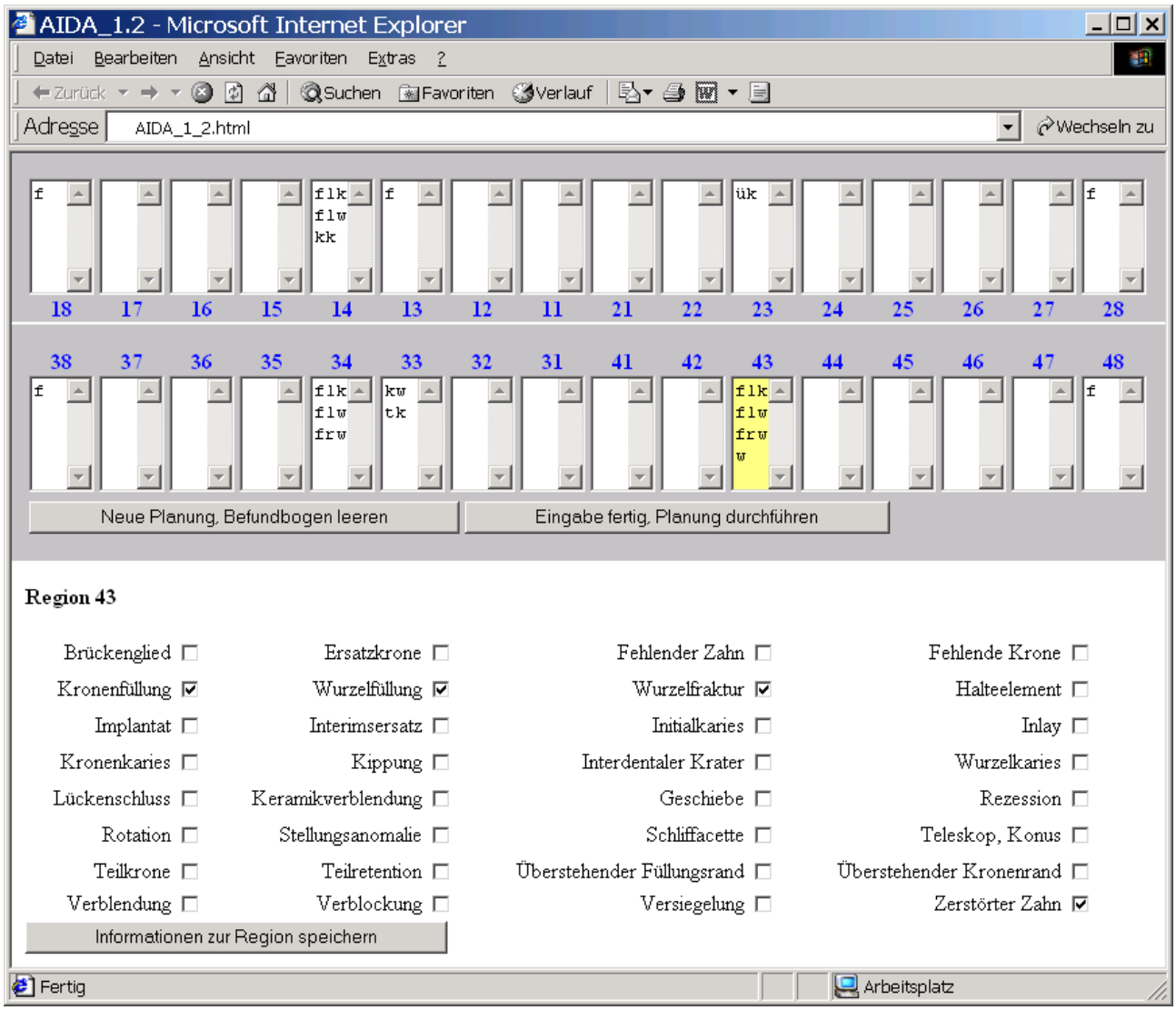

Figure 67: The Web-based interface allows entering the diagnosis using the browser. Planning can be initiated directly from there.

Version 1.1 of the AIDA planning machine focuses on planning the minimal amount of fixed prosthetic restorations required. This demands that standard diagnoses are available for each region. In addition, the dentist must specify which teeth are located within the visible region (see slide controller in Figure 66). The restorations spanning several teeth are described by the proposed treatment alternatives, so that the forces expected to act on each abutment can be estimated.

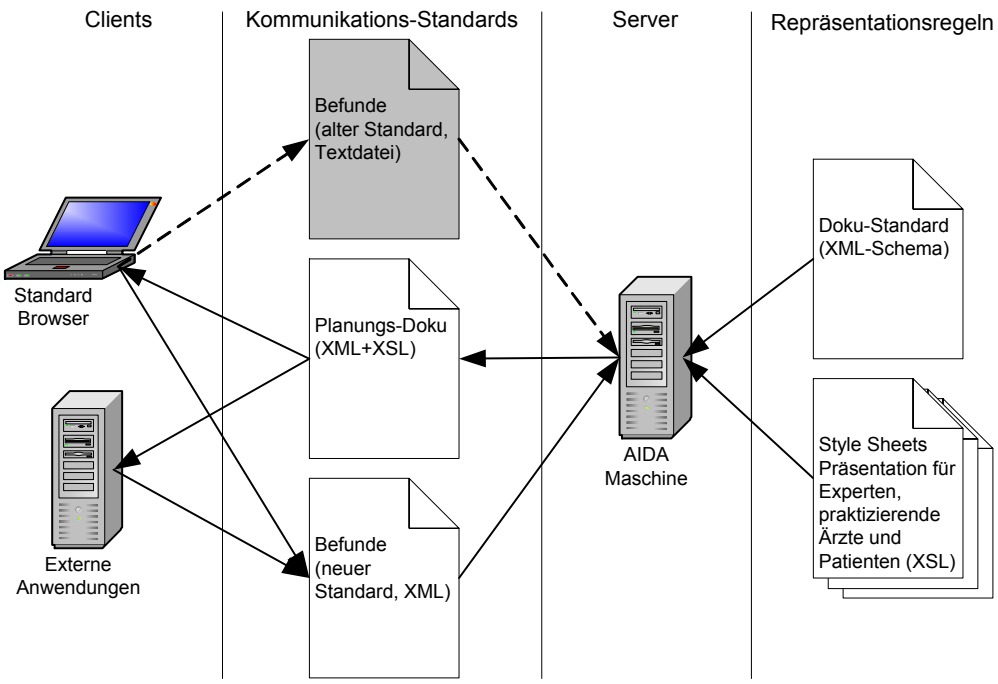

Figure 68: The dental documentation model, which has been completed in part, serves as the foundation for data entry and output for future versions of AIDA, thereby, replacing the old standard.

A comparison between the actually planned cases and the machine-planned cases was conducted during the first phase of the evaluation of the AIDA planning module. Only actual cases requiring prosthetic treatment were used for this comparison. Additionally, the cases were evaluated by a team of dental experts to uncover any inconsistencies within the actual cases. The experts were familiar with the cases only by file.

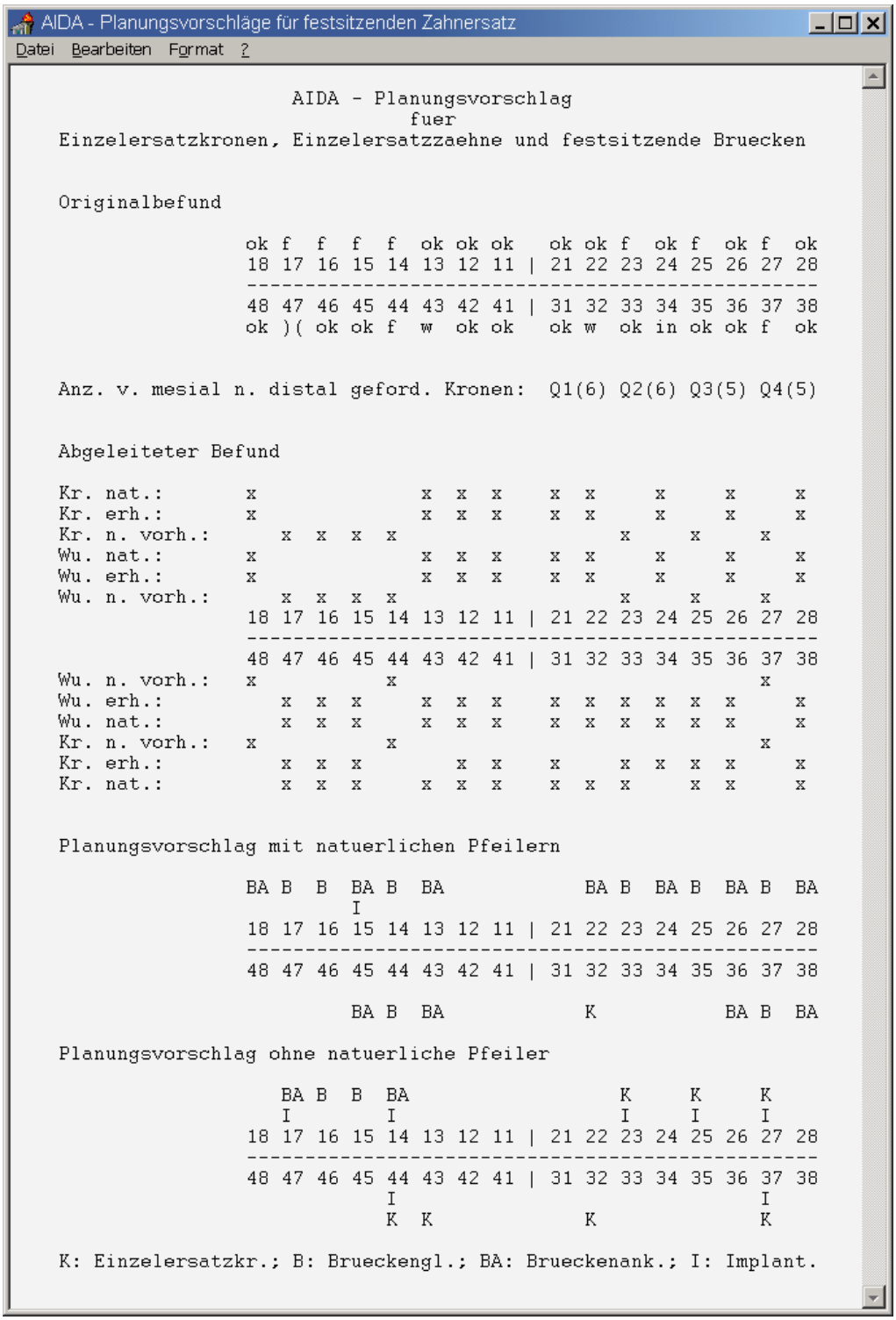

Figure 69: AIDA presents treatment alternatives for fixed restorations.

The information from the AIDA system can be transferred directly to the billing software, where it can be integrated in the therapy and cost plan.

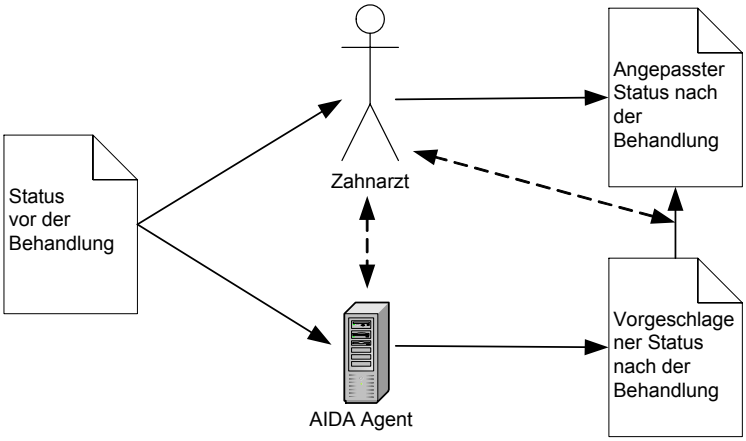

Figure 70: AIDA – computer generated second opinion in dental medicine. Practical us of the AIDA system in daily routine.

Anonymous patient records were used, because a classical gold standard was not available. The records were prepared by an evaluation team and examined by a scientific board. AIDA, therefore, will converge to the state of current knowledge and develop into a comprehensive gold standard itself.

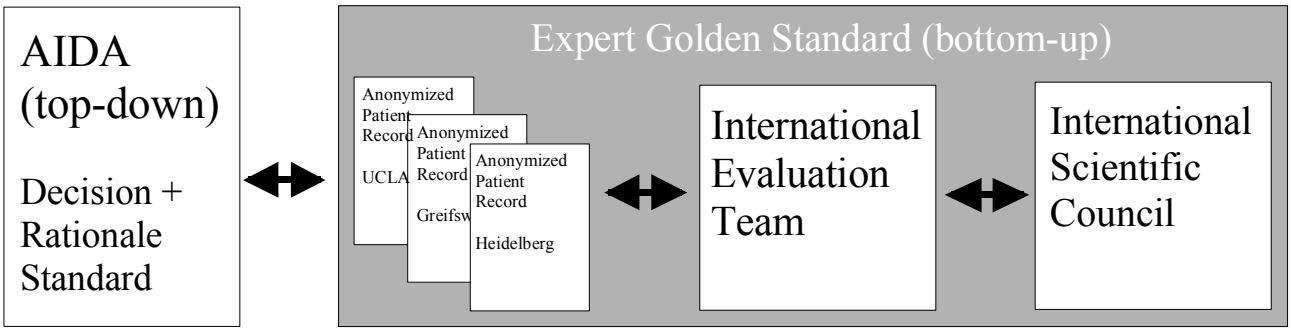

Figure 71: Basic structure of the evaluation study. The results of the AIDA planning system should compared with a gold standard.

Some example cases are presented in the following, because the dentists must be able to understand them by explanation only. The procedures used during the analysis will be discussed afterwards.

Table 1: 20 simplified examples for comparing actual planning and planning conducted by AIDA 1.1. It was assumed that at least one of the AIDA solutions matches the actual solution, because the prototype is not yet able to fully specify the solutions within this planning step (see appendix for a list of abbreviations of diagnoses).

#	Exam. results	AIDA Planning	Actual Planning	Problems
008	24 fl, 25 f, 26fl	One tooth implant only 25	Bridge 24-26	No conventional bridge planning, because 24 + 25 have fillings and, therefore, not in need of restoration
008	46fl, 46f, 47c, 48f	Bridge 46-48	Bridge 45-48	"45 fl" has already been provided for and, therefore, not in need of restoration, 47 recognized and included in planning. Previously minimal solution BA+B standard planning for AIDA
010	24k, 25b, 26k, 27b, 28f	No planning	Bridge 24-26	According to file, bridge loose at 26 ⇒ abbrev. for result not yet given.
012	45k, 46f, 47k	No planning	Bridge 45-47	According to file, veneer fractured/blistered at 45 and bridge loose ⇒ abbrev. not yet given for diagnosis
013	13k, 14b, 15k, 16b, 17k, 18f	No planning	Bridge 13-15-17	According to file, veneer fractured at 15 + 016 ⇒ abbrev. not yet given for diagnosis.
013	34 ok, 35 k, 36 b, 37 f, 38 fl	One tooth implant 37	Bridge 35-38	Condition following X 37 ⇒ remaining bridge construction 35 - 036 not considered faulty, since BA+B currently still minimal solution, and standard AIDA planning.
017	16c, 17c	No planning	Dental crown 16+17	According to file, 16 fl+c, 17 fl+c, general need for action "c" not yet recognized ⇒ more precise differentiation required; a)

#	Exam. results	AIDA Planning	Actual Planning	Problems
				"c" existing crown, untreated tooth and b) classification of caries in case of expansion/invasiveness
017	37w	Dental crown 37	Dental crown 37	"w" = damaged, but worthy of saving, need for planning recognized ⇒ correct planning.
017	44fl, 45fl, 46f, 47fl, 48ok	One tooth implant only 46	Bridge 45-47	Lacks conventional bridge planning, Neighboring teeth of 46 already have fillings ⇒ no need for action recognized by AIDA (s. a.).
20	24fl, 25fl, 26fl, 27fl, 28f	No planning	Bridge 24,25-27	Faulty entry of diagnosis: 26 registered with filling – according to file, tooth 26 is missing ⇒ AIDA planning off course of actual planning, but feasible due to faulty diagnosis.
029	23ok, 24f)(, 25in, 26 f, 27 k	One tooth implant 25	Bridge 25-27	Planning error ⇒ possible difficulties in recognizing gap closure ")(", no planning for 026, because support area sufficient up to 2nd premolar.
036	13ok, 14k, 15f, 16k,	No planning	Bridge 14-17	According to file, veneer fractured 16, 017 included in renewed planning, because 47 without antagonist otherwise (no support ⇒ danger of elongation).
037	45ok, 46f, 47ok, 48ok	Bridge 45-47, one tooth implant 46	Bridge 45-47	Teeth 45 + 47 marked "ok" and previously not treated ⇒ included in planning as "treatable".

#	Exam. results	AIDA Planning	Actual Planning	Problems
038	44ok, 45fl, 46f, 47f, 34ok, 35fl, 36)(, 37fl, 38f, 16fl	046BrI-047-48; 46BrI-47, No planning for 3rd quadrant, No planning for 1st quadrant	Bridge 44,45-48, Bridge 35-37; 16 partial crown	Planning possible, but standard planning without implant missing or, in other words, erroneous planning of implant + cantilever pontic, symbol for partial gap closure ") (" (in contrast to full gap closure ")(") not recognized ⇒ planning missing. 16 was treated with partial crown due to occlusal balance ⇒ elongation of tooth 16 not marked in diagnosis.
055	44ok, 45k, 46b, 47f	No planning	Bridge 44, 45-046	No planning by AIDA, because faulty construction BA+B not recognized ⇒ modification of standard minimal treatment necessary.
058	44fl, 45k, 46e, 47k	No planning	Bridge 45-47	AIDA can not differentiate between "e" for definitely replaced (e.g. a cone prosthesis) and "e" meaning intermediate treatment ⇒ further input modalities required.
061	21k, 22b, 23k, 24f, 25f, 26k, 27f	Bridge 024 implant + cantilever pontic 025	Bridge 21-23-26	Faulty implant planning with cantilever pontic (analogous to minimal planning BA+B of natural teeth), conventional planning missing without implant ⇒ Modification of minimal planning (BA+B) and ⇒ conventional planning must become standard
069	13ok, 14fl, 15f, 5f)(, 16c	Bridge 015 - 16, 15I, 16I, implant 13 !!	Bridge 14-16	Minimal solution insufficient ⇒ modification required, Implant planning faulty at 13, since 13 is not missing ⇒ problem not yet solved.
069	21ok, 22ok, 23ok, 24c, 25f)(, 26fl, 27fl,	Bridge 24-25, 25I, 21I !!	Bridge 24-26	Minimal solution insufficient ⇒ modification required, , Implant planning faulty a 21, since 21 not missing ⇒ problem not yet solved.

#	Exam. results	AIDA Planning	Actual Planning	Problems
	28ok			
074	24k, 25k, 26b, 27c, 28fl	No planning	Bridge 25-27	According to file, "c" at crown 27 ⇒ not recognized by AIDA from diagnosis, since no differentiation is made whether "c" pertains to crown, filling, or the not yet treated tooth.

At this point, it must be repeated that the following figures can not be used as direct quality measures for the AIDA prototype, because an overall measure is not available for evaluating the quality of planning. However, the comparison can point out for which cases or decision rules a consensus has not yet been found among domain experts. The results of the analysis are now briefly presented and shown in Figure 73:

AIDA generated planning recommendations and treatment alternatives for 237 problem areas for the 100 evaluated patient records (compare Figure 4). A distinction can be made between strictly and not strictly reproducible alternatives:

1. 162 of the treatment alternatives planned by AIDA (68%) were comprehended by dentists without difficulty.
2. For the remaining 75 treatment alternatives (32%), the following error sources were identified:
   a. In 15 cases (20%), the diagnosis abbreviation could not be clearly interpreted by the system. The interpretation table must be adjusted for these cases.
   b. In 28 cases (37%), a bridge unit with an extension was planned as the minimal solution. This solution requires an additional abutment for further stability. In 12 cases (16%), an implant with an attached bridge unit was planned. This solution also requires an additional abutment. Both mistakes are a result of the same planning error.
   c. In 4 cases (5%), a bridge with a natural and an artificial abutment was planned. Mixed forms are not yet covered by the planning rules.
   d. In 26 cases (34%), the planning errors were more complex and require comprehensive examination. Of these, 20 cases (26%) involved

problems in planning natural abutments, while 6 cases (8%) involved difficulties in planning implants. These problems involve relationships to other dental disciplines (e.g. conservation dentistry) that must given consideration to ensure the strict generation of the treatment plan. The AIDA prototype must, therefore, be extended in this regard.

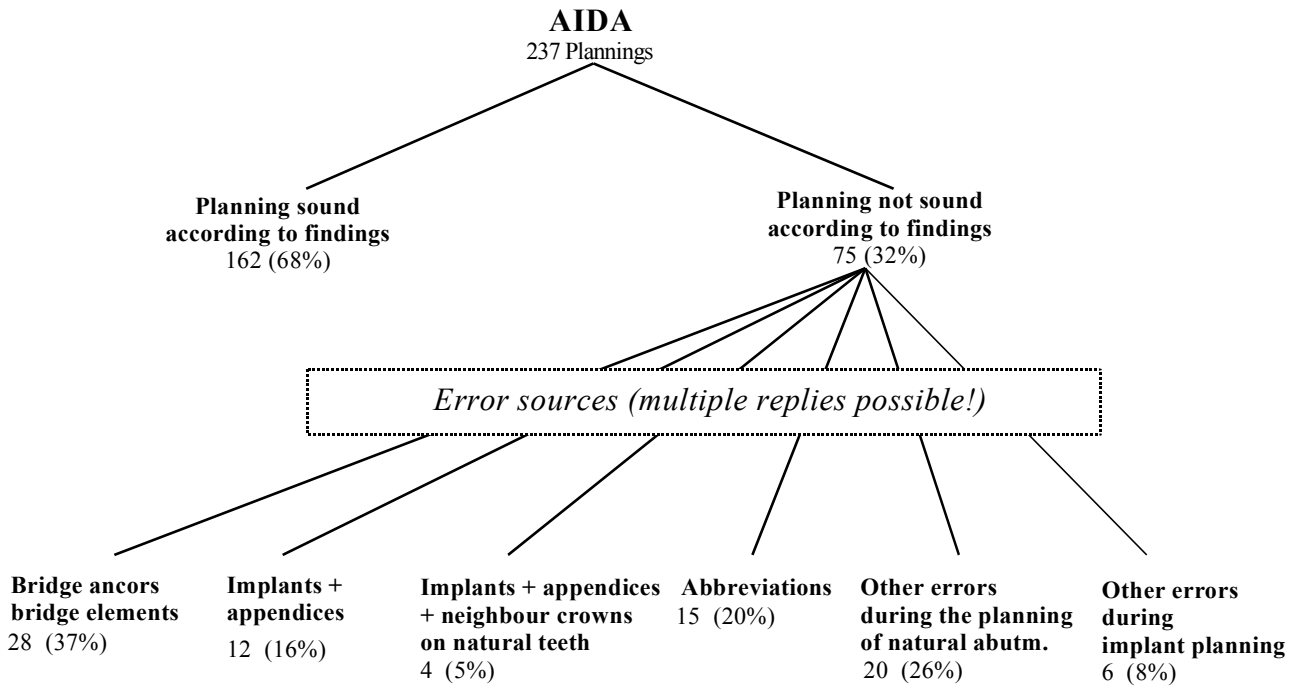

Figure 72: AIDA planning results. The errors could be identified for most cases. A higher hit score can be expected for the next AIDA prototype.

So far, the intermediate results have been presented from the AIDA perspective. The results of the actual cases can also be evaluated. However, in this case, the significance of the evaluation results is limited, because of the low degree of reproducibility of the patient records.

1. Actual planning, conducted by dentists, that was not understood: 33 cases (21%). Investigated reasons: either the diagnosis was entered incorrectly (7 cases, 21%) or the diagnosis was generally undetermined (26 cases, 79%).
2. Actual planning that was understood: 124 cases (79%) were accepted for a comparison with AIDA. These cases were classified as follows:
   a. An evaluation took place only if the treatment could be comprehended based solely on the diagnosis: The first evaluation cycle identified

inconsistencies in 82 cases (79%). Their causes must be investigated further to make the necessary changes to the AIDA methodology, or to correct programming errors (compare next section).

b. In the other cases, additional file information was required to comprehend the treatment (26 cases, 21%). The information could not be interpreted due to a lack of standardization. Therefore, formalization is required to create a strict association between the diagnosis made prior to treatment and the situation following it.

Figure 73 shows how the actually planned cases are structured[88]. A general differentiation was between problems relating to dental documentation and those relating to the rule-based decision structure (see grey or white boxes).

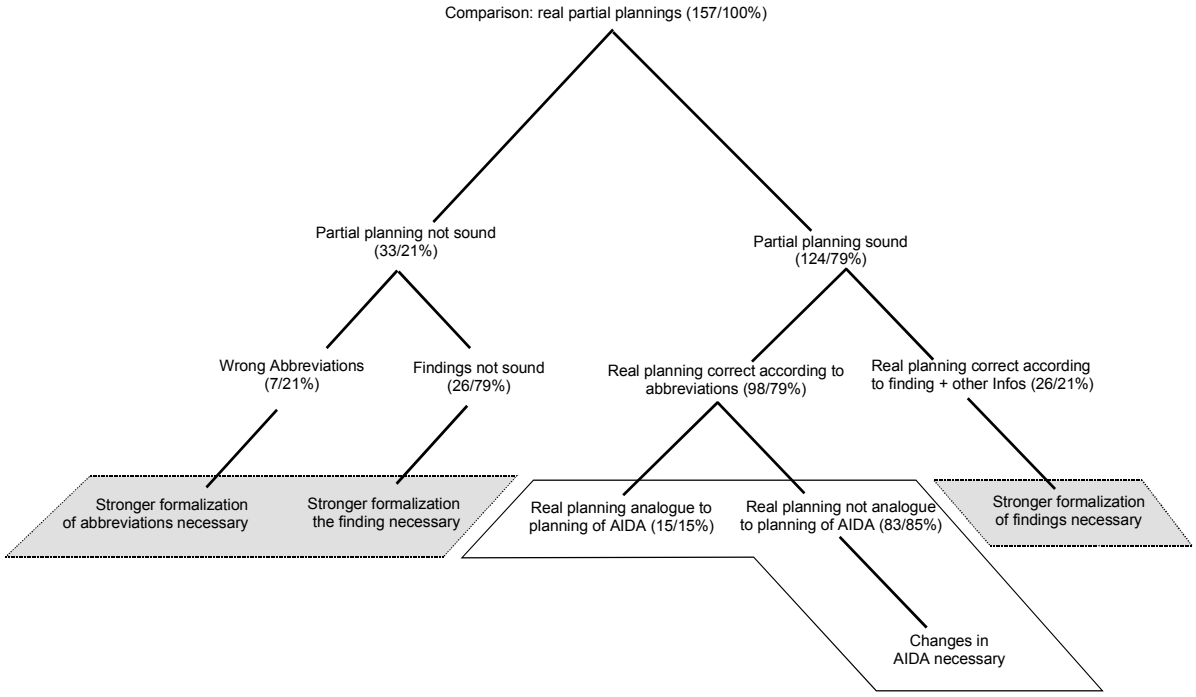

Figure 73: Evaluation of the AIDA methodology from the perspective of the actual cases – only conditional conclusions of the quality of the AIDA planning methodology can be derived from the values presented in this figure (compare with the text)!

[88] It should be pointed out that the structure presented Figure 73 is generally independent of the dental domain. It refers to an arrangement of the actually planned cases, whereby a distinction is made between purely dental problems (grey boxes) and their comparability to rule-based planning (white box).

Direct improvements could be suggested for the first three problem areas of the described methodology (2a-c). Therefore, a new and improved version can be expected showing a much higher rate of planning accuracy.

The planning errors were complex in the remaining cases. The reasons for the errors require further investigation based on a larger set of cases.

However, adjustments must not only be made to the decision rules. The more precise the decision making process is, the mightier the diagnosing language used must be. Otherwise, an objective foundation for formulating the relationships is not secured.

To ensure long-term security, adjustments to the decision rules must be followed by adjustments to the table of abbreviations of the diagnoses. The overall process if improving the methodology can be summarized as follows:

1. Implement the planning agent.
2. Compare AIDA planning results to actual cases.
3. Determine the changes required to the decision rules from the comparison.
4. Extend, or specific the diagnosing language and the abbreviation table.

Based on the results of this sequence, the agent can be re-implemented, leading to a spiral model for meta-planning dental treatment (planning the planning process). Figure 74 shows this relationship:

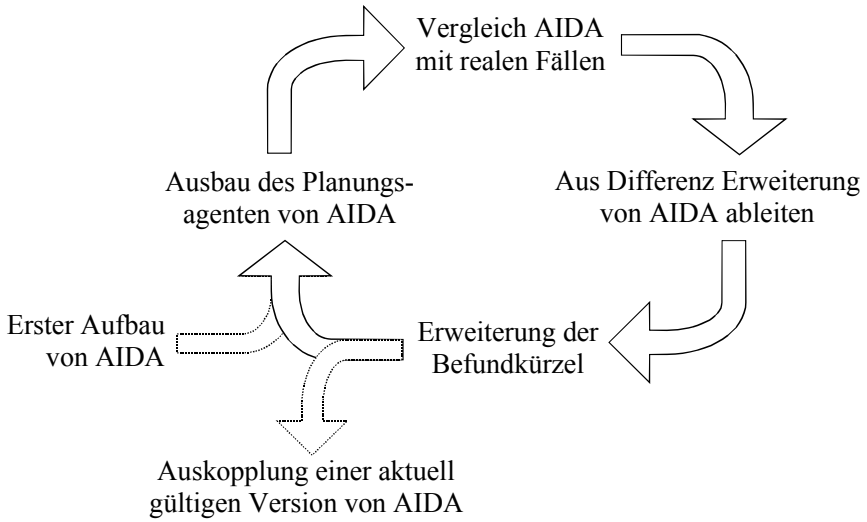

Figure 74: Development cycle of the AIDA software module. By comparing the AIDA planning results to actual cases, evidence for expanding or adjusting the AIDA methodology can be found. A fine-tuning of the

diagnoses abbreviations is necessary to describe the adjustments. This process results in a spiral model of the development cycle.

This iterative model for improving the methodology can help to permanently advance its further development, and to achieve a greater precision of rule-based planning methodologies.

A large group of experts should be included in the further development of the methodology to achieve a broad consensus for dental decision making. A separate authoring system should be developed to support cooperative work among the authoring experts – even across distances.

Evaluations within the AIDA project have shown that a formally represented decision model can help to examine and improve a coherent representation of the dental decision methodology. The model serves as a neutral representation of the decision structures. The structure chart developed of the underlying decision methodology for dental medicine serves as a suited base for discussion not only among software developers, but also domain experts.

The decision structure developed for the AIDA project should be made available nation-wide to allow broad based critique and discussion of the treated areas.

A further development of the methodology will continue in the future to specify treatment alternatives, e.g., for conservative dentistry, periodontics, and the development of prognoses. all of the suggested treatment alternatives are outputted as a result of prior planning. The solutions can, for instance, be passed on to a billing system, or presented in standard planning form sheets. The dentist can either freely accept or edit the suggested alternatives. Therefore, the dentist is not limited by the planning methodology.

Since he can make use of the suggested solution alternatives, a time savings is expected to result from the planning step. Computer-based planning can help relieve the dentist and create more free space for severe or complex cases reaching the limits of the acknowledged decision methodology.

6.3.3 Visions for Presenting Information “On Demand”

The use of a dental decision model is not limited to a knowledge based system for decision support. It can also be used as a foundation for common

communication media. The following describes how the decision methodology can be used to automatically generate other types of knowledge presentation.

6.3.3.1 Generating common media “on demand“

Previous sections described how the dental knowledge required for decision making can be secured on a computer-based decision support system. It is also conceivable to secure presentation data describing how various user groups use which data. It is, for example, imaginable to store presentation instructions of the decision structure in order to output the data on a CD-ROM or in a print file for printing a reference book upon command. Similar processes are already known and used to document databases, and are supported by documentation description languages such as XML. This translation process can be termed “compiling” in analogy to translating source code into an executable program. This special form of compilation for generating reference books could be termed “book compiler”.

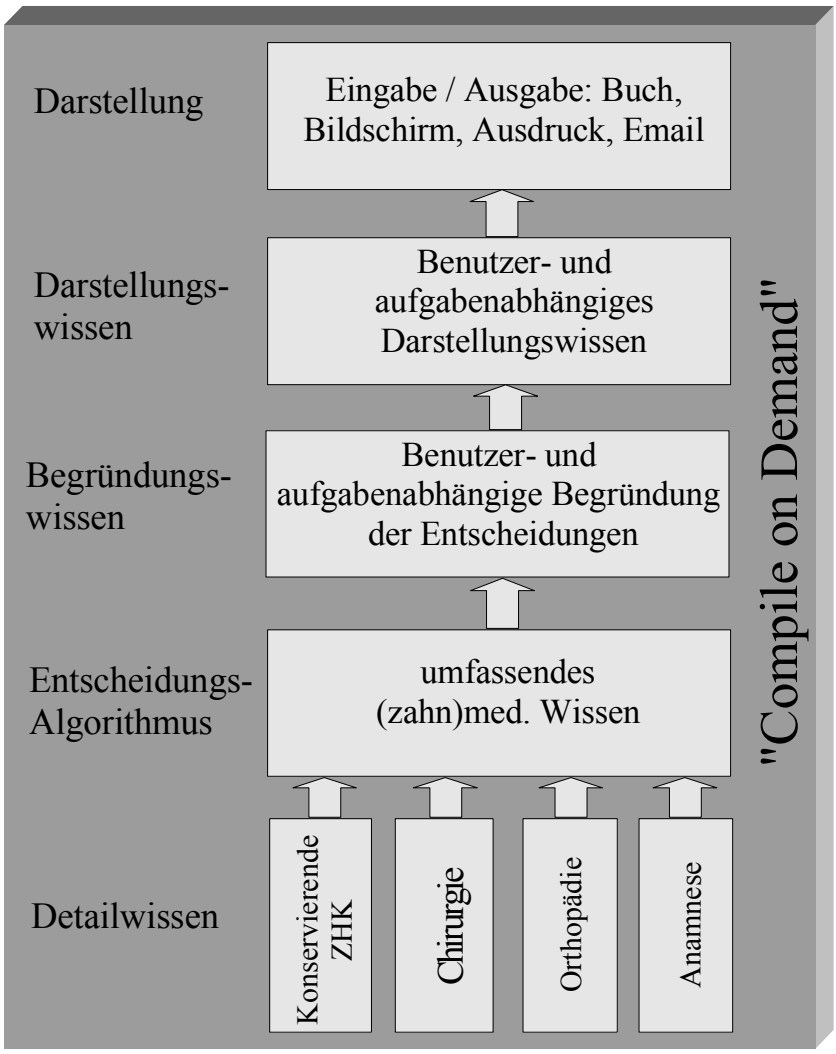

Figure 75: "Compile on demand" generates the presentation forms used by the domains on various knowledge levels.

In combination with "print on demand"[89] [122,123], the creation of print media opens a door to continually current books. The underlying knowledge is constantly kept up-to-date by scientists on the various levels. For each new order, the current knowledge is loaded, compiled in a print file, and directly outputted in book form using "print on demand". This helps to avoid long waiting periods between new editions, while always having full advantage of the resource.

[89] "Print on demand" is a modern form of printing by which books are printed with a print run of one book. In a continuous process, the print file of the book is loaded, the pages and covers printed, and the book bound.

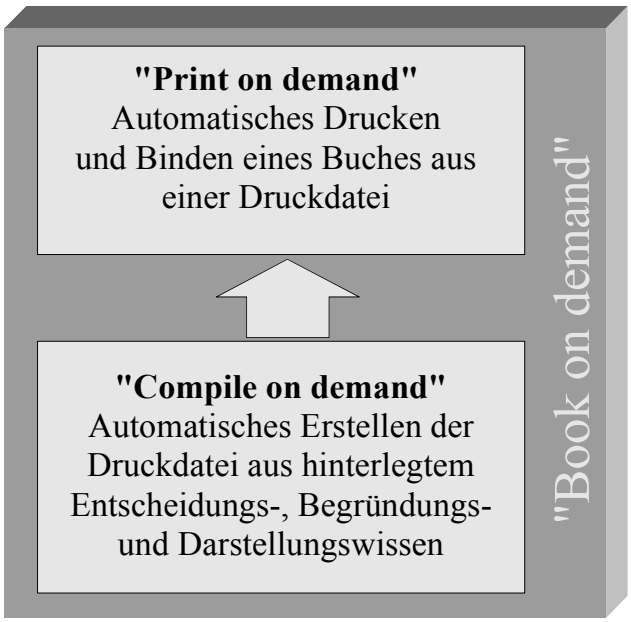

Figure 76: 'Book on demand' combines 'print on demand' and 'compile on demand'.

A print file can, however, also be used for display on electronic media. Here for, several standard formats are available to display the data in form of e-books, as well as common books[90].

6.3.3.2 Determining guidelines from the decision model

Generating text books from the decision model is not the only thing conceivable. A strict decision model is also suited to customize guidelines and procedures to specific target groups. Guidelines represent a role-oriented view of the actual model.

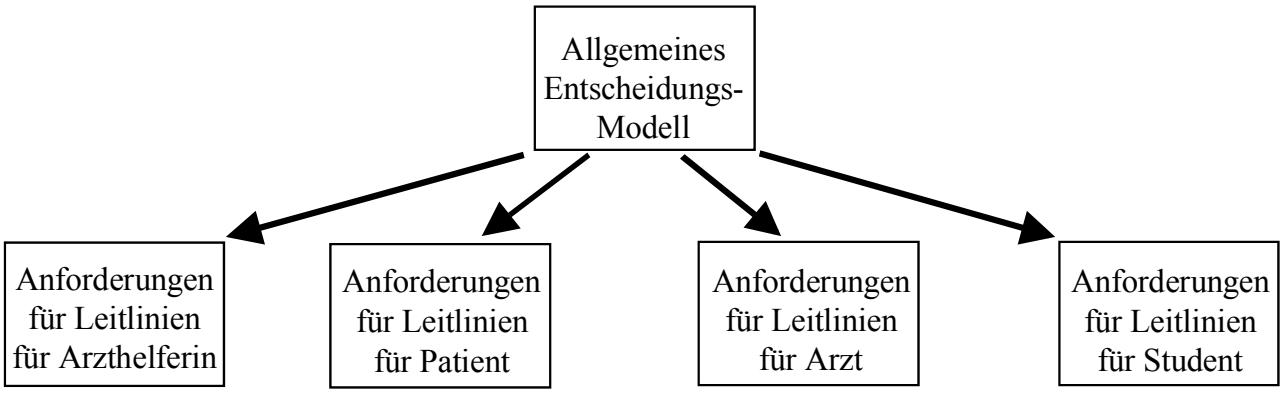

Figure 77: Determining guidelines from the general model "view models".

[90] Common formats are, e.g. HTML, XML, PDF.

Rather than formulating the guidelines explicitly; only those decision rules that regulating which target group must receive which information when are formulated explicitly. In this case, the guidelines and procedure definitions only include the meta-knowledge required to create the respective guideline. This guarantees that changes to internal decision making processes are consistently passed on to the individual guidelines.

6.4 SUMMARY AND OUTLOOK OF THE MACHINE SUPPORT

The basic relationships of dental medicine can be described in form of a decision model. The relationships can be transferred to a machine to support individual planning, and to generate common information media as reference material for a detailed further development of dental decision making.

The decision structures have been realized for the example area of fixed crown restorations. The evaluation of the prototype shows much more exact dental diagnosing is required to understand and gain clear conclusions for treatment planning.

It does not suffice to develop and implement software-based decision support in dental medicine. More importantly, machines can help to support a new, formally secured view of the dental domain, and can serve as a secure basis for discussion for future research.

Neither the dentist, nor the patient should be limited in their freedom of decision by the decision model. Rather, they should find support for their decision making processes. An expressive diagnosing language is required to enable information exchange between humans and machines.

Control structures are necessary during planning to break down the complex problem into comprehendible pieces. Every decision made is explained to allow comprehension and, thereby, ensure the transparency of the decision making process.

7 DISCUSSION AND OUTLOOK

A general concept for describing dental decision structures was developed within this research work. Also, the goals of dental medicine were defined, treatment alternatives were generated, treatment processes derived, and suited treatment alternatives selected based on general decision theory. The approach creates a criticizable decision reference that, although never fully complete, can be expanded continually. This, in turn, enables a lasting improvement of the structural, process and outcome qualities of the domain, and leads to a neutral communication platform for discussing relevant problem areas. Within the scope of modern scientific theory, Kuhn [91] and Lakatos [124] consider this an acceptable approach for researching dental relationships.

7.1 SUMMARY OF THE PRESENTED APPROACH

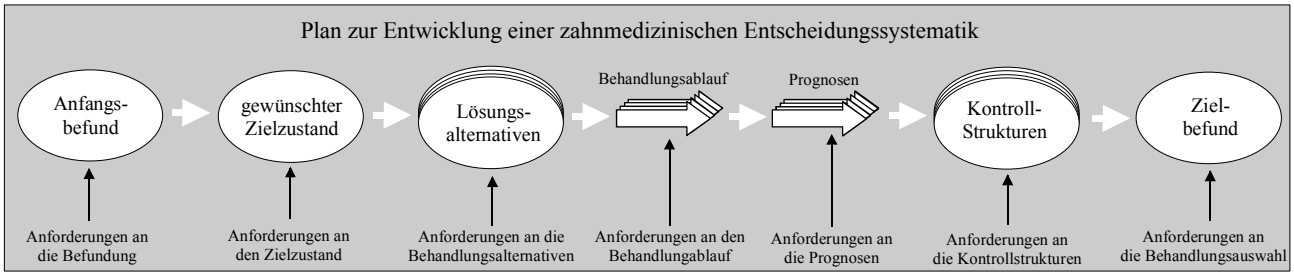

Figure 78: Plan for developing a medical decision methodology in accordance to general decision theory.

An underlying problem identified within dental medicine is that a strict approach to treatment planning is missing. Although some parts of the treatment plan have been described in detail, decision theory [75,76] requires that the description of the situation (= environmental state), the possible alternatives (= actions), and their results (= consequences) are also parts of the decision. Necessary preconditions for the overall decision are: decision components for evaluating preferences, the selection of suitable treatment, and the description of the benefits of each treatment alternative. The following can help to meet these

preconditions: defining the dental goals and the goal criteria needed to achieve the set treatment goals, treatment planning to generate treatment alternatives, and prognoses to rate each treatment alternative.

A holistic patient view and comprehensive solutions for the posing dental problems are required. The medical goal criteria provide quality assurance for treatment planning and the treatment itself. Dental goal criteria specify these goals for the stomatognathic system. The dental sub-goals are, and must remain, subordinate to the overall dental goal, and, therefore, to the general medical goal criteria.

However, not only the decision structure must be scientifically acknowledged. Argumentation of individual solutions must also be possible to target the needs of specific groups of people to allow respective interpretations. Therefore, each decision must be justifiable.

Economic requirements must also be fulfilled to integrate a decision structure into practice. Financial aspects have purposefully been excluded from the argumentation in order to develop a purely medically based decision structure. Also, optimized treatment planning makes sense from a purely medical standpoint, because it focuses only on the necessary. Te condition of a patient can not be evaluated exactly, because diagnosing is innately limited (due, among others, to timely, technical and invasive reasons). Therefore, it is not possible to develop a fully complete and definite treatment plan.

Knowledge navigation offers a solution. It generates all possible treatment alternatives based on an innately incomplete interpretation of the diagnosis. Further information is then required to fine-tune a specific treatment alternative. As further information appears, it can lead to excluding specific alternatives from the initial over-supply of selections. The exclusion of an alternative is also considered fine-tuning. With help of the methodology, the dentist can elaborate upon and fine-tune his solutions. Backward planning the treatment alternatives – from the targeted goal of the dental crown via the root and the jaw, to the temporomandibular joint – is required to comply with the goal-orientation. Backward treatment planning begins by defining the goal criteria for dental crowns and derives the needs of the "underlying" structures from them. Treatment, however, begins with those structures building a foundation for the "above" structures them.

Additional information can be collected to simplify the selection of a treatment alternative. Prognoses and example cases can help explain the relationships involved and their effects. The actual decision is always left to the dentist and the patient, because a scientifically acknowledged methodology for a comparing prognoses does not exist and, due to the indeterminacy of the future, will probably never will. A decision methodology is, therefore, limited to a decision support which, ideally, helps the user navigate to a satisfactory solution.

An integration of decision support into standing office-based systems is needed to use the information stored there for quality assurance. This can only take place, however, if a uniform concepts exist allowing an explicit interpretation of the contents. This could also greatly benefit communication between information systems. In the end, both the dentist and the patients could benefit from the more precise information.

7.2 A CRITIQUE OF THIS RESEARCH WORK

Thematic limits (dental medicine)

The problem area has been narrowed down considerably to reach a degree of detail allowing the discussion of a concrete dental problem. For example, pediatric and juvenile dental medicine were largely left out of the reflections presented here.

The danger of losing sight and excluding interactions occurring between dental problems and other medical sub-disciplines is given, because of the strong focus placed on the dentition. This danger should be emphasized more strongly in future fine-tuning of this research work, since interdisciplinary research questions should receive a high standing to continually work toward fulfilling the vision of synoptic medicine.

Conceptual limits (static view)

Treatment planning was described on the premise that the patient condition does not change during the planning phase. This static perspective is necessary to describe planning as the transformation from a time point t_0 to a later time point t_1. This simplification seems acceptable for most dental cases. However, in the future, further investigation should determine for which dental situations this premise does not hold.

The dynamics of the overall methodology is a result of: (a) the individual diagnoses are collected upon request, one at a time; and (b) treatment planning starts over as soon as the initial condition of the patient, upon which the assumptions were based, changes considerably.

An important conceptual limit to the methodology is its focus on fixed facts and rules. This does not seem appropriate at first glance, considering the current discussion surrounding probabilities. However, it is often overseen that collectively valid statements can not automatically be transferred to individual cases. A decision rule is always needed that transfers the probability from a cohort onto the individual.

Therefore, it is no longer necessary to deposit the probability model for an individual decision. However, it very well should be considered whether a formal integration of the probability models could support scientific communication.

Functional deficiencies

Neither the manifold options available for combining natural and artificial abutments, nor the various possible combinations of prosthetic restorations, has been given sufficient thought. These variations could either be integrated by extending the basic model, or they are seen as exceptions to be treated before or after the respective decision level.

A specification of the materials has not been addressed, because this would require a comprehensive list of all technical possibilities and their characteristics. This would, however, go far beyond the scope of an initial basic analysis of a decision structure. As mentioned previously, this does not, however, stand in conflict with the proposed methodology, because the materials support rather than contradict its actual realization.

Value in terms of the philosophy of science

As described in this work, absolute precision is not possible. Therefore, the developed methodology can not be 100% precise. However, a framework is necessary to neutrally represent a dental decision methodology. An acknowledged worldwide analysis and criticism must be allowed within this concept to continually reduce the deficit of imprecision.

Navigation is the answer to individuality of treatment planning. Although the model is an abstraction of reality, it can be fine-tuned to the degree of granularity desired by the individual user.

It is difficult to estimate the limits of modeling dental relationships. The present system theory-oriented approach allows the break down and description of complex relationships, but possess the already critically stated dangers (compare [95,125,126]) regarding the system approach:

System theory is not a theory in the sense of the real sciences. It does not contain empiric information. Therefore, there is no way to prove the derivation of the model. An uncritical observation may, therefore, lead to false analogies.

The system approach may foster uncritical thinking, and, therefore, create a type of "system ideology". This danger is critical, because – especially in regard to computer-based treatment planning –one may depend too strongly on the model, and not grant the necessary attention to special cases.

Also, it is not certain that all of the relationships within dental medicine can actually be included in a unique model - as a superficial observation of the suggested approach may imply.

7.3 REASONS FOR DENTAL TREATMENT FAILURES

Treatment can fail due to various reasons. For example, either an insufficient amount of time has been invested into planning, or the exclusion criteria prevent a necessary treatment.

Even if treatment planning is possible, errors can be made during its realization, leading to principally false results. Planning errors can occur due to: incorrect diagnosing, communication problems with the machine, or a faulty decision methodology. Errors can also occur during treatment, even if planning was conducted correctly. Decision support can help minimize treatment errors, because planning is conducted more precisely. However, it can not eliminate them.

Also, unexpected occurrences can arise even if treatment planning was conducted correctly. This is due to the innate incompleteness of diagnosing., Situations can occur during treatment that are virtually undetectable during the initial examination, because they are so rare or complex. In addition, the patient

could have an accident, for example. In such cases, treatment planning must be re-conducted.

It is of underlying importance that planning is repeated as soon as the documented diagnosis has changed strongly. A new, comprehensive examination and diagnosing can clarify such changes, and initiate comprehensive planning. In straightforward cases, the available knowledge can often be taken from previous planning, whereby changes can be integrated quickly.

If a planned treatment was unsuccessful, the condition just after the unsuccessful treatment can be used as the starting point for new planning. The decision methodology can presently not determine the time point at which failure becomes obvious. This would be important to avoid such mistakes in the future.

Determining when the treatment has failed is very difficult, because such an evaluation requires an objective decision methodology. However, since such a comprehensive model is not available, the concept of failure can not always be objectified with certainly either.

The discrepancies between the actually treated cases and the alternatives suggested by the decision methodology can provide valuable insight for individual planning activities of the dentist, for system developers, and for the quality of the outcome.

7.4 OUTLOOK

The presented approach can find use in practice based on formulated rules. The planning rules may not, however, limit the dentist in his practical work. Rather, they should offer new alternatives that may not be used otherwise, due, for example, to their rarity.

Transferring the approach to other medical disciplines could help identify which parts of the decision structure are universal to medicine, and which are specific to dental medicine.

Using knowledge servers to technically realize and represent the decision methodology, could serve as a neutral base for dental knowledge. Modern network architecture allows virtually instantaneous world-wide mediation and

criticism. Specialists can present their experiences, which can then be worked into the overall structure by acknowledged experts.

7.5 CLOSING STATEMENTS

To date, expert systems are (still) systems from expert to expert, because the complexity of the decision structures must be mastered to benefit from its use (compare [42]). Knowledge-based decision support primarily serves the scientific formulation of the planning process and the structural quality.

Such a system must attain a sufficient amount of maturity, before it can be successful in routine use. Basically, a computer can process rules much faster than humans, promising a quick transferal of current knowledge into everyday practice. However, the transparency of the decision foundations must be fostered. An overview of the overall problem should be apparent to the user at all times.

Deterministic logic does not seem to mirror reality perfectly. Causality apparently has limits to representing data within models. Still, humans seem to have no other alternative than to make use of these manual tools. It seems frustrating at first glance, because the end of the search is not in sight, not even a satisfactory intermediate result. Yet, there is a continually growing space for thought and for visions. New challenges bring new life to the culture of thought.

The approach presented here must also be seen in this context. It raises more questions than providing answers. But, it underlines the value of the individual, despite the intense research conducted in artificial intelligence. Because, “no real problem exists that can determine the result of a modeling process without realizing the subject” (author unknown).

„es gibt keine reale Problemsituation, die ohne das erkennende Subjekt das Ergebnis des Modellbildungsprozesses determiniert“ (Autor unbekannt).

APPENDIX

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ABBREVIATIONS OF DIAGNOSES

Table 8: The list of abbreviations used in diagnoses and their numeration within the AIDA prototype, as well as the respective dental explanations. It should be noted that the abbreviations may be defined differently in other sources.

Running No.	Abbrev.	Term	AIDA #	Explanation
	-	Splinting	101	Fixed connection of several artificial crowns.
2	)(	Gap closure	102	A gap is closed, in an orthodontic approach, by displacing the teeth from a distal to a mesial position.
3	b	Bridge unit	103	Part of a fixed bridge that replaces a crown and is not attached to an abutment.
4	c	Caries	104	Irreversible decalcification of the crystalline enamel through bacterial acidulous effect.
5	e	Restored tooth	105	Artificial one-tooth restoration.
6	el	Elongation	106	Extension, a tooth outgrows its dental socket; most often due to the lack of an antagonistic counterpart. For correct masticatory functionality, elongated teeth must be shorten (by abrasion); the missing counter-tooth must be replaced.
7	f	Missing tooth	107	Neither crown nor root existing in a region (gap).
8	fl	Filling	108	Generally made of synthetic material.
9	fr	Fracture	109	Fracture of a dental crown or root. Crown fractures can either be fractures of the enamel with exposed dentin, or complicated fractures with exposed pulpa. Dental root fractures can be located in either be upper, middle or lower third of the root.

Running No.	Abbrev.	Term	AIDA #	Explanation
10	h	Retainer	110	Metal clamp to fasten a removable, gingivally positioned partial prosthesis to suited anchoring teeth.
11	i	Implant	111	Restorative root that has been surgically set into and fixed onto the jaw.
12	ik	Initial caries	112	Reversible, early stage of caries that can be treated by means of remineralization.
13	in	Inlay	113	Laboratory-fabricated, exact-fit inserted filling.
14	k	Crown	114	Restorative crown fastened to a natural root.
15	kp	Tilt	115	Abnormal tilt of the dental axis respective to the vertical axis of the occlusal plain is out of its normal position.
16	kr	Interdental crater	116	Bone loss between two teeth.
17	m	Ceramic veneer	117	Ceramic lining of a restorative crown.
18	o	(Retaining) attachment	118	Specially prepared artificial crown used to fasten a removable restoration. The retention between the primary and secondary anchorages is realized by making use of friction forces between the two parts.
19	ok	Tooth is okay	119	No known problems within the region.
20	re	Recession	120	Gingival recession.
21	ro	Rotation	121	Longitudinal rotation of the tooth.
22	sa	Anomalous position	122	The tooth is not positioned exactly within the dental row. Also known as malocclusion / occlusal discrepancy
23	sf	Abrasion area	123	Areas of abrasion caused by collision of the antagonists during chewing.

Running No.	Abbrev.	Term	AIDA #	Explanation
24	t	Telescope crown / cone	124	Crown restoration that serves as anchorage for removable restorations. It is composed of a cylindrical or cone-shaped inner part, which is attached to the natural root, and an outer part, which serves as a connector to the prosthesis.
25	tk	Partial crown	125	Partially artificial crown.
26	tr	Partial anchorage	126	In the case of a partially retained tooth, only a part of the clinical crown is visible.
27	ür	Projecting edge of a filling or crown	127	Edge of filling, or crown, does not close exactly with the natural dental surface.
28	v	Resin veneer	128	Resin coating for a crown restoration.
29	vs	Sealing	129	Sealing of fissures using deposits.
30	w	Damaged tooth, worthy of restoring	130	Conservation treatment is not possible. The dental apparatus is still intact. A prosthetic is required for the tooth.
31	x	Tooth not worthy of restoring	131	Tooth shows no vitality and must be extracted.
32	za	Dental tartar	132	Mineral deposits. Saliva resident substances, especially, calcium phosphate, intermixed with organic tissue residues and microorganisms residing on the teeth.
33	zd	Dental cervix/ neck defect	133	Caries or wedge-shaped defect of tooth neck, also known as dental cervix.

GLOSSARY

antagonist	A tooth in one jaw that opposes a tooth in the other jaw.
anterior	Frontal.
apical	At the tip of an organ; Relating to or affecting the apex of a tooth root.
proximal	Neighboring.
basal	Directed toward the base of the skull.
treatment	Treatment includes all of the measures and activities of the people involved in a treatment process.
treatment (realized)	The practical, executed part of the overall dental treatment / management.
bridge	A bridge is the sum of all connected bridge fixations and units, as well as the implants set for the purpose of fastening a bridge. In contrast to a cone bridge, a normal bridge can not be removed.
bridge fixation / anchor	A crown restoration that is mesially and/or distally fastened to a bridge unit.
bridge unit	A crown restoration that is not apically fastened to an abutment. Rather, it is mesially and/or distally fastened to a bridge unit of bridge fixation.
bridge beam	The total of all bridge units of a fixed bridge.
bridge abutment	Abutment to which a bridge is fastened.
bridge span	The span of a bridge is made up of two bridge anchors and the bridge units between them.
buccal	Of, or regarding, the cheek.

Cochrane Collaboration	World-wide scientific network that creates and updates systematic overviews of randomized, controlled trials (RCTs) to increase the effectiveness of medical measures. The collaboration provides makes its information available by providing current CD-ROMS containing overviews and Databases, which serve as a knowledge source for scientists and practicing physicians [124].
data	Data are constructs of symbols or continual functions (e.g. sound signals) that represent information based on known or supposed agreement. Data are the basis or events for processing steps.
design model	Implementation-near model from which executable code can be generated.
distal (dent)	Away from the median sagittal plane; in a dorsal direction from any given point of reference.
diagnosis	Determination and recognition of diseases; the nosological, systematic naming of diseases; in practice, the sum of all results stemming from medical examinations or actions.
differential diagnosis	Each diagnosis (disease) that must be taken into consideration during differential diagnostics.
decision space	Set of all decision alternatives.
crown restoration	see crown (artificial).
FDI	Federation Dentaire Internationale.
cantilever situation	One or more gaps not followed by a crown.
frontal	Of, or relating, to the forehead.
FZB	Anterior tooth region.
Gingiva	Dental gums.

gingival	Of or related to the gums.
HTA	”Health Technology Assessment (HTA) is the analysis and evaluation of the effects of health technologies (product and programs) with the goal of finding a decision foundation for their use. In Europe, HTA is developing to a central strategy in health care system reform, especially in aspects of quality improvement and cost efficiency of health care ” [125].
e.g.	Exempli gratia ; for example
implant	See: root (artificial).
information	Information is the knowledge of certain facts or processes.
incisal	Pertaining to the cutting edges of incisors and cuspid teeth
AI	Artificial intelligence.
configuration	Spatial arrangement of a structure.
construction	Structures of artificial materials.
coronal (dent)	Toward / near the crown; related to the dental crown (Corona dentis).
conceptual model	Model of the relationships of the terminology of the individual domains as a foundation for cooperation between domain experts and informatics experts (in this case, dentists and medical informatics experts).
crown (general)	The part of a tooth visible within the oral cavity. A crown can be artificial or natural. It possess a crown number. The number, which corresponds with the FDI number of the respective tooth - with whose root the crowns forms the tooth.

crown (artificial)	An artificial crown (crown restoration) can be fastened to either an artificial, semi-artificial, or natural abutment. At least one of these types of anchors must be available.
crown (natural)	A natural crown is connected to a natural root. No connection exists to a neighboring crown.
crown (semi-artificial)	A semi-artificial crown is apically fastened to a natural abutment. Mesial and/or distal connections to other artificial or semi-artificial crowns can exist.
crown gap	Region, in which no, or no conservable crown remains, but a conservable root still exists.
labial	Relating to the oral labia, or lips.
lateral	Related to the side; situated at the side.
lingual	Toward / near the tongue.
gap	Region lacking a crown.
mesial	Toward the median plane; Toward / near the center of the dental arch.
nosological	Systemic (Description and study of diseases; area of pathology).
No.	Number.
upper jaw	Part of the facial skull to which the teeth of the upper dental arch are fastened.
OK	Upper jaw.
occlusal	Of or relating to occlusions of the teeth, especially the chewing or biting surfaces.
oral	Relating to the mouth.
palatal	Of, or related to, the palate.
Pat.	Patient

abutment (general)	Part with which the tooth is fastened to the jaw. An abutment can be natural or artificial (implant) and is occlusally connected to a crown, as well as apically connected to the jaw.
abutment (artificial)	An artificial abutment is occlusally connected to a crown, as well as apically connected to the jaw. The later connection is fixed.
abutment (natural)	A natural abutment can occlusally be connected to a natural or an artificial crown. It is connected to the jaw via the periodontium.
pharyngeal	Of, or related to, the pharynx.
planning	Timely planning of a structure or unit.
posterior	Of, or related to, the back of a structure.
regeneration	See therapy.
region	Position of the jaw reserved for a tooth. Upper or lower jaw can hold 16 regions each. Each region possess a 3-digit number. This number is composed of the FDI number of the tooth that normally is found in that position, as well as a preceding 0 (e.g. “011”). The reason for differentiating between regions and teeth is that teeth are not always available in a particular position. For example, the tooth No. 12 is missing and, due to gap closure, the tooth No. 13 now occupies the region 012.
reconstruction	Artificial structure that has been set into the oral cavity. It serves fulfillment of the goal criteria, in case the available structures do not.
repair	See reconstruction.
interdental gap	Gap, whose neighboring regions both have crowns (in other words, a gap between two crowns).

span	Distance between two neighboring bridge anchors. The breadth may maximally span three bridge units.
status	The condition of a patient, whereby his patient history and current condition at a specific time point are also included.
stomatognathic system	Tissue structures within the oral cavity. Alternative names: orofacial system, maxillofacial system, masticatory system, maxillomandibular system, chewing apparatus, or chewing organ.
SZB	Lateral tooth area.
therapy	Treatment of diseases; healing power or quality.
UK	Lower jaw.
lower jaw	Part of the facial skull, to which the teeth of the lower dental arch are fastened.
lower jaw	Part of the facial skull, to which the teeth of the lower dental arch are fastened.
support polygon	Notional polygon formed by the bridge fixations, or anchors, of a fixed bridge. It serves to estimate the stability of a construction.
splint	The connection of two or more crowns due to one or more missing antagonists. A natural tooth – or a tooth made up of a natural abutment and an artificial crown – without an antagonist may protrude.
splint	The connection of two or more crowns due to missing antagonists. For the connection, natural crowns are replaced with artificial crowns, because the natural crown - or a tooth made up of a natural abutment and an artificial/semi-artificial crown – may protrude, due to the missing antagonist.

vestibular	Of, relating to, or serving as a vestibule – in other words, a cavity that leads into another cavity.
knowledge	Knowledge is the acknowledged consensus within a specialty area at a given point in time in regard to terminology, regular relationships and context, as well as guidelines and procedures.
root (general)	The root attaches the tooth to the jaw. The area of the dental cervix, or neck, is considered part of the root. A root can either be natural or artificial and is coronally attached to the dental crown.
root (artificial)	An artificial root (implant) is surgically set into the jaw and is fixedly fastened to it. A periodontium does not exist. The artificial root is coronally attached to an artificial crown. .
root (natural)	A natural root can either be attached coronally to a natural, artificial, or semi-artificial crown. It is attached to the jaw via the periodontium.
tooth (abstract)	Structure made up of a dental crown and root.
tooth (natural)	Bone-like structure symmetrically fastened to the alveolar processes of the upper and lower jaw; disparateness among humans (heterodont dentition, or unequal set of teeth). Alongside each of the two incisors, a pointed cuspid tooth follows, proceeded by the premolars, which are, in turn, proceeded by the three molar. The sum of the teeth results in the dentition. The dentition diagram contains the unique identification of each tooth. The natural human tooth is made up of dental enamel, dentine, cementum, and the pulpa.
dental cervix / tooth neck	Tooth neck; corresponds to the cemento-enamel junction of a natural tooth.

tooth neck / dental cervix	Dental cervix; corresponds to the cemento-enamel junction of a natural tooth.
periodontium	It supports the teeth and includes the periodontal ligament, gingiva, cementum, and alveolar and supporting bone.
dentition diagram	The dentition diagram serves the unique identification of the teeth. The most common schema today is the international dentition diagram of the FDI (Federation Dentaire Internationale) dating 1970. Hereby, each tooth is given a two-digit number. The first number represents the quadrant (permanent dentition 1-4, deciduous dentition 5-8), whereby numbering begins clock-wise from the perspective of the treating dentist from top left to the bottom left. The second digit (1-8) represents the tooth, whereby numbering takes place from mesial to distal.
cervical	Of or related to the (dental) cervix, or neck.

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