Original Article

Computational Formulation of Orthodontic Tooth-Extraction Decisions

Part II: Which Tooth Should Be Extracted?

Masakazu Yagi[a]; **Hiroko Ohno**[b]; **Kenji Takada**[c]

ABSTRACT

Objective: To develop a mathematical model that simulates optimum site(s) for tooth extraction and to examine what kinds of dentoskeletal traits, in the model, influence optimizing decisions for extraction site(s).

Materials and Methods: Conventional orthodontic records were obtained for 193 women who had received orthodontic tooth-extraction treatments judged as excellent treatment outcomes. The feature vector-elements that represented dentoskeletal traits, and weights of their contributions to achieving optimum simulation in the model, were determined.

Results: The rate of coincidence between recommendations made by the optimized model and the actual judgments was found to be 86.0%. The elements that were sensitive to increasing the rate of coincidence and corresponding weights in judging the site(s) of tooth extraction were: protrusiveness of the upper and lower incisors (2.0), overjet and overbite (1.5), the membership grade for the skeletal Class II jaw relationship, molar relationship in the sagittal direction, the mandibular plane angle, and the severity of tooth crowding in the lower dentition (1.0). The remaining 10 feature vector-elements were also found to be indispensable for the model.

Conclusions: A mathematical model that simulates optimum site(s) for orthodontic tooth extraction, with a high agreement rate (86.0%) between the system's recommendations and the actual judgments given by orthodontists, was developed. The dentoskeletal structural traits that affected optimizing decisions for orthodontic tooth-extraction site(s) were formulated and subdivided into five major categories, ie, the sagittal dentoskeletal and soft tissue relationship, the vertical dentoskeletal relationship, the transverse dental relationship, the intra-arch conditions, and the pathological conditions. (*Angle Orthod.* 2009;79:892–898.)

KEY WORDS: Tooth; Extraction site; Decision-making; Mathematical model

INTRODUCTION

The decision whether or not to extract a tooth (teeth) is a key judgment in designing concrete orthodontic treatment procedures. If orthodontists judge the case as one in need of tooth extraction, they must decide which tooth should be extracted. In regard to the selection standards for tooth-extraction sites, opinions based on personal experiences of practitioners have been reported,[1–5] and treatment outcomes regarding this information have been accumulated. Today, this clinical information is taught as ‘‘standardized knowledge’’ that residents and practitioners should acquire. Because most ‘‘knowledge,’’ however, is described as fragmentary features pertinent to specific conditions on the basis of an orthodontist's personal experiences and textbook-style knowledge with ‘‘typical’’ paradigms, it is necessary to test if the ‘‘theories or doctrines’’ that stood out in this knowledge are reasonable.

To date, there has been no well-grounded standard logically robust enough for use in selecting appropriate site(s) of orthodontic tooth extraction. To formulate quantitatively the sensitivity of the aforementioned standardized knowledge and experiences shared by orthodontic practitioners for optimizing decisions for

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[a] Associate Professor, The Center for Advanced Medical Engineering and Informatics, Osaka, Japan.

[b] Clinician, Department of Orthodontics, Osaka University Dental Hospital, Osaka, Japan.

[c] Professor and Chair, Department of Orthodontics and Dentofacial Orthopedics, Graduate School of Dentistry, Osaka, Japan.

Corresponding author: Dr Kenji Takada, Osaka University, 1-8 Yamadaoka, Suita, Japan 565-0871
(e-mail: opam@dent.osaka-u.ac.jp)

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the tooth-extraction site(s) would be beneficial for both patients and orthodontists because such an effort would certainly reinforce practitioners' accountability, ie, the ability to provide patients with a rational basis of why they decide to extract teeth. It will also be helpful for practitioners, educators, and residents to comprehend objectively on what kinds of elements knowledgeable medical decision-making depends. Therefore, in Part I of the present study, we reported a mathematical model that simulates whether or not to extract a tooth (or teeth), and determined which elements were meaningful and increased the prediction accuracy of the model.[6]

The purpose of the present article is twofold: the first is to develop a mathematical model that simulates optimum sites of tooth extraction from patients' pretreatment conditions; the second is to examine what kinds of structural traits are sensitive in the model to optimizing decisions for the tooth-extraction site(s).

MATERIALS AND METHODS

One hundred ninety-three female patients (mean age: 20 years 6 months; age range: 11 years 1 month–47 years 8 months) who had visited the university dental hospital or a private office of an orthodontist (with a clinical career of more than 15 years at the university dental hospital) between 1990 and 2006, and had acquired good orthodontic treatment outcomes[7] for extraction of premolar and/or anterior teeth, were selected (according to the order of registration). Medical charts and conventional pre- and posttreatment records such as dental casts, lateral, and posteroanterior head films, panoramic radiographs, facial photographs, and intraoral photographs, were employed for each subject. Those who had the following conditions, in addition to the conditions described in Part I, were excluded:

- —Agreement regarding non-extraction cases by at least two of the three orthodontists
- —Disagreement on the extraction sites among the three orthodontists

Definitions of the Sets of Tooth-Extraction Sites

The following sites were examined for each subject:

- —S_R: The site(s) actually chosen and recorded in the medical charts after extraction of the tooth/teeth was completed.
- —S_J: The set of the site(s) that were agreed upon by at least two of the three orthodontists who each have had clinical experience for more than 8 years.
- —S_{RJ}: The complex of S_R and S_J

The judges were allowed to choose a maximum three kinds of possible extraction sites for each sample. All subjects were categorized into 16 kinds of extraction sites S_R, and 35 kinds of extraction sites S_{RJ}.

Development of Simulation Models

Twenty-one feature variables employed in Part I of the present study and the additional five variables that were assumed to contribute to the orthodontists' decisions for tooth-extraction site(s) were measured on the pretreatment records (Table 1 and Figure 1). As for the five variables, ie, malpositioning and pathological conditions of each individual tooth, their scores e_i were determined according to their severity criteria given in Table 1. The evaluation value E, was computed by

$$E = \sum_{i=1}^{20} \alpha_i e_i$$

where i is an index number of tooth ($i = 1, 2, \ldots, 20$) and α_i denotes weight parameters (0.01 for the upper central incisors and the upper and lower canines, 0.1 for the upper lateral incisors and lower central and lateral incisors, and 0.9 for the upper and lower premolars). The simulation models M_R and M_{RJ}, as illustrated in Figure 2, were developed with feature-vectors composed of the variables that were heuristically selected (1000 ways) and sets of extraction site(s) S_R and S_{RJ}. The Nm (seven ways) template vectors nearest to an input feature-vector extracted from the pretreatment records were searched in the model with the weighting coefficients Ws that were determined on the basis of the expertise knowledge (8000 ways). The optimum extraction site was predicted by means of majority voting of the selected templates. In this study, a statistical modeling technique was not employed for developing the model. The present model is the solution of an optimization problem that maximizes the objective function rate of coincidence (ROC), which was defined as the rate of coincidence between the suggested extraction site(s) by the model and S_R (S_{RJ}). The ROCs were computed for all models, and the model having the highest ROC was assigned as the optimum model. The modeling technique has been described in more details in Part I of the present study.

RESULTS

The ROC of the optimized model M_{RJ} with $N_m = 5$ was 86.0%. The adopted feature vector-elements and their associated weights are shown in Table 2. The ROCs of the models with possible choices of feature elements from those adopted in the optimized model and of different conditions of weighting coefficients were compared with those of the optimized model

Table 1. Definitions of the Additional Five Variables Examined in This Study

Variable	Definition
Intra-arch condition	
MP	Malpositioning of each individual tooth. TM*i* was a mesiodistal diameter of *i*-th tooth, and d*i* was a distance between the distal anatomical contact point of the adjacent tooth positioned to the mesial of *i*-th tooth and the mesial anatomical contact point of the adjacent tooth positioned to the distal of *i*-th tooth (Figure 1).
$ei = 0$	$di > 2/3\ \mathrm{TM}i$
$ei = 1$	$di < 2/3\ \mathrm{TM}i$
Pathological conditions	
RCP	Root canal and periapical conditions
$ei = 0$	Without the history of root canal filling or the existence of the tooth apical lesions
$ei = 1$	With the history of root canal filling
$ei = 2$	With the existence of the tooth apical lesions
R	Restorations
$ei = 0$	Without a restoration
$ei = 1$	Restored with a partial veneer crown
$ei = 2$	Restored with a complete veneer crown
C	Carious condition
$ei = 0$	Without carious condition
$ei = 1$	With carious condition but judged as preservable
$ei = 2$	With carious condition and judged as nonpreservable
MF	Malformed crown and/or root
$ei = 0$	Without malformed crown and/or root
$ei = 1$	With malformed crown and/or root

(Figure 3). When equal weight was given to each feature-vector element in the model, the ROC decreased to 78.6%. When only the elements with weights of greater than 1.5 in the optimized model M_{RJ} were employed, the ROC degraded to 64.3%. However, when elements having weights of greater than 1.0 were applied to the model, it demonstrated an ROC of 82.9%. The ROC of the model M_R was 55.4% when the optimized conditions of the model M_{RJ} were applied.

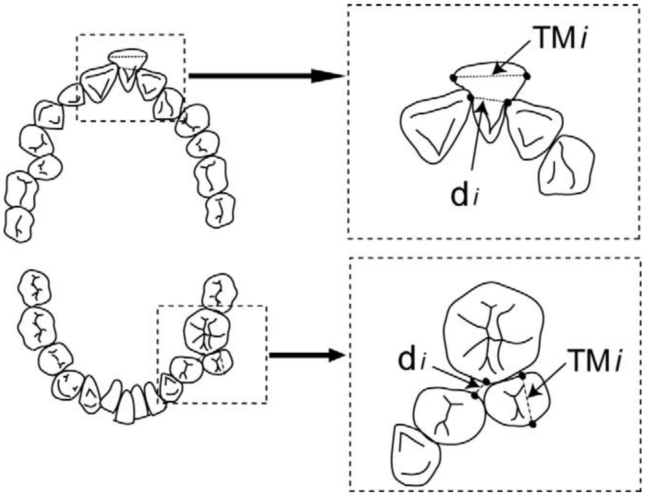

Figure 1. Illustration of the feature variable that represents the malpositioning of each individual tooth in both dental arches.

DISCUSSION

The "judgment call" a practitioner makes in deciding whether to extract a tooth/teeth or not is a combination of many elements; "external" knowledge obtained from textbooks and articles, "internal" knowledge based on experience, and "estimated" knowledge, or the practitioner's self recognition of his/her own skillfulness. However, the validity of any of this knowledge cannot be determined except in cases where practitioners themselves doubt their knowledge, or when the knowledge is exposed to external examination by a third party. Furthermore, the last category of "estimated" knowledge would be particularly difficult to validate because, since it is essentially the product of self-judgment, it is thus unlikely to come to surface at the moment of decision-making. In addition, the patients' motivations and biological responses to their treatments are elements that can only be settled after the treatment has started. Therefore, the aforementioned elements were assumed as uncertain in judging the extraction sites and ruled out in the present study, with an assumption that patients were cooperative, and significant difference in biological responses did not exist between them.

In the present study, the model M_{RJ} that performs objective simulation of the site(s) of tooth extraction was developed with the measurements of three groups: those (cases) judged as "good treatment out-

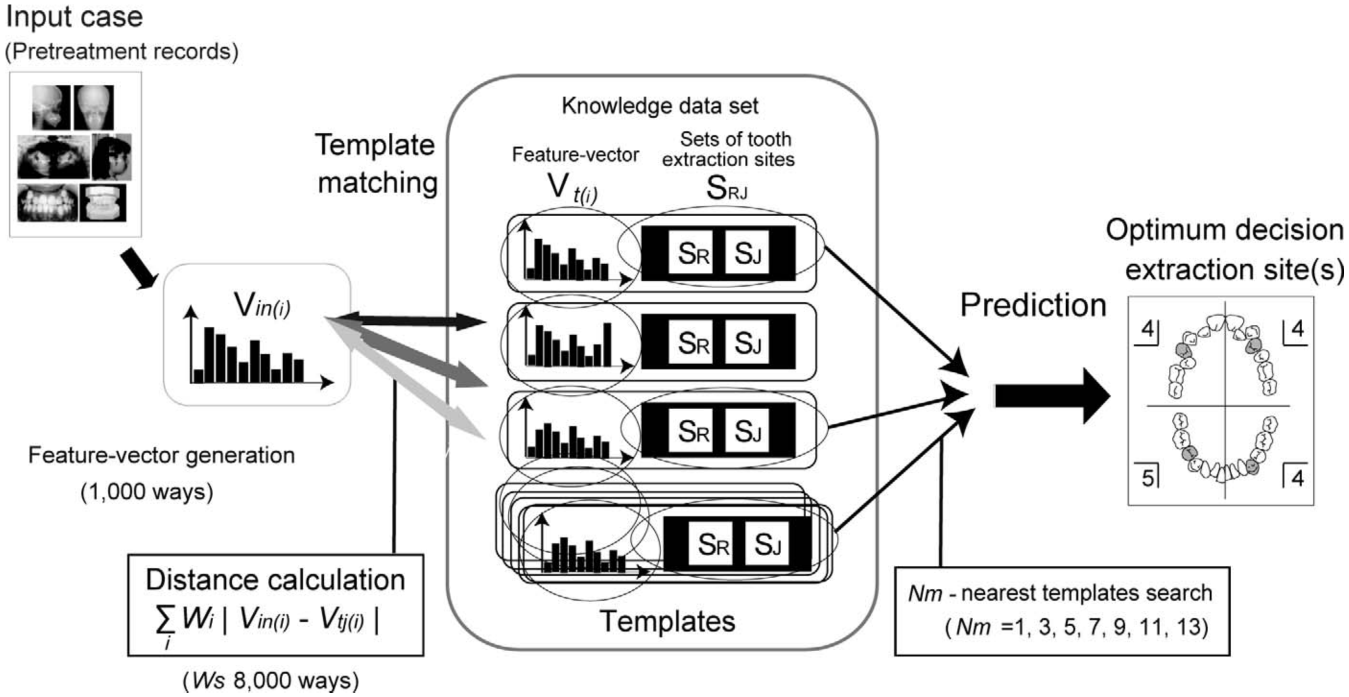

Figure 2. Development of the simulation model. The model was optimized by computing a total of 56,000,000 kinds of models.

Table 2. Feature Variables and the Associated Weights of Contributions Employed in the Optimized Model

Variable	Weight
Sagittal relationship	
1 to NA	2.0
1 to NB	2.0
OJ	1.5
Sk2	1.0
Molar-R	1.0
Molar-L	1.0
FMIA	0.25
EL-ls	0.25
EL-li	0.25
Vertical relationship	
OB	1.5
FMA	1.0
Transverse relationship	
MDL_U	0.5
MDL_L	0.5
Intra-arch conditions	
II_L	1.0
MP	0.5
II_U	0.25
Pathological conditions	
RCP	0.5
R	0.25
C	0.25

comes'' by the objective measures, those whose actual site(s) of tooth extraction were recorded in the medical charts, and those site(s) chosen independently and agreed upon by at least two of the three orthodontists as ''possible precise sites.'' The model was optimized by altering heuristically the combination of the feature variables, weights, and the template-matching parameter N_m with the success/failure of the simulation output (ROC) as an index guide. The model M_R, with the optimized conditions of the model M_{RJ}, achieved the ROC of 55.4%.

Multiple options are generally given to patients in proposing treatment plans, and there can be multiple potential sites of tooth extraction. Any of them can be regarded as ''possible precise sites of extraction,'' and the site where the tooth was actually extracted (S_R) is the one chosen by the orthodontists and their patients. Therefore, the model M_R, using the site(s) S_R as the fiducial extraction site(s), achieved a low ROC. On the other hand, the model M_{RJ} attained an ROC of 86.0% by implementing all ''possible precise sites of extraction'' in the model.

The feature vector-elements adopted in the optimized model M_{RJ} were classified into five major categories, ie, sagittal dentoskeletal and soft tissue relationship, vertical dentoskeletal relationship, transverse dental relationship, intra-arch conditions, and pathological conditions.

It was found that possible contribution/noncontribution of the elements in improving facial profiles was

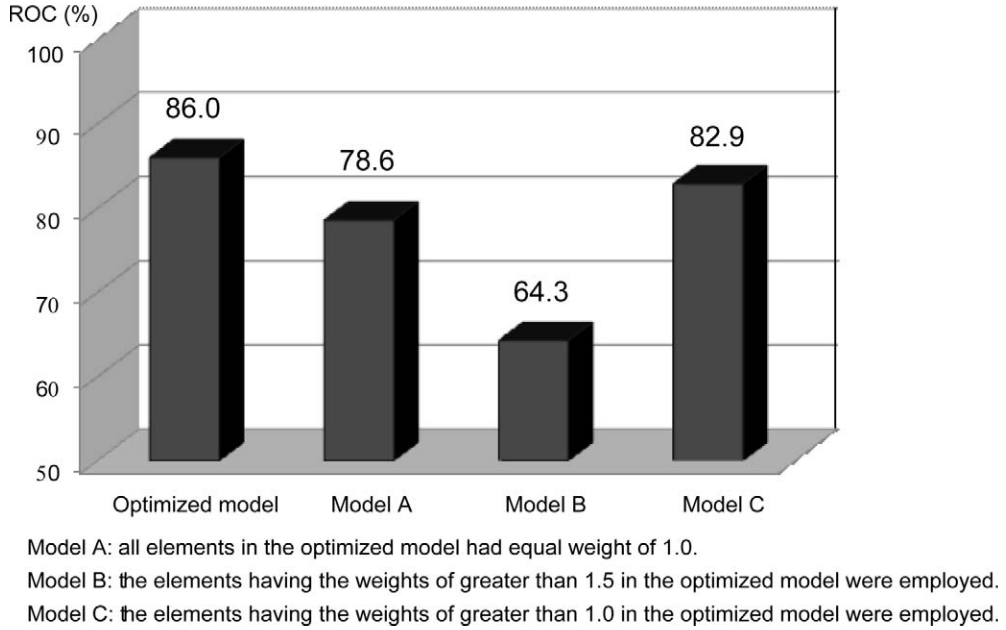

Figure 3. Comparison of simulation results between the models with possible choices of feature elements from those adopted in the optimized model and of different conditions of weighting coefficients.

considered most important in choosing the optimum extraction sites, with a particular concern for the proclination of the upper and lower central incisors (2.0) and the overjet (1.5). This agrees with the views provided by Nance[1] and Carey,[8] who claimed that in cases of severe bimaxillary protrusion with prominent tip-out of the upper incisors, extraction of the first premolars should be considered foremost, whereas in patients whose sagittal position of the incisors should not be altered, no extraction of teeth or extraction of the second premolars should be considered. We adopted the variables that represented the degree of lip protrusion because of its significance in making a proper diagnosis and treatment plan,[9] and a recent report has documented a positive correlation between tooth extraction and improvement.[10] Taking these reports into consideration, the degree of lip protrusion is not the sole determinant of tooth-extraction site(s), but rather seems to be an element that contributes to our decision of whether or not to extract teeth. The decision was also found to be sensitive to the membership grade for representing the skeletal Class II jaw relationship, with a weight of 1.0. This agrees with a previous report[11] that documented the necessity of extracting the upper first premolars alone, or the combined extraction of the upper first premolars and the lower second premolars for camouflage treatment of patients having a skeletal Class II jaw relationship.

The second category of elements that was found to be important was the vertical dimension that included the overbite (1.5) and the mandibular plane angle (1.0). This may reflect and parallel practitioners' attitudes in determining the ease or difficulty of the vertical control of occlusion when deciding tooth-extraction site(s) for possible best treatment outcome. It is generally accepted that tooth extractions cause an increase in overbite.[1] Thus, practitioners hesitate to extract teeth in patients with a deep overbite, whereas in cases showing a reduced overbite, it encourages them to increase or at least maintain the overbite, considering the extraction's side effect as good for the treatment.

Excessive midline deviations, particularly in the maxillary dental arch, cannot only be a cause of esthetic problems, but also a factor that disturbs orthodontic reconstruction of tight intercuspation of teeth bilaterally. The present results also elucidate that the variables featuring dental problems in the horizontal plane contribute to experts' decision-makings for tooth-extraction site(s). They thus give a rational basis to the views[12] that recommend the tooth-extraction in a more anterior position on the non-deviated side in one dental arch, or both dental arches on the same side, to correct the deviated dental midline.

There is also a noteworthy fourth category regarding the malpositioning of the teeth in the dental arch that was composed of: the severity of tooth crowding in the lower dentition (1.0), the degree of malpositioning of each individual tooth in both dental arches (0.5), and the severity of tooth crowding in the upper dentition (0.25). A previous study[13] has claimed that the criteria for dentists to follow when judging whether or not to extract a tooth/teeth is as follows, in order of priority: tooth crowding, the incisor convexity, facial proportion, improvement of skeletal Class II jaw relationship, and achievement of occlusal stability. The severity of tooth crowding in the upper dental arches and the severity in the lower dental arches were found to be important vector elements having weights of 1.5 and 1.1 in deciding whether or not to extract in our previous study (See Part I). It would be true to state that tooth crowding is fairly visible, and extraction may likely be a simple possible solution for orthodontic experts when they are exposed to the problem, setting aside the magnitude of the sacrifice. In contrast, what orthodontists should do first in solving the problem, namely, choosing the extraction site(s), is to consider treatment a procedure and technique that will be necessary to solve the specific orthodontic problem that lies before the practitioners; this leads to reasonable selection of the proper extraction site(s). The weight for the severity of tooth crowding in the lower dentition was greater than that of the upper dentition, and this result came in contrast to that of Part I. Because the mandible has more severe anatomic constraints on the direction of tooth movements than the maxilla, tooth extraction sites in the lower dental arch significantly influence the degree of difficulty in orthodontic treatment. To achieve improvement of facial esthetics and to establish tight interdigitation of teeth by positioning the upper and lower teeth accurately in space, practitioners are required to provide elaborate techniques, as well as to shorten the treatment period to a permissible extent. The elements and their weights adopted in the optimized model suggest that orthodontists give the improvement of facial proportion, and considerations on those factors for which technical control is more difficult, more priority over intra-arch dental malpositioning problems in choosing the tooth-extraction site(s).The feature variables that characterized each individual tooth malpositioning were also adopted in the model. The lateral incisors and/or second premolars are often palatally or lingually displaced. If the severity of tooth displacement is too large, the time required for realigning the displaced teeth would be prolonged to a period greater than anticipated. The probability of success for moving them to proper positions may likely be decreased, resulting in increasing the probability of extracting the malpositioned teeth. The results of the present study may validate the application of such an empirically learned clinical rule in order to achieve good treatment outcome.

In regard to the feature vector-elements that designated the pathological conditions of each individual tooth, the history of root canal filling, the existence of the tooth apical lesions, restorations, and carious teeth were employed in the model. It is given that we have cases with Class II type face and occlusions that were typically diagnosed as in need of extracting the first premolar teeth. Taking the improvement of facial esthetics into account, the atypical extraction of the second premolar teeth may often be adopted if there is evidence of the mentioned pathological condition in the second premolars, while the first premolars are in healthy condition.

The results of the present study give evidence quantitatively that the conditions of each individual tooth are the elements that influence the decision-making by experts on which tooth should be extracted; for example, teeth with malformed crowns and/or roots can often be subjected to the extraction in orthodontic treatment.[14] In the current optimized model, however, the elements that represented such features were not adopted. This is because the current sample only included three cases that showed malformation of teeth.

It would be reasonable to assume that those variables that have larger weights are the variables specialists focus on with particular concern. However, it must be stressed that the ROC of the model decreased when those elements having smaller weights were ruled out from the model. From these results, it would be inferred that orthodontists do not necessarily evaluate those major elements that exhibited greater weights alone, but rather thoroughly note the fine details of numerous structural and biological traits of the patients in deciding the extraction site(s).

In summary, the evaluation of the feature vector-elements and their weights adopted in the current optimized model clarified what kinds of biological and structural characteristics orthodontic experts focus on in deciding the optimum tooth-extraction site(s). The results of the present study provide evidence that helps orthodontists to explain the significance of the tooth-extraction site(s) for achieving desirable treatment outcomes, and to justify their judgments in choosing the extraction sites. To set up treatment plans based on objective judgment logic is equal to practitioners assuming their due responsibility to their patients, and is also highly useful for dentists and residents to comprehend objectively what feature elements human intelligence values in making decisions on choosing the proper extraction site(s).

CONCLUSIONS

- A mathematical model that simulates optimum site(s) of orthodontic tooth extraction was developed and confirmed to show a high simulation performance with a rate of coincidence of 86.0% between the system's recommendations and the actual judgments given by orthodontists.
- The feature vector-elements adopted in the optimized model M_{RJ} were subdivided into five major categories, ie, the sagittal dentoskeletal and soft tis-

sue relationship, the vertical dentoskeletal relationship, the transverse dental relationship, the intra-arch conditions, and the pathological conditions.

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