Short Communication

Automatic drawing of customized removable partial denture diagrams based on textual design for the clinical decision support system

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Abstract: Qualified diagrams of removable partial denture (RPD) designs created by dentists provide technicians with clear and dynamic information. Generating RPD design in the clinical decision support system (CDSS) can be achieved by producing the RPD design in a textual format and then transferring the design onto diagrams. The drawing of RPD diagrams automatically and efficiently for the given textual designs is still under investigation. A new workflow consisting of three major steps is developed to produce and visualize two-dimensional RPD design diagrams. Annotations and orientations of teeth are established from the base maps in the first step, and built-in rules are then incorporated to describe the variations caused by the interactions of the RPD components. Finally, the software draws each component using a series of curve functions. To validate the performance of the software, 112 RPD clinical design plans are randomly selected as inputs for the software, and the outputs are independently verified by experienced clinicians. The proposed methods are proven to be efficient and accurate and thus can be used to improve clinical quality.

Keywords; automatic visualization, clinical decision support system, computer-aided software, curve function, RPD design diagram, structure tree

Introduction

A removable partial denture (RPD) is a type of removable prosthesis that has been widely used in the past; it will gain more demand in the future as aging populations with partially edentulous conditions increase. The design of the RPD framework is challenging for most junior dentists due to the variety of patients' oral conditions and complex combination of different RPD components.

A clinical decision support model was developed for the RPD design, in which the process was separated into several stages [1]. By comparing the patient's oral conditions with those of cases in the previous research, the model generates an RPD design of the most similar case as an output in textual format. This paper achieves a visualization of the textual design and transfers the descriptive designs onto two-dimensional diagrams following the drawing rules and guidelines provided by dentists.

Current research combines RPD design with the drawing of diagrams as an integral aspect of human-computer interactions [2]. Alternatively, a two-dimensional visualization of RPD was considered by Hammond et al., who combined the visualization function and computer-aided design (CAD) of the RPD framework; the active shape model and path grammar were developed to automatically draw major connectors (Hutton TJ,

Hammond P, Davenport JC, 1999; Active shape models for customized prosthesis design. European conference on artificial intelligence, 448-452) [3]. However, the research did not mention the drawing of other components; therefore, the key issue regarding the fact that major connectors would vary within customized RPD designs was not taken into consideration. In addition, the performance of the methods was not verified for the automatic drawing of a whole RPD design.

In this paper, a workflow is proposed that comprises several novel automatic drawing methods of creating diagrams of RPDs based on textual designs (Fig. 1a). The procedure starts with a given base map, in which only two-dimensional contours of teeth are presented. An RPD class structure based on a series of rules is then set up to adjust the components of the shape. Finally, on the base maps, a set of curve functions are described to visualize individual RPD components.

Materials and Methods

To achieve the automatic visualization of the arbitrary RPD design without human intervention, several procedures will be combined and designed to work coherently (Fig. 1a). Initially, base maps will be analyzed to determine the topology and position of each tooth. The software will then tackle the interactions between the combined RPD components, according to the design descriptions, by implementing rules and an RPD class structure tree (Fig. 1b). Finally, curve functions with rules will be used to adjust and resolve the information on the base map to provide a complete RPD diagram (Fig. 1c).

Base map recognition

Base maps (Fig. 2a) are initially printed on work authorizations for RPDs. This procedure aims to identify and label the contour of each tooth and annotate the direction of each tooth as mesial, distal, buccal, or lingual [4]. Tooth contour identification determines each tooth's contour in topological graphs (Fig. 2b). By identifying the position of each tooth, each one is labeled using the Fédération Dentaire Internationale (FDI) notation system. The tooth position is captured by the centroid of its contour, which is calculated through spatial moment analysis. More specifically, the spatial moment with the order i, j is defined as

$$m_{ij} = \int_A I(x,y)x^i y^j \, dx \, dy$$

where $I(x, y)$ is the indicator function of whether vector(x, y) is occupied (in this case, whether it is within the contour). Thus,

$$\bar{x} = \frac{m_{10}}{m_{00}}, \ \bar{y} = \frac{m_{01}}{m_{00}}$$

the upper and lower arches together are regarded as an ellipse, which is divided into quarters. Each tooth is labeled with a number based on its order in the quarter. Thus, each tooth is labeled with its FDI annotation as shown in Fig. 2c.

Within one tooth, the polar coordinates $\rho(0)$, $\rho(90)$, $\rho(180)$, and $\rho(270)$ are used to depict mesial, buccal, distal, or lingual directions. The buccal point of each tooth is found in reference to the outer normal $n = (b^2 \cos \theta, a^2 \sin \theta)$ of the tooth's ellipse. The points corresponding to the full 360 degrees are interpolated using the buccal direction as a reference (Fig. 2d).

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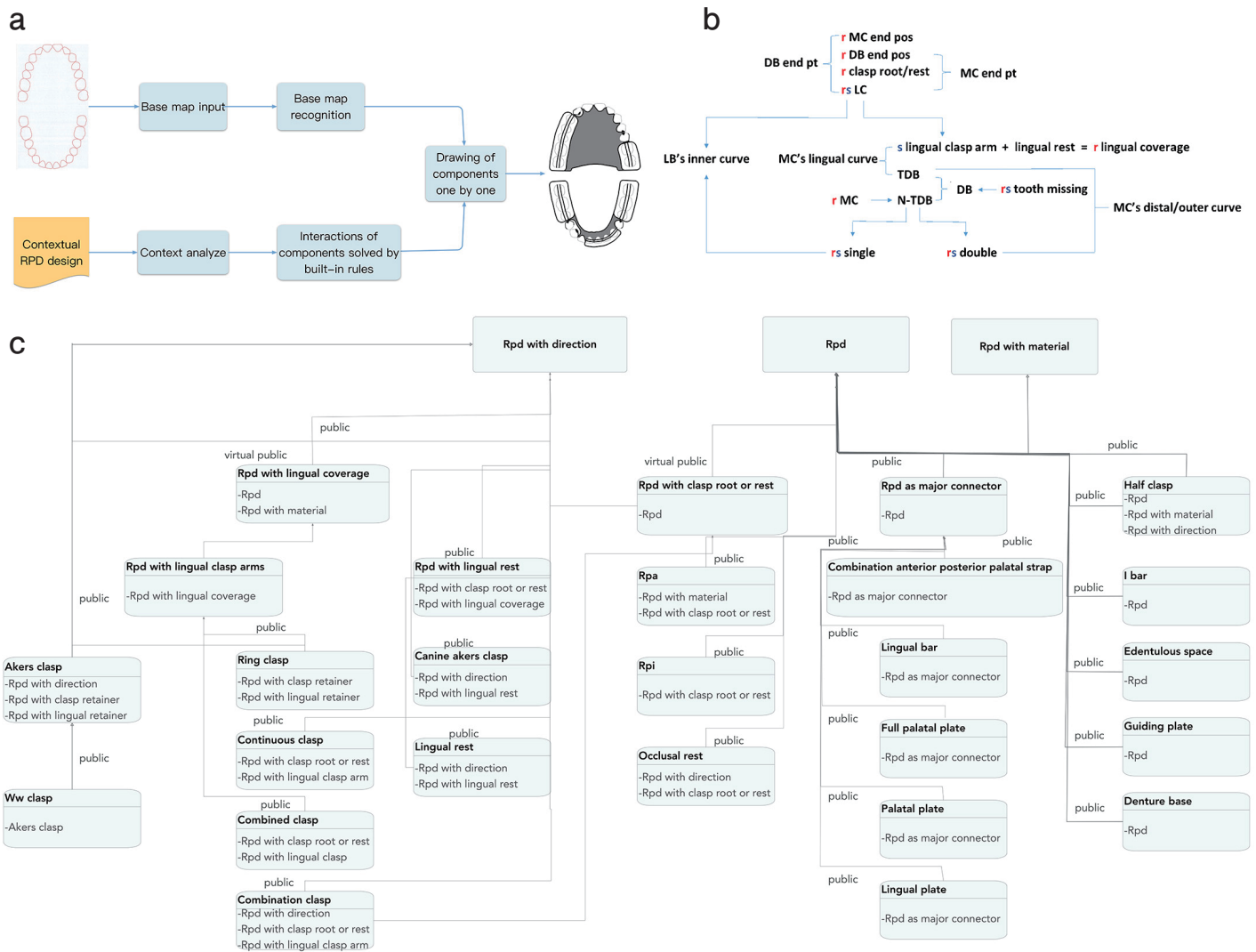Fax: 86-10-62173402 Email: kqzhouysh@hsc.pku.edu.cn

Fig. 1 (a) Workflow framework of the RPD visualization. A contextual RPD design is the input. After many analysis and calculation procedures, two-dimensional sketches are outputted and support printing. (b) Interaction relationships among different RPD components. (c) Structure tree of RPD visualization knowledge. The boxes circling with orange lines are abstract classes. Subclasses in boxes with gray lines are connected to their abstract classes.

Following these procedures, the topology, FDI annotation, and orientation of each tooth on the base maps are labeled, which facilitates production of the components at the next stage.

Textual RPD design visualization

A series of curve functions are defined to draw the curves of each component using Java language. By programing the curve functions defined above, each independent component can be drawn automatically (Fig. 2e-g).

Drawing a complete RPD diagram using software is complicated due to the variety of component interactions nearby. Rules initially concluded from the literature are organized in a chaotic manner, and require computer programing (Carr AB, Brown DT, McCracken's removable partial prosthodontics, Elsevier Health Sciences, 2015). A list of rules is summarized to delineate the interactions among components in a diagram as shown in Fig. 1b. Some objects have a red "r" to the left, which stands for "register" and means that the existence of such objects will be registered so information can be publicized. Meanwhile, the blue-arrowed lines, "object 1→object 2" indicates that the existence of object 1 will influence the state of object 2. "Tailing DB" refers to the denture base for the distal extension type. "Non-tailing DB" refers to the opposite. Likewise, an orange-arrowed line means that as object 1 is influenced, it will morph into more specific states as indicated by object 2.

To deal with these interactions and extend the rules, the RPD class and its derivatives are built (Fig. 1c). Abstract classes highlighted with an orange frame are specifically developed to handle such interaction rules.

Evaluation

Several metrics, derived from the evaluation of the software's results, were used to validate the performance of the presented software. From the clinic, 112 RPD work authorizations were randomly selected for evaluation, among which 52 designs were in the maxilla and 60 designs were in the mandible. According to the Kennedy classification, 32 designs belonged to Kennedy I, 44 belonged to Kennedy II, 28 belonged to Kennedy III, and 8 belonged to Kennedy IV. The designs were transformed into structured texts as inputted software before they were evaluated.

Two independent clinicians from the Prosthodontics Department checked the outputs of the 112 design diagrams. They investigated each component of all of the diagrams and annotated them in relation to their "correctness," "need for improvement," or "error." The criterion for "correctness" states that the diagram fits its contextual RPD design accurately. The "need for improvement" indicates that the morphology of some components is not well portrayed and modification is required. "Error" is referenced when the diagram does not fit with any aspects of its shape when its components are not correctly portrayed.

The significant differences between the precisions in the mandible and maxilla were determined using the Wilcoxon signed-rank test (SPSS Ver. 20, IBM, New York, NY, USA). The significant differences among precisions in the different Kennedy classifications were determined using the Kruskal-Wallis test.
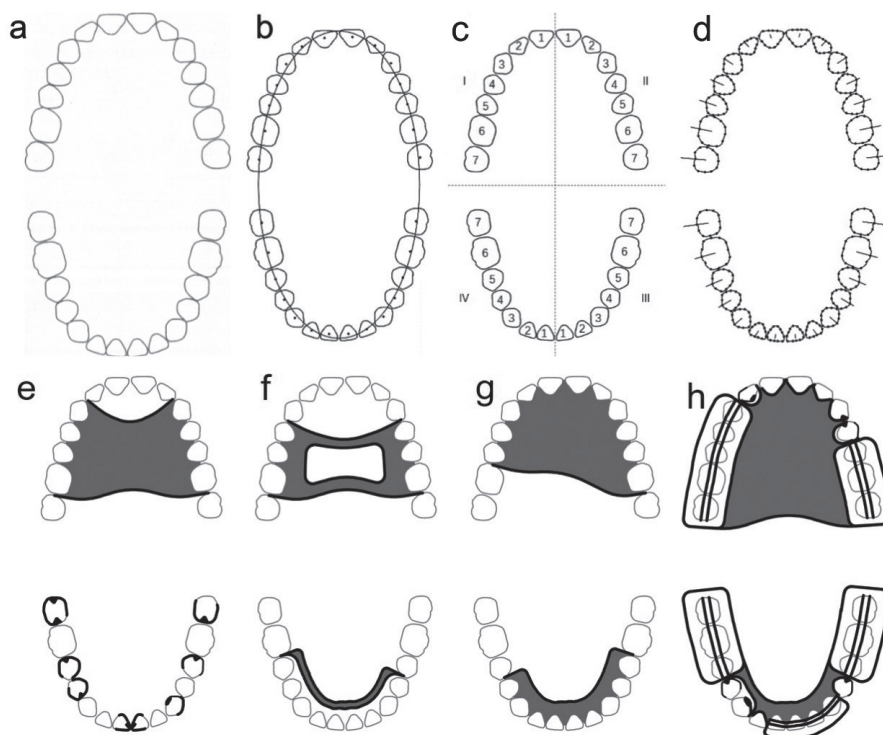
Fig. 2 (a) Base map from a work authorization; (b) topological graph recognized by computer; (c) recognized orientations of each tooth; (d) analyzed sectors and Fédération Dentaire Internationale annotations; (e)-(g) diagrams of individual RPD components drawn by programing defined curve functions; (h) final output of an example

Results

The rates of correctness, need for improvement, and error on both jaws were computed to validate the software's performance. In the maxilla, the average correctness rate was 0.75, the improvement rate was 0.23, and the error rate was 0.02. In the mandible, the average correctness rate was 1.00.

The precision value under different conditions was calculated as a measure of the software's performance, in which the value of the precision was calculated as the number of correct diagrams divided by the number of all diagrams. The average precision was 0.75 in the maxilla, 1.0 in the mandible, and 0.88 in total. According to the Kennedy classification, the precisions were 1.00, 0.87, 0.79, and 0.88, respectively, from Kennedy I to IV.

The results of the Wilcoxon signed-rank test indicated the statistically significant difference between the performance within the maxilla and mandible ($P = 0.000042$, $P < 0.05$), while the results of the Kruskal-Wallis test demonstrated that there was no statistically significant difference between the performances of the various Kennedy classifications ($P = 0.073$, $P > 0.05$).

Discussion

The software was developed to achieve an automatic visualization of an RPD design from original textual designs. Through the integration of the clinical decision support model [1], the software achieved the complete automation of an RPD design and exhibited them as diagrams. Using this system, dentists will be able to automatically provide two-dimensional (2D) RPD design diagrams. RPD diagrams can also be transformed into a structured tree format, through computer-aided design/computer-aided manufacturing (CAD/CAM) software to produce three-dimensional (3D) RPD frameworks [5]. To automatically produce diagrams that meet the requirements of all individuals under the same framework, a novel workflow was presented; this integrated the functions and rules required to create RPD diagrams. A workflow such as this, which embeds several functions and rules, can achieve the production of complete diagrams (Fig. 2h). The precisions in all of the Kennedy classifications were not statistically different, which demonstrates the efficiency of the methods. The software admits the precision of 1 in the mandible as demonstrated by the two independent clinicians. The precision in the maxilla is lower compared to the mandible at 0.75. Most underqualified diagrams in the maxilla come from the poor boundaries and shapes of the major maxillary connectors. This is mainly because the coding of the irregular curves is challenging, especially when they are asymmetrical. The boundaries of the major maxillary connectors that can be adapted with the change in the RPD design usually appear to be irregular and asymmetrical.

The software realizes the precise automatic visualization of the RPD design. As a subsequent CDSS, the software can express dentists' RPD design in a standard format and is able to deliver this information to technicians clearly.

Conflict of interest
None.

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