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(71) Demandeur/Applicant:
DENTALMATIC TECHNOLOGIES INC., CA

(72) Inventeurs/Inventors:
ARAJ, NAOUM, CA;
BRETON, PIERRE, CA;
CHAOUKI, JAMAL, CA;
JELONEK, THOMAS, CA;
PEROT, JEAN-MARC, FR;
MOSKOVAKIS, HERVE, FR;
...

(74) Agent: GOUDREAU GAGE DUBUC

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(57) Abrégé/Abstract:
A method to model teeth, prosthesis and dental material, a method to design dental restorations with predetermined aesthetic qualities, a method to realize aesthetic prosthesis, and a method to communicate information related to dentistry are described herein.

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(72) **Inventeurs(suite)/Inventors(continued)**: SAINT-PIERRE, RENE, CA; TREMBLAY, PIERRE-JULES, CA; WHAITE, PETER, CA

ABSTRACT OF THE DISCLOSURE

A method to model teeth, prosthesis and dental material, a method to design dental restorations with predetermined aesthetic qualities, a method to realize aesthetic prosthesis, and a method to communicate information related to dentistry are described herein.

TITLE OF THE INVENTION

METHODS FOR DENTAL RESTORATION

FIELD OF THE INVENTION

The present invention relates to dentistry. More specifically, the present invention is concerned with dental restoration and prosthesis.

BACKGROUND OF THE INVENTION

Dental material manufacturers often provide guidance to use their different products to achieve dental restorations of a given appearance. However, this guidance is often limited to theoretical cases with a prescribed appearance matching a finite number of shade guide tab. The main problem is that natural teeth never perfectly match the shade tabs and translucency is not usually taken into account.

Furthermore, the recipes provided assume that there is a given constant thickness available to layer the different dental material to achieve the desired result. The problem is that this is often not the case.

The basic laws of physics modelling the interaction of light with matter, including the diffusion of light in translucent material, are well known and documented in literature. In particular, the Kubelka-Munk model has already been suggested for the use of uniformly layered

porcelain. One of the key challenge is the inverse problem, that is, given a desired appearance for teeth, how can one recreate it.

Another problem is in the current commercially available cosmetic software packages that use images of smiling face as input and modify these images with standard photo manipulation tools. The dentists use before and after images to sell dental procedures to patients. In this case, there is unfortunately no correspondence between software tools and the dental procedures available. The dental procedure may yield results that are not satisfactory to the patient because of the representation made with the cosmetic software.

Also, whereas United States Patents Nos 4,611,288, 4,663,720, 4,742,464, 4,952,149, 5,092,022 and 5,237,998 describe devices and methods that measure the shape of teeth and realize dental prosthesis, it is preferable to acquire more information to achieve aesthetic prosthesis. The information needed is the appearance of the desired prosthesis.

An aesthetic smile is based on notion of morphology, symmetry, matched color and translucency, and natural look. There exist various commercially available cosmetic software packages that provide means to modify the shape and alter the color of the teeth. However, no known software is based on precise quantitative data on shape and appearance.

DESCRIPTION OF THE PREFERRED EMBODIMENT

According to a first aspect of the present invention, there is provided a method to model teeth, prosthesis and dental material, a Computer Assisted Design (CAD) system and a database for the different families of teeth and or prosthesis.

The database and CAD system provide the geometrical data that constrain the finishing step in the fabrication of dental prosthesis such as the thickness of the porcelain layer. The final prosthetic work, which is usually done by a dental technician, also has inherent constraints that must be taken into account in providing recipes to achieve a desired appearance.

The interaction of light with the teeth, prosthesis and dental materials is advantageously modeled based on known physical laws and measurements of material properties such as, but not limited to, absorption, transmittance, diffusion, reflection, refraction.

The method is advantageously a knowledge-based system that includes:

- The art of reproducing the desired appearance as described by one or more expert dental technician;
- A basic model of interaction of light with the teeth, prosthesis and dental materials along with specification of dental material properties; and

- The cumulative data of experiments consisting of fabricating prosthesis according, for example, to a given recipe and measuring their appearance.

The method uses the desired appearance as input; the system assumes standard shape constraints. The method can also use the shape constraints provided by a CAD system as input.

The method provides as a result a recipe that is consistent with the art of reproducing the desired appearance. For example, the recipe will state that given a substructure made of a given material, an opaque layer of a given masking paint must first be applied then different given porcelain opaque dentin, dentin and enamel powders should be layered according a given mapping and fired with a given firing sequence and instructions.

The previous method can serve as input to a machine that automatically places the selected dental material at a given position to build prosthesis. The art of reproducing the desired appearance is made to also encompass the machine capacity and constraints.

The previous method can also serve to select and position a block of a given dental material for a milling machine, such as the *PRO 50*™ system from *CYNOVAD* ™, producing prosthesis and or substructures. The block of given material may be selected from sets of blocks of different dental materials of uniform appearance and/or of varying color and/or translucency.

Such a machine could be made for example with the plasma fusion of chosen dental material and projected on the prosthesis' substructures and or molds. Other technology can also be used without departing from the spirit of the present invention.

According to a second aspect of the present invention, there is provided a method to design dental restorations with predetermined aesthetic qualities.

To achieve high quality restorations, the method according to the second aspect of the present invention concerns a cosmetic software that emulates dental procedures and predicts most likely outcomes and standard deviations based on precise quantitative measurements on the teeth's appearance, two-dimensional shapes and preferably also their three-dimensional shapes.

The cosmetic software uses models of the different dental procedures and accounts for their respective constraints, both mechanical and optical. A probabilistic model may also be used for procedures involving uncertainties with respect to their outcome.

The computer-aided design of prosthesis will involve endeavouring a harmonious match with adjacent teeth; propose if appropriate morphology and symmetry with respect to the central axis, interpolate between colours of neighbouring teeth, match the translucency pattern.

The models of the different dental procedures are evolved from the basic models of teeth, prosthesis and dental materials. The actual clinical dental procedures are monitored with before and after quantitative measurements of shape and or appearance. To build a reliable database, this is preferably done at many different beta sites with numerous patients. When appropriate, these measurements are also made during procedures or after some time after the procedures. The range of possibility is thus defined. The knowledge-based system also evolves with the addition of new dental procedures and or of new dental materials and or of an expanded knowledge base of experiments.

E.g. Tooth whitening with a given company's product applied according to specification: the appearance and the shape of the tooth is measured before and after each application and subsequently at each visit by the patient.

According to a third aspect of the present invention, there is provided a method to realize aesthetic prosthesis.

Generally stated, the method comprises following steps:

1. Acquiring quantitative data on both shape and appearance;
2. Processing this information to determine the desired result;

3. Further processing this information to design how to achieve the desired result;

4. Manufacturing the underlying structure or the tools required to prepare the underlying structure if needed; and

5. Finalizing the prosthetic work.

Each of these steps will now be described in more detail.

In Step 1, quantitative data on both shape and appearance are advantageously acquired by:

- Combining the digital measurements of the appearance of the teeth, such as those obtained by devices and methods described in United States Patent No 6,008,905, and the digital measurements of the shape of teeth, such as those obtained by devices and methods described in United States Patents Nos 4,611,288, 4,663,720, 4,742,464, 4,952,149, 5,092,022 and 5,237,998; It is to be noted that other devices may also be used without departing from the spirit and nature of the present invention; and

- Communicating this information through Internet, or another network, to a design center node. The information can be transferred by any other means digital data are usually transferred, such as, but not limited to direct modem line, solid-state, optical and or

magnetic devices such as diskettes, CD-ROM, DVD, Zip drive and flash card. The information on appearance and shape can be acquired by different individuals and sent separately to the cosmetic center node (e.g. dentist acquire and communicate digital data on the appearance; dental technician acquire and communicate digital data on the shape).

In step 2, the processing of this information to determine the desired result may be achieved by:

- An expert, or alternatively a knowledge-based system, using computer-aided design tools to define the best shape and appearance for the prosthesis. Whereas the computer-aided manufacturing requires 3D shape data, the design can be limited to appearance and 2D shape data if fabrication is done with the traditional artisan techniques. Furthermore, the task of designing the desired morphology and or shape and the task of designing the desired appearance can be done separately. However, it is preferable that the shape and appearance design be done in a coordinated fashion to take into account of the constraint due to the available dental material; and

- Communicating this desired result to a calculation center node.

The processing of this information to design how to achieve the desired result (step 3) is advantageously achieved by:

- An expert, or alternatively a knowledge-based system, using computer-aided manufacturing tools to define the best process to manufacture the prosthesis and or the underlying structure and or finishing requirements; and

- Communicating the manufacturing process instructions to a production center node.

In step 4, manufacturing the underlying structure or the tools required to prepare the underlying structure is advantageously achieved by:

- People and machine executing said manufacturing process instructions. Manufacturing process can be, but are not limited to, machine milling and or rapid prototyping and or deposition on model; and
- Communicating the finishing process instructions to a dental laboratory node.

In step 5, the prosthetic work is finalized by advantageously:

- People and machine executing said finishing process instructions. Finishing process can be, but are not

limited to, polishing and etching substructures, masking, layering porcelains, ceramics, resins and or composites dental material and or firing, hardening.

A method that consists of the following steps allows to outsource task to achieve aesthetic dental prosthesis:

1. Dentists initiating dental procedures that require the restoration or cosmetic alteration of the teeth;

2. Design centers processing the shape and or appearance information to determine the desired result;

3. Calculation centers processing this information to design how to achieve the desired result;

4. Manufacturing centers executing instruction to produce the underlying structure if needed;

5. Dental laboratory centers finalizing the prosthetic work; and

6. Dentists completing dental procedures.

Each of these general steps will now be described in further detail.

In step 1, a dentists

- make imprints of patient's teeth; or
- use sensors to acquire digital shape information of patients' teeth directly in patients' mouth; or
- make imprints of patient's teeth and models to register the shape of teeth; or
- use sensors to acquire digital shape information of patients' teeth from imprints and or models; and/or
- use sensors to acquire digital appearance information of patients' teeth directly in patients' mouth.

Dentists communicate digital information of appearance and or shape through Internet or modem line or other means of transmitting digital data to design centers along with complementary information to document cases and or for transactional need. If needed dentists send imprints or models to design centers.

In step 2, design centers

- make models from imprints, if needed;
- use sensors to acquire digital shape information of

patients' teeth from imprints and or models, if needed;

- use sensors to acquire digital appearance information of patients' teeth directly in patients' mouth, if needed;

- process this information to determine the desired results.

Design centers communicate desired results through Internet or modem line or other means of transmitting digital data to calculation centers along with complementary information to document cases and or for transactional need.

In step 3, calculation centers process this information to design how to achieve desired results and communicate how to achieve desired results through Internet or modem line or other means of transmitting digital data to manufacturing centers along with complementary information to document cases and or for transactional need.

In step 4, manufacturing centers execute instructions to achieve desired results and send product to dental laboratory center.

Manufacturing centers communicate remaining instructions, if any, to achieve desired results through Internet or modem line or other means of transmitting digital data to manufacturing centers along with complementary information to document cases and or for transactional need.

Step 5 consists in a skilled technician in the dental laboratory centers executing final instructions to achieve desired results and or complete the prosthetic work, performing quality assurance procedure, sending final product to dentists, and communicating quality assurance data, if desired, to achieve desired results through Internet or modem line or other means of transmitting digital data to dentists along with complementary information to document cases and or for transactional need.

Finally, dentists complete the dental procedures (step 6).

It is to be noted that, all communications between dentists, design centers, calculation centers, manufacturing centers and dental laboratory centers are preferably made via communication centers where the processes can be monitored and status reported to interested parties.

Also, the communication centers are configured to select the best process center to distribute work given geographical constraints, resources availability and current workload.

The communication centers acquire knowledge on processes and use this technical and transactional knowledge to optimize the processes, including among others technical and material improvements.

Both design centers and manufacturing centers can be also

installed at dental laboratories and or dental offices. Dental technicians are the preferred users of design centers CAD software tools for most major dental restoration procedures.

The design centers and manufacturing centers can have varying facilities according to the marketing decision with respect to perceived needs (e.g. a manufacturing unit for ceramic inlays such as the *CEREC*™ system from *SIRONA* can be installed in a dental office; a manufacturing center can be specialized only in precious alloys).

According to a final aspect of the present invention, there is provided a method of communicating information related to dentistry and prosthesis.

More specifically a system to Measure the Appearance of a Tooth (herein refers to as "MAT System") such as the *ShadeScan System*™ from *Cortex Machina Corporation.* can be seen, by the nature of the data that it produces, as a means of communication between dental laboratories and dentists. Application specific portals centered around such a device can control and collect : transaction information, scientific information regarding natural teeth as well as marketing information ancillary to the system.

From this perspective the e-commerce and e-products of an ASP based model revolving around a "MAT system" such the *ShadeScan System*™ may take one of the following alternative or complementary forms :

1. A Pay-Per-Use or Pay-Per-Click business model.

According to this embodiment:

(a) The practitioner takes measurements of the patients teeth using a MAT system;

(b) A software included with the system maintains an historic database of the images and/or of the appearance maps, including the number of images, produced by the MAT system or the number of uses of the system accrued by the practitioner;

(c) The number of images and/or the images are then transmitted, either from the device itself or from a computer running the MAT system software, to a central server to be collated and integrated with the accounting information of the practitioner; and

(d) The practitioner then either receives a bill or has his account directly debited.

It is to be noted that the term “practitioner” is intended here to include dentists, dental assistants, dental technicians and any users in a dental office or in a dental laboratory.

2. Knowledge Information System (KIS).

According to this embodiment, a web-site collects and analyses information of the MAT system transmitted between the dentists and dental laboratories to aid in the design and fabrication of dental prosthesis.

To achieve this, the KIS:

(a) Uses collected shade guide information to build and design the appearance properties of the materials (both ceramic and composite materials) by advantageously, but not exclusively, using:

i. The information to design the translucency scale for tooth restoration materials; and

ii. The range, distribution and granularity of colors that define the keys of the shade guide and correspondingly the appearance properties of the elements composing the material systems that correspond to the shade guide. The design of a virtual shade guide that is self adapting as more information is accumulated; and

(b) Obtains information regarding the buying practices, services offered and internal procedures of both dentists and dental laboratories. This information could in turn be marketed externally as well as having internal value, for example, to obtain information on the performance of tooth bleaching systems over time.

The KIS may also act as a clearing house where dental

laboratories who desire a complete recipe would download the case information to a portal, for example, at the end of the business day.

These requests are then entered into the clearing house where trained technicians can analyze them and determine the exact recipe to fabricate the restoration.

This information mat be verified and given an approval stamp by trained technicians before being passed back to the dental laboratory who can receive the information before the start of the next business day.

A web site may advantageously follow one of these business models and apply it to digitize three-dimensional models of teeth.

Also, an e-commerce service allowing to connect the end-user with technicians specially trained in interpreting reports produced by the MAT system, and to provide exact recipes to the client may be provided. The resulting knowledge that is accumulated may be analyzed to develop the following expert systems that are purely computer based:

1. Resin recipe expert. To provide expert software that will enable the dentist to quickly and accurately select the correct resin composite recipe for partial tooth restoration.

2. Ceramic recipe expert. To provide expert software that can advise the dental technician on the best ceramic recipe to use when

fabrication replacement teeth and crowns.

Although the present invention has been described hereinabove by way of preferred embodiments thereof, it can be modified without departing from the spirit and nature of the subject invention, as defined in the appended claims.

WHAT IS CLAIMED IS:

1. A method to model teeth, prosthesis and dental material as described in the present application.

2. A method to design dental restorations with predetermined aesthetic qualities as described in the present application.

3. A method to realize aesthetic prosthesis as described in the present application.

4. A method to communicate information related to dentistry.