Integration of digital dental casts in 3-dimensional facial photographs

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Introduction: Since 1915, various researchers have tried to make a 3-dimensional (3D) model of the complete face, with the dentition in the anatomically correct position. This was a difficult and time-consuming process. With the introduction of 3D digital imaging of the face and dental casts, researchers have regained interest in this topic. The purpose of this technical report is to present a feasibility study of the integration of a digital dental cast into a 3D facial picture.

Methods: For the integration, 3 digital data sets were constructed: a digital dental cast, a digital 3D photograph of the patient with the teeth visible, and a digital 3D photograph of the patient with the teeth in occlusion. By using a special iterated closest point algorithm, these 3 data sets were matched to place them in the correct anatomical position.

Results: After matching the 3 data sets, we obtained a 3D digital model with the dental cast visible through the transparent picture of the patient’s face. When the distance between the matched data sets was calculated, an average distance of 0.35 mm (SD, 0.32 mm) was shown. This means that matching the data sets is acceptable.

Conclusions: It seems technically possible to make a data set of a patient’s face with the dentition positioned into this 3D picture. Future research needs to establish the value of this 3D fused data set of the face and the dentition in orthodontic diagnosis and treatment planning. (Am J Orthod Dentofacial Orthop 2008;134:820-6)

Three-dimensional (3D) representation of the dentition in the face has been of interest for a long time. In 1915, Van Loon1 introduced his cubus cranioforus. In this 3D model, he placed plaster models of the dentition and the face into the anatomically correct positions for the patient. Because of the time-consuming procedure to make these models, it was not useful in the orthodontic office.

In the 1980s, 3D images of the maxillofacial region started to develop. These techniques include laser scanning,2 computed-tomography scanning (and stereolithography),3 Moiré topography,4 and stereophotogrammetry.5 All of these techniques have shortcomings.2-5 At the moment, stereophotogrammetry seems to be the most popular technique. With the introduction of the 3dMDface (3dMD LLC, Atlanta, Ga) and di3D (Dimensional Imaging, Glasgow, Scotland, United Kingdom) systems, the applicability of 3D photographs in daily practice became possible.5,6 The capture time for these images is less than 1 second, and, in contrast to conventional lateral headfilms, no radiation is involved. The limitation of stereophotogrammetry is that it captures only 1 part of the triad bone, soft tissues, and dentition.

Also, new methods for the assessment of the relationship between bone and soft tissue were studied. The search for a substitute for the original cephalogram was reported in 2 studies. Zhang et al7 compared measurements on 2-dimensional facial photographs with cephalometric measurements. They concluded that facial photography is at least as reliable as cephalometrics to study facial morphology. In spite of these findings, they stated that lateral headfilms are still necessary for good diagnostic purposes, since not all soft-tissue points are in close relationship to the hard-tissue location. In 2003, Nagasaki et al8 developed a nonradiographic cephalometric system, in which measurements are made directly on the patient’s face with a 3D digitizer. This 3D direct cephalometric system has the advantage of no radiation exposure for the patient. In the digitizing process, all landmarks needed for the cephalometric analysis should be digitized directly on the patient’s face. The software program then constructs a 3D coordinate system, with all required points in it. In this system, it is not possible to add other landmarks later.
No clinically significant differences were found between measurements on this 3D model and lateral headfilms.

To 3D photographs, a similar coordinate system can be added; it has the advantage that digital points can be added whenever the clinician wants.

With the introduction of digital dental models at the end of the 20th century, 3D digital data sets, combining the triad bone, soft tissues, and the dentition, have regained interest.9-11 Curry et al12 developed a 3D data set, combining 3D facial photographs, digital dental casts, and anteroposterior and lateral headfilms. The only disadvantage of this method is that 2 x-rays must be taken, 1 of which is not routinely taken in orthodontic patients—the anteroposterior x-ray.

If it would be possible to add the dentition to the 3D photograph, this would give a 3D data set of the patient’s face with the dentition in an anatomically correct position. This might give enough information to make lateral headfilms unnecessary for many patients.

The purpose of this technical report was to present a feasibility study of the integration of a digital dental cast into a 3D facial picture to visualize the anatomic position of the dentition in the face in 3 dimensions.

**MATERIAL AND METHODS**

For the integration, 3 digital data sets need to be constructed: a digital dental cast, a digital 3D facial photograph of the patient with the teeth visible, and a digital 3D facial photograph of the patient with the teeth in occlusion, with the soft tissues as relaxed as possible.

For the digital dental casts, impressions were made of the patient with plastic impression trays (TP Orthodontics, LaPorte, Ind) and orthodontic alginate (Cavex Orthotracer, Cavex Holland BV, Haarlem, The Netherlands). To register the relationship between the arches, a wax bite was made (Tenastyle modeling wax, Kemdent Associated Dental Products, Wiltshire, United Kingdom).

The impressions and wax bite were sent to Orthoproof (Nieuwegein, The Netherlands), where a digital dental cast was constructed. Orthoproof uses a flash computed tomography scanner (Hytec, Los Alamos, NM) to scan the impressions and wax bite. The tube voltage was constant, set at 160 kV, and the voxel resolution was 0.002 in. The scanner makes 780 slices in a rotation of 360°; this takes about 28 seconds. Image processing then takes about 20 minutes for a digital dental cast. By using specially designed software, the digital dental casts of the 2 jaws are aligned, with the wax bite as the reference. When both models are properly aligned, the wax bite is digitally removed, and the digital dental casts are sent to the orthodontist (Fig 1).

For the digital 3D pictures, a 3D stereophotogrammetrical camera setup and the software program modular system (version 1.0, 3dMDface System) were used. The camera consists of 2 pods, each containing 1 full color and 2 black-and-white cameras. Both pods are connected to a computer (Pentium 4 CPU, 3.2 GHz processor speed, 512 Mb RAM, NVIDIA GeForce fx 5500 128 Mb graphics card) with a fire wire cable. The pictures are captured by light photography, without radiation. The capture time is approximately 1.5 ms, which limits the risk of artifacts. The 6 simultaneous photographs are reconstructed into a 3D stereophotogrammetrical picture (.tsb-file). The digital 3D picture can now be viewed in the 3dMDpatient software program (version 2.0). For our study, the .tsb-file needed to be converted into an .obj-file, so that it could be imported into the Maxilim software program (version 2.0.3, Medicim NV, Mechelen, Belgium).

For matching the digital dental casts to the digital 3D picture, the anterior teeth were used as the matching surface. To see the teeth on the digital 3D picture, cheek retractors were used to pull the lips open. Then a digital 3D picture was made, by using the 3D stereophotogrammetrical camera (Fig 2).

For a good evaluation of the patient’s face, the above-mentioned picture with cheek retractors is not suitable. Therefore, a second digital 3D picture was made from the patient at rest with the teeth in occlusion (Fig 3).

To integrate the 3 models, the digital dental cast is matched to the digital 3D picture of the patient’s face...
with cheek retracters. These 2 models were imported into the Maxilim software program, which was used for matching (Fig 4, A). The matching was done with the Maxilim 3D texture matching tool. The registration process has 4 steps.

1. Initial positioning of the surfaces. To perform a correct registration of the digital dental cast and the digital 3D picture, these surfaces must be aligned. The initial alignment was performed by identifying 4 corresponding landmarks spread over the dental surface on both the digital dental cast and the digital 3D picture (Fig 4, B and C). These 4 corresponding landmarks give an initial registration of the surface. This step minimizes the need for further translation and rotation of the surfaces during the actual registration (Fig 4, D).

2. Selecting corresponding regions. To improve the accuracy of the registration, corresponding regions on both data sets were selected. For this study, only the maxillary and mandibular central and lateral incisors were selected for registration in both the digital dental cast and the digital 3D picture (Fig 4, E and F). These parts of the digital 3D picture are the most reliable regions. The lateral parts become distorted on the digital 3D picture. Including these points would reduce the accuracy of the matching procedure.

3. Registration of the digital dental cast with the digital 3D picture. After initial positioning and selecting the corresponding regions, the 3D picture of the teeth was matched with the digital dental cast by using a 3D surface matching algorithm. The algorithm used by Maxilim is based on the iterated closest point algorithm. Specific modifications of this algorithm were described by De Groeve et al (Fig 4, G).

4. Computation of the distance between the digital dental cast and the digital 3D picture. After performing the iterated closest point registration algorithm, the differences between the digital dental cast and the 3D picture were computed. This was visualized with a distance kit (Fig 4, H). In the colored bar of the distance kit, the distance between the 2 surfaces is shown. Each color represents 0.25 mm of distance between the 2 surfaces. Greens represent the distances when the digital dental cast is in front of the 3D picture—the so-called positive distances—and reds are the distances when the digital dental cast is behind the 3D picture—the so-called negative distances (ie, dark red means a distance of −2 mm between the surfaces). As can be seen in Figure 4, H, the distance between the surfaces on the matched areas was between −1 and +1 mm.

With the digital dental cast positioned into the face, we needed to project a digital 3D picture of the patient with the teeth in occlusion on the digital 3D picture of the patient with cheek retractors. This procedure was the same as the matching between the digital dental cast and the digital 3D picture of the patient with cheek retractors (Fig 5). The only difference is that the surface matching was done on the forehead instead of the teeth.
By using the Maxilim software program, it was possible to show only the digital dental cast and the digital 3D picture of the patient with the teeth in occlusion. The digital 3D picture of the patient’s face can be made transparent to see the digital dental cast in the patient’s face (Fig 6).

RESULTS
The total time for this procedure is about 15 minutes for an experienced person.

As shown in the Figures 4 and 5, good matching is possible for the 3 models. By using the mathematical environment Matlab (R2006a, Mathworks, Natick, Mass), it was possible to calculate the average distance of the 2 surfaces for the matched areas (Figs 4, E and F, and 5, E and F). For this patient, the average distance for the anterior teeth was 0.35 mm (SD, 0.32 mm). For matching the 2 digital 3D pictures, the average distance was 0.29 mm (SD, 0.21 mm).

DISCUSSION
The use of stereophotogrammetry has proven to be useful in facial and human body 3D imaging. Although the resolution is high enough for digitizing a complete face, for parts of the face (eg, the teeth), the imaging is not good enough. After matching the anterior teeth of both data sets, some great differences can be seen in the distance kit (Fig 4, H). These differences
can be ascribed to the resolution of the digital 3D pictures and the shininess of the teeth and the gingiva. When digital 3D pictures are made, a digital wire frame (Fig 7) is calculated by the computer. This wire frame consists of many polygons. From the parts of the face and teeth, which are well visible, small polygons can be constructed. From the parts that are less visible or the shiny surfaces, larger polygons are constructed, resulting in artifacts.

Fig 5. Matching procedure of the 3D pictures: A, manual alignment of the 2 models; B, placement of the landmarks on the 3D facial picture with cheek retractors; C, placement of the landmarks on the 3D facial picture of the patient at rest; D, matching the anatomic points (initial alignment); E, region for surface matching (yellow), indicated on the 3D facial picture with cheek retractors; F, region for surface matching (yellow), indicated on the 3D facial picture of the patient at rest; G, 2 models after the matching procedure; H, distance kit, indicating the difference between the 2 surfaces.
The black parts in the distance kit (Fig 4, H) are where the difference between the 2 surfaces is more than 2 mm. By using Maxilim, it was seen that, during the reconstruction of the digital 3D picture, large polygons were made, resulting in a great difference between the 2 surfaces.

When 2 surfaces were matched, the mean distance and the standard deviation between the 2 surfaces were calculated. Part of this difference can be caused by the matching error in the program. Our research group is conducting a study to evaluate the measurement error of the 3dMD camera combined with the Maxilim software program. Even if the distance between the digital 3D picture with cheek retractors and the digital dental cast is 0.35 mm, this will probably not be clinically relevant. The last step in the procedure to make the 3D digital data set is to match the digital 3D picture of the patient with the teeth in occlusion with the digital 3D picture of the patient with cheek retractors. As shown in the Figure 5, E and F, this matching is performed on the patient’s forehead. We also matched with an enlarged matching surface, including the supraorbital ridges and the upper part of the orbital rim. This matching procedure did not give better results. From this we can conclude that, for the matching procedure, an irregular surface is sufficient. The inclusion of discrete surfaces does not contribute to a better matching result.

CONCLUSIONS

It seems to be technically possible to make a 3D data set of a patient’s face, with the dentition positioned in the anatomically correct position in this 3D picture. Future research needs to establish the value of this 3D fused data set of the face and the dentition for orthodontic diagnosis and treatment planning. When this proves to be useful, this matching procedure should be automated by the software manufacturers, so that the orthodontist immediately can start analyzing the data set.

REFERENCES


