Stereophotogrammetry for Recording the Position of Multiple Implants: Technical Description

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Dental implants are one of the most widely used treatments for the rehabilitation of partially or completely edentulous areas. Achieving proper passive adjustment of the implant-supported prosthesis improves its long-term prognosis. This article discusses a new technique for digitally printing prostheses supported by multiple implants with optimum passive fit. The technique is based on a stereophotogrammetry system that captures the exact location of prosthetic implant platforms. This photogrammetry device takes 10 pictures per second with an error margin of less than 10 μm between two scanbodies and identifies the spatial position of each implant without physical contact. Three-dimensional data for each implant are registered in vector format, together with interrelated implant angles and distances. The information is then stored in an STL file. *Int J Prosthodont 2015;28:631–636. doi: 10.11607/ijp.4146*

Dental implants are one of the most widely used treatments for the rehabilitation of partially or completely edentulous areas. It is scientifically proven that achieving proper passive fit of implant-supported prostheses improves their long-term prognosis.[1-8]

The classic system for the manufacture of an implant-fixed prosthesis supported by multiple implants consists of taking impressions with impression materials and then casting the rehabilitation in plaster after registering the implant post positions from the impressions. More recently, new digital intraoral scanners have been used for impression taking and their reliability has been demonstrated in cases involving multiple implants for rehabilitating edentulous areas of limited span. However, reliability is compromised when intraoral scans are used for the prosthetic rehabilitation of a complete arch.[9-12]

Photogrammetry is another new option for direct and reliable recording of the position of intraoral implants. It registers the geometrical properties of three-dimensional (3D) objects and their interrelated spatial positions from photographic images. Its most important feature is the precision with which it measures objects and distances without contact.

Photogrammetry can be used in a range of scientific fields and techniques. It has been mainly applied to topography, but it also has plenty of nontopographic applications, including different areas of medicine, such as radiology (to improve accuracy) surgery (eg, neurosurgery, plastic surgery, sinus surgery), and rehabilitation.[13-26] The most important feature of this technique, measurement accuracy, offers great potential for improving the accuracy of implant-supported dental prostheses.

This article describes the use of a photogrammetry system to record the positions of multiple dental implants to rehabilitate patients with implant-supported fixed prostheses.

Technique

The PICcamera (PICdental) is a stereocamera that records the position of implants in the mouth by photogrammetry. It consists of two charged couple device (CCD) cameras designed and optimized for clinical use that locate the positions of the implants accurately by identifying special abutments (PICabutment, PICdental) with single encoding that screw onto the implants.

The camera has an infrared flash that illuminates the object constantly and eliminates shadows cast by ambient light. The PICcamera needs to capture 50 two-dimensional images of the hardware for each pair of implants, taking 10 extraoral images per second with an error margin of under 10 μm.[27,28] The system's software calculates average angles and distances

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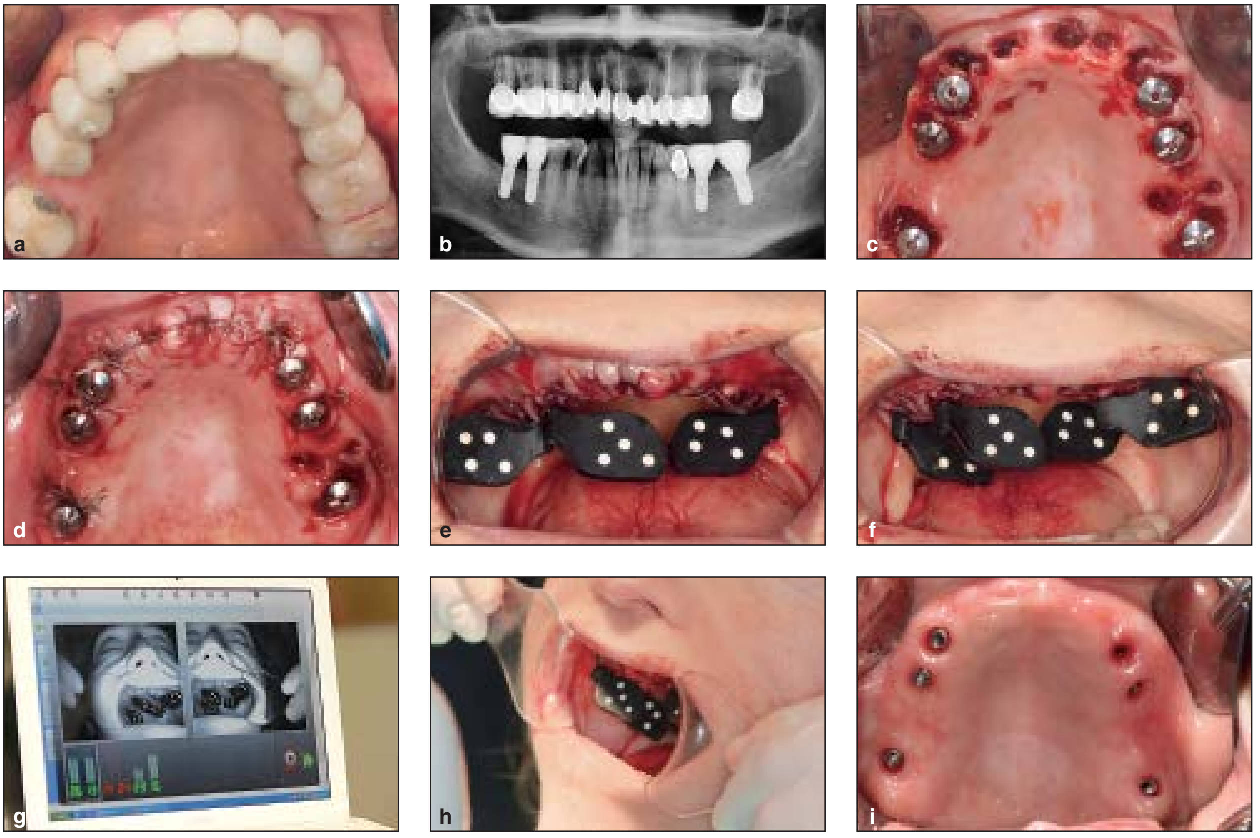


Fig 1 **(a)** Pretreatment intraoral image. **(b)** Pretreatment diagnostic orthopantomography. **(c, d)** Intraoral surgery images of implants placed in the maxilla (Mozo-Grau, Osseus, external hexagon connection). **(e, f)** PICabutments screwed onto prosthetic implant connections. **(g, h)** PICcamera photogrammetry identifies the spatial position of the implants. **(i)** Intraoral image of implants placed in maxilla 4 months after surgical intervention.

between implants, registering this data as a single unit in vector form.

The system software extracts the averages of angles and distances between each implant from these photographs, obtaining relative angle and distance between each implant position in vector form. A stereolithography (STL) file extension (PICFile, PICdental) is created that contains all the interrelated information on implant geometries, interfaces, healing abutments, and screws, for later use with CAD software.

The clinical procedure for capturing the positions of prosthetic implant platforms and designing the internal structure of the prosthesis is as follows:

Patient identification and medical history data are introduced into the system (PIC Pro Software, PICdental). The arch to be rehabilitated is registered. The area where the implants are placed is chosen. Implant positions in the arch are recorded and introduced, together with implant data (manufacturer, cast, platform diameter, and diameter and height of the healing abutments) and the scanbodies code (PICabutment, PICdental) selected for each implant (Figs 1a to 1d).

PICabutments are screwed onto the implant prosthetic platforms. These are encoded to determine the position of each (Figs 1e and 1f).

The PICcamera is located 15 to 30 cm from the patient's mouth at a maximum angle of 45 degrees to the PICabutments. It takes 50 to 60 3D photographs of each pair of PICabutments. The PICcamera is mounted on a tripod to ensure stability, and the patient's head is moved into the correct position for capturing all the PICabutments. Data registered by the PICcamera for each abutment appear on screen. When the computer is registering data, a red bar is shown, which turns green when the registration process is completed (Figs 1g and 1h). There can be no obstacles impeding the capture of scanbodies, so if the codes of all the PICabutments cannot be visualized at one time, the registration can be performed in two phases. This is usually the case when more than five implants are being registered. When the capture is done in two phases, PICabutments are first screwed to four to five anterior implants and captured. These PICabutments are then removed, leaving at least one in place. Then PICabutments are screwed to all of the remaining implants and captured. At least one PICabutment must be shared between the two captures in order to relate the direction vectors and prosthetic platform positions between the two sets of data. Each capture takes about 2 minutes.

Photogrammetry (PICcamera) identifies the spatial positions of implants (Fig 1i), without physical contact with the implants or their screw attachments. For eight implants, the system captures a total of 350 images to determine the relative position of each implant (angle and distance) in vector format. This information is recorded in the system's STL file (PICfile) (Figs 2a and 2b).

However, the PICcamera does not register the patient's peri-implant soft tissues, only the vectorial relationship between the implant prosthetic platforms. To record the patient's mucosa and relate this information with the implant vectorial registers (PICfile), healing abutments are screwed to each implant. These must be the same length to provide the software information about implant prosthetic platform depth. Then, an impression of the soft tissues is taken with irreversible hydrocolloid and a type IV stone plaster cast is fabricated, which acts as a master model.

The stone cast is digitized by an extraoral scanner to create an STL file. As an alternative to creating a master model and then scanning it with an intraoral scanner, the soft tissues and healing abutments can be scanned directly with an intraoral scanner to create an STL file.

The next step is to align and merge the PICfile and the soft tissue STL archive to create a single digital archive containing the implants' spatial positions and the peri-implant mucosa register, a process performed with Exocad software (Exocad), using three-point registration. Alignment is then enhanced using Best-fit (Figs 2c and 2d). In this way, the positions of the implants are registered in relation to

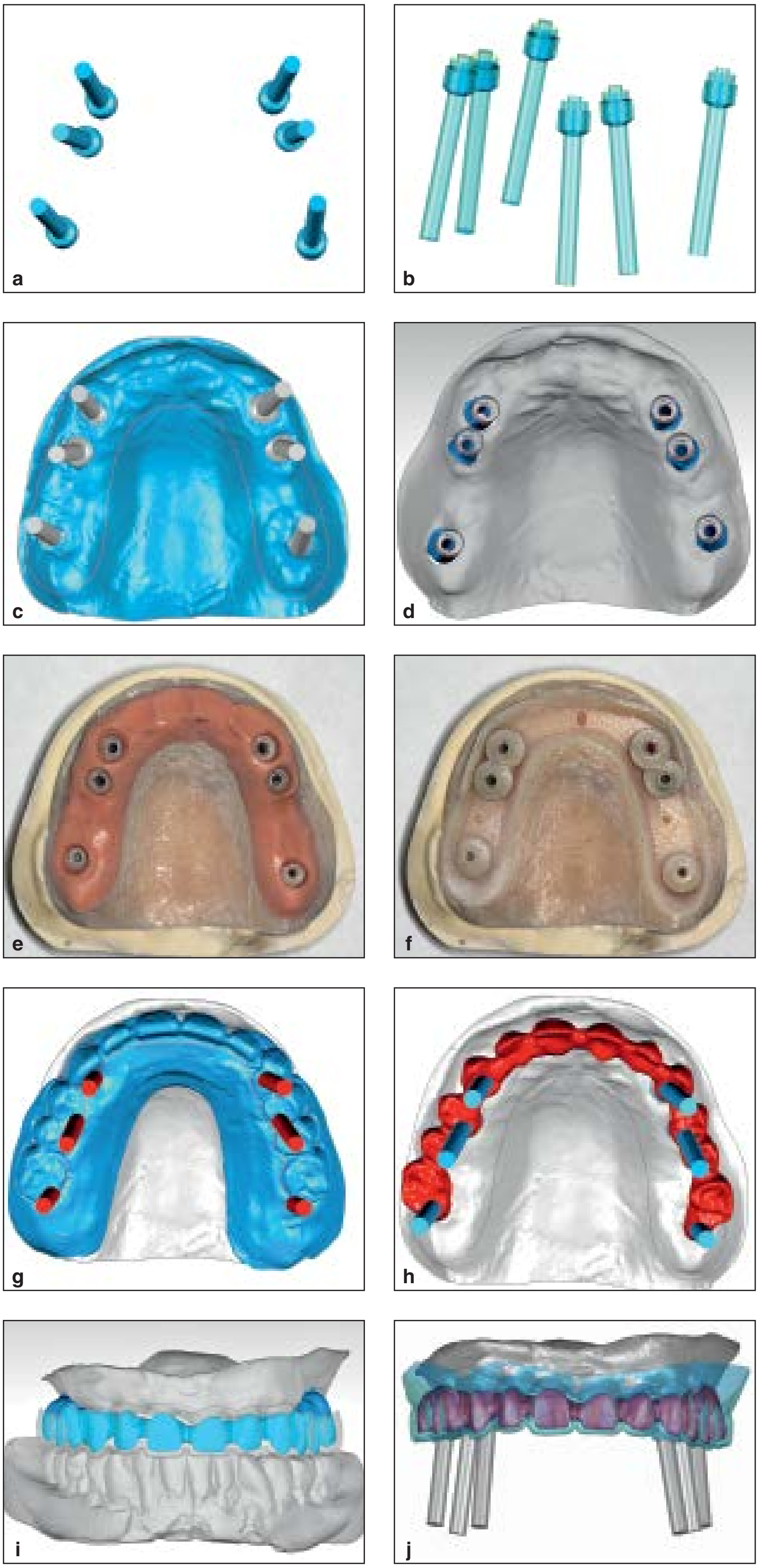


Fig 2 **(a, b)** PICfile with implant position vectors captured by photogrammetry. **(c, d)** Alignment by means of Best-fit from the PICfile vector file and digitized plaster model. **(e, f)** Stereolithography model. **(g, h, i, j)** Virtual images of diagnostic wax-up for subsequent prosthesis design.

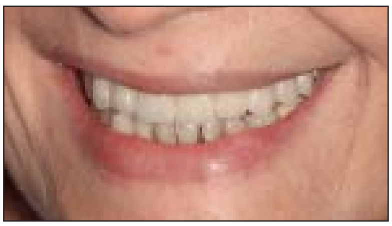


Fig 3 Rehabilitation by implant-supported prosthesis.

the digital cast of soft tissue shape to ensure a correct interface between the finished prosthesis and the patient's gums.

The cast of the antagonist arch is scanned and entered into the CAD design software. If the patient has occlusal stability, the two casts are made to occlude and scanned together to register the interdental relations. If the patient has no occlusal stability or is totally edentulous, the conventional tests (tooth test in wax) to determine vertical dimension and teeth position are performed. This test is scanned, which allows the two arches to be related in the software and the metal structures to be designed accordingly.

The working model is fabricated out of epoxy resin by stereolithography using a 3D printer (Objet 250, Eden) from the digital cast in STL format. Unlike other systems that use metal replicas, in this system the replicas that provide the volumes and specific geometries of each implant are produced within the cast and faithfully reproduce the implants' prosthetic platforms and the thread of the prosthetic screw (Figs 2e and 2f).

The prosthetic structure is designed with Exocad software in STL format (Figs 2g to 2j). After the internal structure of the prosthesis is designed, the STL file is sent to a machining center for fabrication by five-axis milling. The prosthesis can be made from titanium, cobalt chrome, or precious material (gold type IV).

Once the metal structures are fabricated, they are placed in the patient's mouth. Interarch relations are registered again using wax, and the models are remounted in a semiadjustable articulator.

Depending on the design of the prosthesis and the choice of metal for its internal structure, its outer covering material may be acrylic resin, compomer, or ceramic (Fig 3).

The Sheffield test, screw resistance test, and visual fit probe test are used to check the prosthesis's passive fit. Intraoral radiographs are made using the paralleling technique to check for correct fit between the implants' prosthetic connections and the prostheses (Figs 4a to 4d).

Lastly, any required occlusal adjustments and prosthetic finishing are carried out.

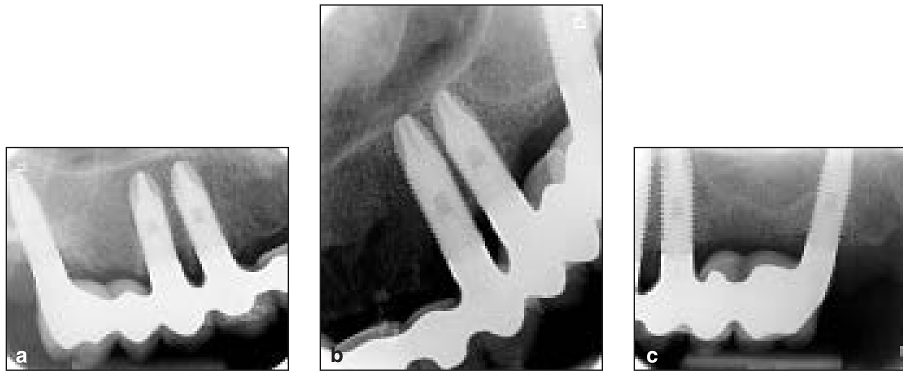
Discussion

Tension-free fit is a prerequisite for success in the medium- and long-term success of implant-supported fixed prostheses. This is only achieved when a prosthodontic treatment provides passive fit.[1,20]

In vitro studies have shown that tensions in the superstructure can cause stress and failures of implant-supported prostheses. Jemt et al[8] and Rubenstein and Ma[21] have suggested that the fit between the prosthesis and the abutment is a key parameter for avoiding high loads on the screw attachment that might lead to prosthetic failure.

Photogrammetry, the concept of "metric writing with light" (ie, obtaining reliable metric information from photographs), provides a method for transferring all the information required to fabricate a prosthesis directly from the patient's mouth to a computer file. Using more than one camera, the shape of each photographic object and its location in space are reconstructed in relation to an external system of reference points. To make the necessary calculations for reconstruction, special cameras identify this system of reference points.

Photogrammetry has been applied in different areas of medicine[13,14] and dentistry.[15–19] In the field of



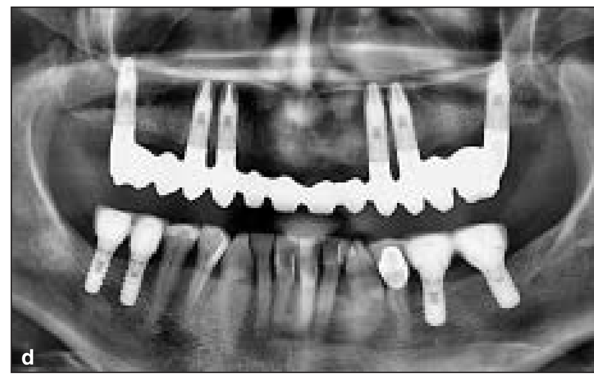


Fig 4 (a, b, c) Passive fit check-up by intraoral radiograph, **(d)** Orthopantomography of definitive rehabilitation.

implant dentistry, it has been used in in vitro studies to test the reliability of other impression techniques.[24–26] The present article describes a new system that adapts this technology to clinical use to easily and accurately register the positions of multiple dental implants.

Photogrammetry avoids the inconvenience accompanying conventional impression techniques. There is no need for impression abutments, implant body analogs, trays, and impression materials. The PICcamera measures angles and distances between prosthetic attachments placed on the implants, allowing the patient total freedom of movement. The presence of blood, saliva, or any other organic or inorganic residue does not affect measurement precision. Avoiding the use of impression materials to register implant positions potentially reduces the possibility of error due to dimensional changes of the materials. According to the authors' perception, other advantages such as reduced chairside time, reduced economic costs in the long term, and better patient comfort may be associated with the presented technique.

Photographic and video scanners share some of the advantages of photogrammetry. Scanners generate 3D images on the basis of a cloud of points that are able to reproduce surfaces. To join the points, they use an algorithm called Best-fit, which makes as many points as possible coincide. Although practical evidence is limited, theoretically these successive unions of clouds of points could cause an accumulation of error. For this reason, reliability diminishes progressively as the number of implants analyzed increases.[23] But in contrast to intraoral video and photographic scanners, photogrammetry generates direction vectors of the exact positions of the implants in relation to one another. The information that makes it possible to calculate the positions of the implants is obtained without superimposing photos, which potentially ensures greater precision and a better prosthetic fit. However, further studies (both in vitro and in vivo) with control groups are needed to evaluate potential advantages of photogrammetry compared to the other techniques available to register implant positions.

This technology has the limitation that it does not register the soft tissues. The PICfile only contains the position and angulation of the implants. This inconvenience is easily solved by scanning the patient's cast, which provides the missing information. The two sets of data (PICfile and scanned cast) are aligned by Best-fit, which allows virtual relation of the implants to the soft tissues.

The PICcamera can be used for partially edentulous cases. PICabutments are not higher than transfers used for conventional impression techniques, so this technique has no additional limitation in cases of reduced interarch distance. However, due to their flag shape, they do require a minimum horizontal dimension, so they cannot be used in interdental cases with limited mesiodistal space or when only two teeth are missing. The technique is especially indicated in extensive partial edentulism (≥ 4 teeth missing) or total edentulism.[28]

Conclusions

Photogrammetry allowed precise registration of the position and angulation of multiple implants in three dimensions, transferring all the information directly from the patient to a digital archive and eliminating the need for impression posts, implant analogs, trays, impression materials, and casting. While this technique has the limitation that it does not register the soft tissues; this can be easily solved with an irreversible hydrocolloid impression. Moreover, the abutments used required a minimum horizontal dimension, so they cannot be used in interdental cases with limited mesiodistal space.

Further studies with control groups are necessary to compare photogrammetry with the other techniques available to register implant positions.

Acknowledgments

The authors reported no conflicts of interest related to this study.

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