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In vitro accuracy of a novel registration and targeting technique for image-guided template production

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Abstract

Objectives: The objective of this study was to evaluate the accuracy of a novel registration and targeting technique for image-guided template production (IGTP) in a preliminary phantom study.

Material and methods: Registration of four standard dental stone casts with integrated target pellets to the corresponding computed tomography (CT) data was performed via a vacuum mouthpiece and an external reference frame (Medical Intelligence GmbH, Germany). Using the Treon navigation system (Medtronic Inc., Minneapolis, MN, USA) a surgical path with the entry in the centre of the dental crown and the target in the centre of the target pellet was planned on the CT data. An aiming device was adjusted according to the planned trajectory and guided drillings into the dental stone casts. The accuracy was evaluated on postoperative 3D-CT data.

Results: The mean fiducial registration error as given by the registration software was 0.4 mm. One hundred and twelve navigated drillings showed a mean accuracy [*xy*] of 0.42 $\pm$ 0.26 mm (maximum 1 mm). For the *z*-axis, a mean accuracy [*z*] of 0.25 $\pm$ 0.12 mm (maximum 0.6 mm) was found.

Conclusions: Comparing the presented registration technique to existing registration methods in IGTP and burr tracking, no radiographic and registration templates are needed. The procedure is easy and requires only minimal effort. Navigation-controlled drillings could be performed with an accuracy that approaches the intrinsic navigation system's accuracy, a fact that warrants its use for surgical template production. Further accuracy studies of template-guided drillings are necessary before the presented registration technique can be implemented for patient treatment.

Successful oral implant treatment consists of proper osseointegration, as well as optimal positioning of the implants for an aesthetic and functional restoration (Kopp et al. 2003). Ideal placement through meticulous preoperative planning and a well-trained surgeon warrant the establishment of favourable forces on the implants and the prosthetic components while ensuring an aesthetic outcome. To increase the predictability of success, computer-assisted techniques have been introduced. Implants are planned using 2-D reformatted computed tomography (CT) scans and 3-D surface-rendered models via computerized planning programmes (Verstreken et al. 1996; Jacobs et al. 1999; Dula et al. 2001; Ito et al. 2001). The precise transformation of the planning procedure into the operative site is executed by virtue of navigated instrument tracking (Watzinger et al. 1999; Sießegger et al. 2001; Ewers et al. 2004) or

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image-guided template production (IGTP) (Klein & Abrams 2001; Fortin et al. 2002; Klein 2002; van Steenberghe et al. 2002; Tardieu et al. 2003). All image-guided techniques depend on the use of image-to-physical (IP) transformation (registration) which is defined as the determination of a one-to-one mapping between the coordinates in one space (virtual space – image data) and those in another (physical space – patient), such that points in the two spaces that correspond to the same anatomical point are linked to each other (Maurer et al. 1997). By this virtue, the virtual planning data can be transferred to the surgical site.

At the University Hospital Innsbruck, the Vogele–Bale–Hohner (VBH) vacuum mouthpiece (Medical Intelligence GmbH, Schwabmuenchen, Germany) (Fig. 1) was invented for non-invasive patient fixation, registration and point-to-point multimodal image fusion (Bale et al. 1997, 2000a; Sweeney et al. 2003). The individualized VBH-mouthpiece is attached to the upper jaw by negative pressure through an obtained vacuum area in the maxillary impression and provides submillimetric repositioning accuracy (Martin et al. 1998). Precise exchangeable markers for CT, MRI, SPECT, PET on the SIP-Lab external reference frame (Fig. 3) which is attached to the VBH-mouthpiece allow for registration of different imaging datasets to each other and image–patient registration for surgical navigation.

This technique is successfully and routinely used for diagnosis and for application in radiotherapy, ENT-, and neurosurgery (Gunkel et al. 1999; Bale et al. 2000a, 2000b).

In order to additionally use the University Hospital's stereotactic intervention – and planning equipment for image-guided oral implant surgery we adapted the above-mentioned registration technique to the requirements of IGTP. The aim of this preliminary phantom study was to evaluate the registration – and targeting accuracy of the novel method.

Material and methods

Standard dental stone casts were generated from a dental impression of a volunteer. Using a duplication form, a total of four complete sets of dental casts were fabricated. In order to get CT visible targets for the accuracy analysis, the dental casts were prepared with lead pellets (diameter 2 mm) near the apex of the hypothetical dental roots. Holes were drilled laterally into the dental casts, filled with one lead pellet per tooth and fixed with wax. The dental casts were mounted on the SAM II dental articulator system (SAM Präzisionstechnik GmbH, Munich, Germany). Guided by the articulator, a VBH-mouthpiece was fabricated with both, a maxillary and a mandibular impression (Fig. 1).

In the spiral CT Light Speed QX/i (GE Medical Systems Inc., Waukesha, WI, USA) data acquisition of the dental casts with the attached VBH-mouthpiece and the SIP-Lab reference frame with seven registration markers was obtained following clinical standard parameters for dental CT (slice thickness 1.25 mm, 120 kV, 80 mA, gantry 0°, rotation time 0.8 s, reconstruction interval 0.6 mm, algorithm bone plus). Via the hospital's own intranet the datasets were transferred to the Treon navigation system (Medtronic Inc., Minneapolis, MN, USA) in the laboratory. The navigation system consists of a transportable workstation, a high-resolution touch-screen display, the Cranial-3 surgical navigation software, an optical-based 3D localization system and various pointers and instruments.

Laboratory set-up for registration, planning and targeting

Three mechanical arms (Medical Intelligence GmbH) for fixation of the unmodified dental cast, the dynamic reference frame and the targeting device were mounted on a base plate (Fig. 3). The carbon-made base plate (40 × 30 cm) (Fig. 3, D) has multiple fixing areas to hold the mechanical arms. Each of the mechanical arms consists of three axes and six degrees of freedom and the variable position can be locked by a screw. The dynamic reference frame (Fig. 3, C) is necessary to correct for

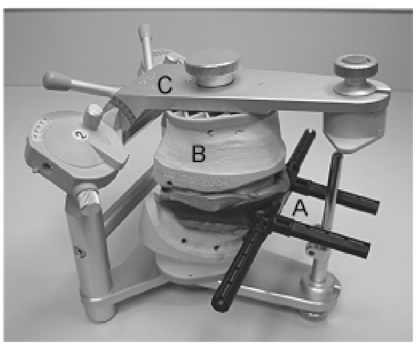

Fig. 1. Fabrication of a Vogele–Bale–Hohner mouthpiece (A) of the dental stone casts (B) with maxillary and mandibular impressions guided by the dental articulator (C).

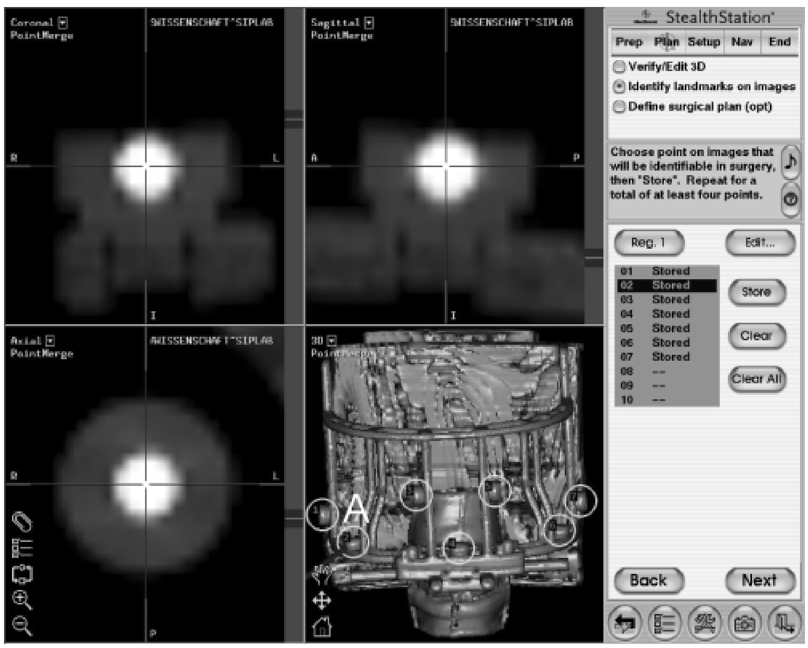

Fig. 2. Definition of the seven reference markers of the SIP-Lab reference frame (marker 2 – A) on the axial, sagittal and coronal reformatted computed tomography slices.

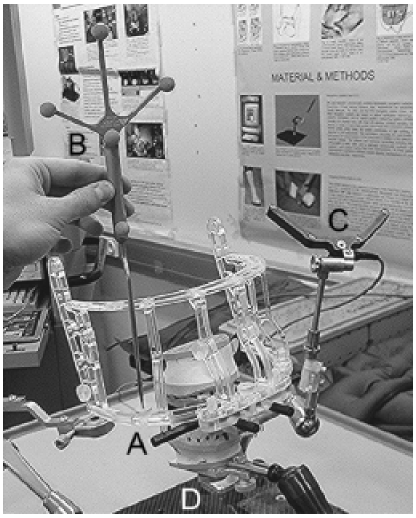

Fig. 3. Image-to-physical (IP)-transformation of the dental stone cast to the corresponding computed tomography (CT) data by touching the markers on the SIP-Lab reference frame (marker 2 – A) with the navigation probe (B). The 'virtual' registration markers on the CT data are linked to the corresponding 'real' markers on the planning set-up. Thus, a navigation space around the dental stone cast was generated which allowed for navigation. The dynamic reference frame (C) which was rigidly mounted on a mechanical arm on the base plate (D) corrected for movements of the whole planning set-up with respect to the stereotactic camera of the navigation system.

possible movements of the set-up with respect to the stereotactic camera. The first prototype of our patented EasyTaxis aiming device (Adams, L., van den Brug, P., Vogele, M., Bale, R. J., European Patent PHN 16.013/alignment device) consists of a spherical alignment body (trapped ball) that rotates freely in a bearing and can be locked by a screw (Bale et al. 2001). The alignment body contains a large central cylindrical hole to accept a tube with an incomplete inner sleeve to place the navigation probe or other tubes for the guidance of different surgical instruments (e.g. endoscope, biopsy-needles and pins) (Fig. 4, A).

For registration, the VBH-mouthpiece was attached to the fixed dental stone cast and the SIP-Lab reference frame was mounted to the mouthpiece's anterior extensions. Registration was performed by defining the registration markers on the axial, sagittal and coronal reformatted CT slices (Fig. 2) and touching the corresponding markers on the SIP-Lab external reference frame with the navigation probe (Fig. 3). By this virtue, the seven virtual registration markers on the CT data are linked to the corresponding real markers on the

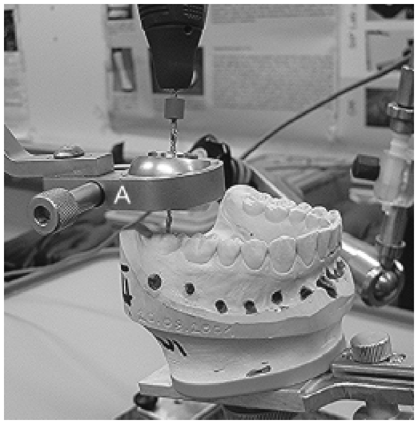

Fig. 4. Drillings to the target pellets guided by the EasyTaxis aiming device (A).

planning set-up. Thus, a navigation space around the dental stone cast was generated which allowed for navigation. The VBH-mouthpiece and the reference frame were removed after the end of the registration process. As the dynamic reference frame (which was rigidly fixed to a mounting arm on the base plate and for this reason is in constant relationship to the dental cast) corrected for movements of the whole planning set-up with respect to the camera, there was no need for a reference frame attached to the model. This approach is different to all existing registration methods.

After checking the registration accuracy by touching landmarks on the cast and comparing the real position to the virtual position on the CT data as shown by the navigation software, an entry- and a target point were defined. The centre of the dental crown was touched using the navigation probe and stored as entry point and the target point was defined in the centre of the CT visible lead pellets on the computer screen. The software calculated the 3-D location and orientation of the planned trajectory and the aiming device was manually adjusted according to the plan under control of the navigation system. The aiming device was secured when the calculated deviation of the setting to the virtual plan was ≤ 0.1 mm and the deviation of the angle of the actual probe position with respect to the planned trajectory (as given by the system) was less than 1°.

Guided by a tube in the aiming device, the dental stone casts were drilled approximately 2 mm to the centre of the target lead pellets in order to avoid displacement of the pellets (Fig. 4). This was guaranteed by using a stop. The diameter of the drill was 2 mm in order to mimic the dimensions of the pilot-drill of the surgical drill set.

Evaluation of accuracy

The drilled dental casts were scanned according to the above-mentioned protocol. On the 3D-CT data a path with its entry point in the centre of the proximal part of the drill hole and the target point in the centre of the distal part of the drill hole was determined. The 'probe's eye view' of the navigation system was used to evaluate the normal deviation of the path from the target. The 'probe's eye view' is the perpendicular plane to the path on a given point. The path was virtually elongated until the centre of the target was visible on the 'probe's eye view'. The accuracy in the *xy*-axis (= normal deviation from the virtually elongated drill hole axis) could be evaluated in this plane. This corresponds to the distance with which the drill would have passed the target (Fig. 5).

Results

The mean fiducial registration error (FRE), which is the root-mean-square-error between the seven registration markers on the SIP-Lab external reference frame as given by the navigation software, was 0.4 mm.

In order to measure the accuracy of frameless stereotactic drillings, a total of four sets of complete dental stone casts, each containing 28 drillings, were evaluated (see Table 1, Fig. 6).

All together, the 112 drillings had a mean accuracy [*xy*] of 0.42 ± 0.26 mm. The maximum deviation was 1 mm. A small learning curve was found leading from 0.43 mm in set 1 to 0.4 mm in set 4.

Evaluating the accuracy in the *z*-axis, 50 separate point measurements to a predefined target performed through the aiming device showed a mean accuracy [*z*] of 0.25 ± 0.12 mm and the maximum deviation was 0.6 mm.

Discussion

The advantage of computer-assisted interventions is based on the virtual linking of the patient's CT planning data to the

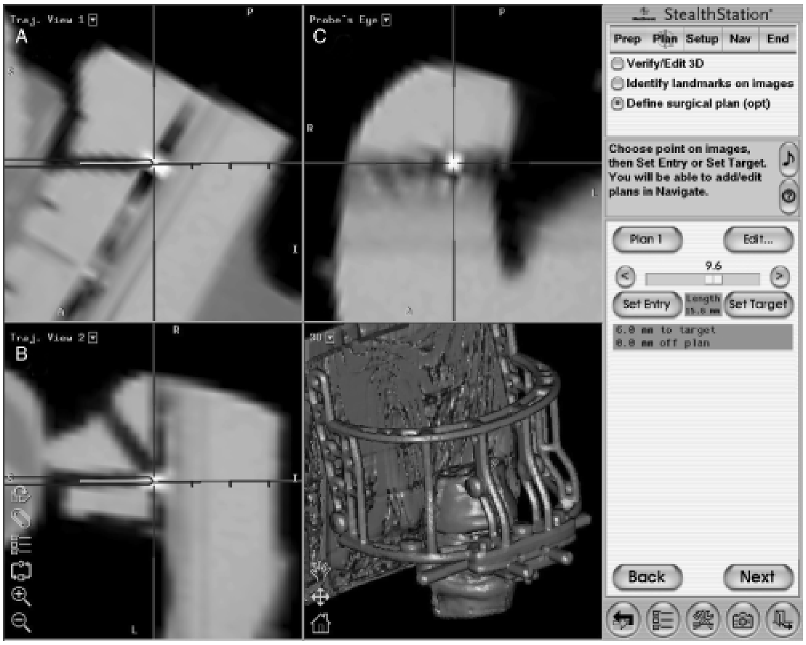

Fig. 5. Evaluation of the accuracy on the postoperative computed tomography data. A path with its entry point in the centre of the proximal part of the drill hole and the target point in the centre of the distal part of the drill hole was determined. The path was virtually elongated until the centre of the target was visible on the 'probe's eye view'. The 'probe's eye view' is the perpendicular plane to the path on a given point. There are two longitudinal views along the path (trajectory view 1 – A and 2 – B) and one perpendicular view that allow following the path by the view of the probe (C). The accuracy in the *xy*-axis (= normal deviation from the virtually elongated drill hole axis) could be evaluated in this plane. This corresponds to the distance with which the drill would have passed the target.

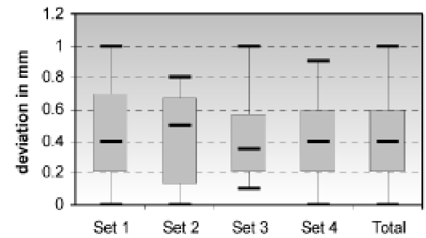

Fig. 6. Boxplots showing median, quartile and extreme values of deviations [*xy*] in the four different casts. Boxes contain 50% of all values; the horizontal line inside the boxes indicates the median, vertical lines end at the minimum and maximum values (without singular values).

real intraoperative situation. This can be achieved by registration- and navigation techniques. The accuracy of the image-to-physical (IP) transformation is therefore a critical issue in the intraoperative use of image-guided therapy.

For cranio-maxillofacial applications, classical frame-based stereotactic devices have been replaced by frameless stereotactic navigation systems (Wagner et al. 1996; Haßfeld & Muehling 2001). These systems rely on point-based IP-transformation and use anatomical landmarks (bone or skin), bone screws or skin fiducials (Alp et al. 1998).

The registration procedure involves determining the coordinates of a minimum of three non-collinear points in different images and the corresponding physical space by computing the geometrical transformation that best aligns these points minimizing fiducial localization error (FLE), which is the error in locating the fiducial points and FRE, which is the root-mean-square distance between corresponding fiducial points after registration (Fitzpatrick et al. 1998; Maurer et al. 1998). A more critical and direct error measure is the target registration error (TRE), which is the distance after registration between corresponding points not used in calculating the registration (Maurer et al. 1998; Birkfellner et al. 2001; Fitzpatrick & West 2001).

The typical feedback provided by the navigation system to the surgeon is confined to a measure of the degree of alignment of the points used in the registration. However, these measures show no correlation to the TRE (Raabe et al. 2002). Fiducial alignment alone should not be trusted as an indicator of registration success of a point-based guidance system and the real error between the image and the patient's anatomy has to be checked by independent markers or anatomical landmarks not used for initial registration.

Registration with surface-applied fiducial markers is significantly more accurate than registration with surface anatomical landmarks (Maurer et al. 1998) and the addition of surface points to the fiducial registration does not increase the registration accuracy but, interestingly decreases it (Helm & Eckel 1998).

Skin marker registration and laser surface registration (Raabe et al. 2002 Marmulla et al. 2003) are sensitive to skin shifts and different tension in muscles. Thus, these methods seem to be unsuitable for oral implant surgery, which demands the best possible accuracy.

Therefore, image-guided burr tracking is based on implanted bone markers or non-invasive reference templates to be attached to the remaining teeth (Ewers et al. 2004). Registration with three implanted fiducial markers on jaw models allows an FLE of 0.69 mm, an FRE of 0.71 mm and a TRE of 1.23 mm (Birkfellner et al. 2001). The drawback of bone fiducials is that they are invasive to the patient, can cause major patient discomfort and should not be left in place over an extended period (Bale et al. 2000a, 2000b). As an alternative, reference templates need to be rigidly fixed to the patient during CT scanning as well as during surgery.

***Table 1.* Accuracy [*xy*] of frameless stereotactic drillings (mm)**

	Set 1 ($n = 28$)	Set 2 ($n = 28$)	Set 3 ($n = 28$)	Set 4 ($n = 28$)	Total ($n = 112$)
Mean	0.43	0.43	0.41	0.4	0.42
SD	0.26	0.25	0.28	0.26	0.26
Minimum	0	0	0.1	0	0
Maximum	1	0.8	1	0.9	1

In order to track the unfixed patient in real time, a dynamic reference frame (DRF) is attached to the reference template or directly secured to the underlying bone. This allows to correct movements of the patient's jaw with respect to the camera array (Watzinger et al. 1999; Sießegger et al. 2001).

Schneider et al. (2001) presented a registration method, which is based on tooth-borne mini-plastic splints that were marked with three to five mini-titanium fiducial screws. For intraoperative registration, a modified impression tray is fixed to the maxilla and supported with a dynamic reference frame. The experimentally determined accuracy including CT data acquisition, registration process and dynamic tracking was 0.68 ± 0.63 mm. However, in extended prosthetic restorations, metallic artefacts may lead to difficulties in marker identification and IP-transformation. Additional problems and sources of error may arise by a possible instability of the system because of unnoticed loosening of the modified impression tray holding the dynamic reference frame.

In IGTP, the IP-transformation of the CT data is not directly performed in the patient but in the patient's dental cast without necessitating intraoperative registration and navigation. Building bricks, reference tubes and -pins are integrated in a radiographic template and are recognized by the software in the CT scan. The 3-D implant planning is transferred into a surgical template by a mechanical positioning device or a drilling machine executing a computerized transfer algorithm (Braun 1999; Struck et al. 2001; Fortin et al. 2002; Mueller & Dotzauer 2002; Kopp et al. 2003).

Compared to the high costs of navigation systems, positioning devices and the appropriate transfer software are less expensive. However, the handling of the registration procedure is often very complicated and time-consuming.

Another approach to IGTP is the use of computer-aided design/computer-aided manufacturing (CAD/CAM) technology to produce stereolithographic bone-, mucosa- or teeth supported surgical templates (Santler et al. 1998; Sarment et al. 2003a, 2003b; Tardieu et al. 2003). The typical accuracy of the laser-driven polymerization of liquid epoxy resin for the production of stereolithographic templates is in between 0.1 and 0.2 mm (van Steenberghe et al. 2002).

In our approach, the accuracy of patient-image-to-dental-cast registration depends on the accuracy of the mouthpiece repositioning to the corresponding jaw and dental stone casts, respectively. The vacuum objectively secures the mouthpiece against the maxilla and provides submillimetric repositioning control, which is regulated by the amount of negative pressure on the vacuum scale of the pump (Martin et al. 1998; Bale et al. 2000a; Sweeney et al. 2003). Should the required negative pressure (-0.5 atm) not be attained, the mouthpiece is not precisely repositioned.

In marker-based registration, the expected TRE is worst near the fiducials that are most closely aligned (Fitzpatrick et al. 1998). For this reason, the SIP-Lab reference frame is designed for a broad distribution of the markers around the volume of interest (the upper and lower jaw).

In addition one has to regard that the markers may get in between two CT slices and the resulting false measurements may lead to rotations of the dataset registered (Marmulla et al. 2003). The further the target is from the markers, the more this rotation reduces the precision of the computer-aided navigation. Thus, the slice thickness should be as small as possible and the makers should be big enough (sufficiently larger then a voxel) to be clearly estimated in the CT data (Maurer et al. 1997). In order to overcome this problem, the fiducials on the SIP-Lab reference frame have a diameter of 6 mm, which is well beyond the slice thickness. Furthermore, the use of multislice helical CT involves continuous patient translation during X-ray source rotation and produces a complete and homogeneous high-resolution image volume.

In fully edentulous patients, the resiliency of the oral mucosa is a critical problem, which remains a general problem for all registration techniques. In burr tracking this can be solved by using invasive markers for the prime registration procedure and by additionally using invasively secured dynamic reference frames for the dynamic tracking of the patient during the navigated surgical procedure. In IGTP, it would be necessary to fix the registration template with temporary inserted bone screws or to attach the template on at least three pre-inserted attachment implants. In our approach, we suggest to insert three small attachment pins in order to obtain a stable fixation of the VBH-mouthpiece and to use the same pins for the fixation of a later produced surgical template. As an alternative CAD/CAM stereolithography enables to produce bone-supported surgical templates.

Using the presented registration technique, no radiographic- and registration templates are required. Instead, a VBH-mouthpiece of the dental stone casts has to be fabricated in the laboratory, which takes only a few minutes. In addition, as the diagnostic wax-up can be directly used to plan the implants by touching it with the navigation probe, a radiographic template conserving the information of the prosthetic reconstruction is unnecessary.

Registration is done by simply mounting the unmodified dental cast supplied with the VBH-mouthpiece and the attached SIP-Lab reference frame on the mounting arm of the planning set-up, identifying the registration markers on the CT data and touching the markers with the navigation probe.

Compared to published registration methods in IGTP and burr tracking, the procedure is easy and requires only minimal effort which is important for a routine clinical application. Image-guided drillings could be performed with an accuracy that approaches the navigation system's technical accuracy.

As a following step, surgical templates may be fabricated by an indirect and a direct burr tube-positioning method: For the indirect method, the dental stone cast is drilled according to the predefined surgical path by the help of the aiming device of the navigation system. Metal rods have to be placed in the drill holes and used to position surgical burr tubes for the pilot drill of the surgical drill set. These burr tubes can be glued into a prefabricated template. For the direct method, the aiming device is used to guide a metal rod, which directly positions surgical burr tubes that need to be glued into the prefabricated template.

Before the clinical introduction of the novel technique further studies evaluating the accuracy of the surgical templates itself will be required. The present paper demonstrates that this registration technique is highly accurate and warrants further investigations of the novel IGTP approach.

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Disclosure: Prof. Bale is a (co)inventor of the Vogele-Bale-Hohner (VBH) mouthpiece, the SIP-Lab Innsbruck frame and the aiming device and a co-shareholder in its financial returns.

Résumé

Le but de cette étude a été d'évaluer la précision d'une nouvelle technique de ciblage et d'enregistrement pour la production d'un gabarit de guide d'image (IGTP) dans une étude fantôme préliminaire. L'enregistrement de quatre moules dentaires standards avec des pastilles de ciblage intégré aux données CT correspondantes a été effectué via une pièce buccale sous-vide et un chassis de référence externe (Medical Intelligence GmbH, Allemagne). En utilisant le système de navigation Trion (Medtronic Inc., USA) une voie chirurgicale avec l'entrée dans le centre de la couronne dentaire et la cible dans le centre de la partie cible a été planifiée sur les données CT. Un système a été ajusté suivant la trajectoire planifiée et des forages guidés dans les modèles dentaires. La précision a été évaluée sur des données CT 3D post-opératoires. L'erreur de localisation fiduciale moyenne (FLE) donnée par l'enregistrement du logiciel était de 0,4 mm. Cent douze forages par navigation ont montré une précision moyenne {xy} de 0,42 ± 0,26 mm (maximum1 mm). Pour l'axe z, une précision moyenne {z} de 0,25 ± 0,12 mm (maximum 0,6 mm) a été trouvée. En comparant la technique d'enregistrement présente aux méthodes d'enregistrement existantes dans l'IGTP et le traçage du forage, aucune radiographie, ni patron d'enregistrement ne sont nécessaires. Ce processus est simple et facile à manier. Le forage contrôlé par navigation peut être effectué avec une précision qui approche la précision intrinsèque du système de navigation, un fait qui justifie son utilisation pour la production de patrons chirurgicaux. Davantage d'études sur la précision du forage par ces patrons sont nécessaires avant que cette technique d'enregistrement ne puisse être utilisée pour le traitement des patients.

Zusammenfassung

Die in vitro Genauigkeit einer neuen Registrierungs- und Zieltechnik für die bildgesteuerte Produktion von Schablonen

Ziele: Das Ziel dieser Studie war, die Genauigkeit einer neuen Registrierungs- und Zieltechnik für die bildgesteuerte Schablonenproduktion (IGTP) in einer ersten Phantomstudie auszuwerten.
Material und Methoden: Die Registrierung von 4 Standardgipsmodellen mit integrierten Zielkügelchen für die entsprechenden CT-Daten wurde mittels eines Vakuummundstücks und eines externen Referenzrahmens durchgeführt (Medical Intelligence GmbH, Deutschland). Mit dem Treon Navigationssystem (Medtronic Inc., USA) wurde aufgrund der CT-Daten ein chirurgischer Weg mit Eingang im Zentrum der Zahnkrone und dem Ziel im Zentrum des Zielkügelchens geplant. Eine Zielvorrichtung wurde gemäss der geplanten Richtung angebracht. Damit wurden die Bohrungen in die Gipsmodelle gesteuert. Die Genauigkeit wurde mit postoperativen 3D-CT-Daten ausgewertet.
Resultate: Der mittlere Registrierungsfehler (FRE), welcher durch die Registrierungssoftware gegeben war, betrug 0.4 mm. 112 navigierte Bohrungen zeigten eine mittlere Genauigkeit (*xy*) von 0.42 ± 0.26 mm (Maximum 1 mm). Für die *z*-Achse wurde eine mittlere Genauigkeit (*z*) von 0.25 ± 0.12 mm (Maximum 0.6 mm) gefunden.
Schlussfolgerungen: Bei der vorgestellten Registrierungstechnik werden im Gegensatz zu existierenden Methoden zur IGTP und intraoperativen Navigation keine Schablonen zur radiologischen Abklärung und zur Registrierung benötigt. Das Vorgehen ist einfach und erfordert nur minimalen Aufwand. Durch Navigation gesteuerte Bohrungen konnten mit einer Genauigkeit durchgeführt werden, welche der Genauigkeit von technischen Navigationssystemen nahe kommt. Diese Tatsache ermöglicht die Verwendung des Systems zur Produktion von chirurgischen Schablonen. Weitere Genauigkeitsstudien der schablonengesteuerten Bohrungen sind nötig, bevor die vorgestellte Registrierungstechnik für die Behandlung von Patienten eingesetzt werden kann.

Resumen

Objetivos: El objetivo de este estudio fue evaluar la exactitud de una nueva técnica de registro y colocación para producción de plantilla guiada por imagen (IGTP) en un estudio preliminar de fantomas.
Material y métodos: Se llevó a cabo el registro de 4 vaciados dentales de piedra con bolitas diana integradas con los correspondientes datos de CT por medio de una pieza de boca al vacío y un marco externo de referencia. (Medical intelligence GMBH, Alemania). Usando un sistema de navegación Treon (Medtronic Inc., USA), se planeó sobre los datos CT una vía quirúrgica con entrada en el centro de la corona dentaria y objetivo en el centro de las bolitas diana. Se ajustó un dispositivo de ayuda de acuerdo con la trayectoria planificada y las perforaciones guiadas hacia dentro de los vaciados dentales de piedra. La exactitud se evaluó sobre datos CT post operatorios.
Resultados: El error de localización de referencia (FLE) dado por el programa de registro fue de 0.4 mm. 112 perforaciones navegadas mostraron una exactitud media [xy] de 0.42 + / − 0.26 mm (máximo 1 mm). Para el eje z, se encontró una exactitud media [z] de 0.25 + / − 0.12 mm (máximo 0.6 mm).
Conclusiones: Comparando la presente técnica de registro con los métodos existentes de registro en IGTP y guiado de fresas, no se necesitan plantillas radiográficas ni de registro. El procedimiento es sencillo y solo requiere un mínimo esfuerzo. Las perforaciones controladas por navegación pueden ser llevadas a cabo con una exactitud que se aproxima a la exactitud intrínseca del sistema de navegación, un hecho que garantiza su uso para la producción de plantillas quirúrgicas. Se necesitan más estudios sobre plantillas de perforación guiada antes que la presente técnica de registro pueda ser implementada para el tratamiento de pacientes.

要旨

目的：本研究の目的は、予備的ファントム試験において画像誘導テンプレート製作(IGTP)のための新規の登録法と標的設定法の正確さを評価することであった。
材料と方法：標的ペレットを含んだ４つの標準歯牙石膏模型を、真空マウスピースと外部標準フレーム（Medical Intelligence GmbH、ドイツ）を用いて、ＣＴデータに登録した。Treon ナビゲーション・システム（Medtronic Inc. 米国）を用いて、ＣＴデータ上で始点を歯冠の中央、標的を標的ペレットの中央とする手術経路を計画した。同装置は、計画した軌跡と歯牙石膏模型の誘導切削に従って調整した。術後の３Ｄ−ＣＴデータ上で正確さを評価した。
結果：登録ソフトウェアによって設定された平均起点位置誤差(FLE)は０．４ｍｍであった。１１２のナビゲーションによる切削の平均正確さ[xy]は０．４２±０．２６ｍｍ（最大１ｍｍ）であった。z 軸に関しては平均正確さ[z]は０．２５±０．１２ｍｍ（最大０．６ｍｍ）であった。
結論：IGTP とバー・トラッキングにおいて本稿で示した登録法と既存の登録法を比較すると、レントゲン上及び登録用のテンプレートは不要である。本手順は簡単で、わずかの手間ですむ。ナビゲーション制御による切削は、ナビゲーション・システムに固有の正確さに近いレベルで実施する事が可能であり、手術用テンプレート製作に使用することを正当化しうる。本登録法を患者治療に用いる前に、テンプレート誘導による切削の正確さについて更なる研究が必要である。

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