Computer-Assisted Design of Orbital Implants

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Purpose: *The purpose of this study is to report on the use of a computer-assisted design (CAD) system for predictable preoperative planning of orbital implant surgery (determination of the optimal number and position of orbital implants).* ***Materials and Methods:*** *Preoperative computed tomographic data were processed by interactive software for predictable surgical planning of orbital implant placement. Reformatted images from axial scans were used to analyze the structure of orbital bone and to plan the number of implants to place and the sites in which to place them.* ***Results:*** *Surgeries to correct orbital defects in 6 patients were successfully designed with this method. Seventeen implants were placed in 6 patients with the CAD system with no intraoperative injuries. Satisfactory anatomic and esthetic results were achieved.* ***Conclusions:*** *The new CAD system optimized preoperative surgical planning for orbital implant placement. The software may be applied in other craniofacial areas for implant placement in the future.* (Case Series) INT J ORAL MAXILLOFAC IMPLANTS 2007;22:132–137

Key words: *computer-assisted design, craniofacial implants, orbital defects, templates, 3-dimensional reconstruction*

Satisfactory surgical reconstruction of the orbit after tumor resection and exenteration is challenging. Good preoperative evaluation, careful surgical planning and preparation, and accurate implant surgery are mandatory for successful reconstruction of such a defect. Craniofacial titanium implants guarantee secure retention of the prosthesis.[1–3] Historically, successful orbital implant surgery has been dependent on the surgeon's clinical experience, and severe complications and low implant survival rates have been reported.[4]

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Software employing spiral computed tomographic (CT) image data can assist in the planning phase.[5] This study reports on a new computer-assisted design (CAD) system for orbital implant surgery and the use of this software for preoperational planning in a series of patients.

MATERIALS AND METHODS

This new CAD system was composed of a spiral CT scanner (GE LightSpeed Ultra; GE Healthcare, Chalfont St Giles, United Kingdom), a vacuum-form machine (DIN 7080-16; Biostar Microtech International, Hsin-Tien City, Taipei Hsien, Taiwan), an Intel Pentium IV computer (Santa Clara, CA) with high-resolution color video card (nVIADIA GeForce4 6800 GT), and the Ease Orbital Implant Planning System (EOIPlan). The EOIPlan is an interactive software program for predictable surgical planning of orbital implant placement developed jointly by Shanghai East Hospital of Tongji University and the Lab of Pattern Analysis and Machines Intelligence (Shanghai Jiaotong University). The software was developed by means of programming Visual C++ and Windows XP system (Microsoft, Redmond, WA). This program was approved by Shanghai Science and Technology Institution in 2002.

Fig 1 The template with radiopaque markers.

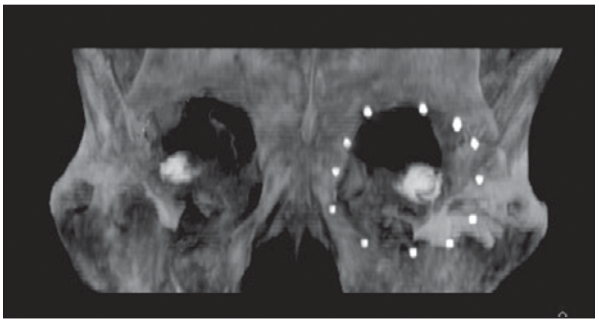

Fig 2 CT image with markers.

To realize this new concept of computer-assisted implant surgical design, every step, including template fabrication, image acquisition, planning, and surgical mimicry by the CAD system had to be developed, tested, and optimized. Training for the procedure was performed initially with models and cadavers.

Template Fabrication

To achieve optimal image quality for the preoperative planning and nearly identical conditions for implant surgery, the vacuum-formed template was placed in the area of the orbital defects. The template was fabricated with the vacuum-formed machine, transparent template (1.0 × 125 mm), and orbital plaster cast by means of heating and vacuum compression. Around the outline of the orbital rim, in the template, 12 holes 2 mm in diameter were drilled and filled in with radiopaque gutta percha as markers. The 12:00 position was located top of the supraorbital foramen, and the 6:00 position was located bottom of the infraorbital foramen. A line perpendicular to an imaginary line connecting these 2 points bisecting the orbital rim was used to determine the locations of 3:00 and 9:00 (Fig 1). These radiopaque markers are visible in the CT images (Fig 2). Because the template was fixed on the patient's skin, errors related to movement of the markers on the skin were minimized.

Data Acquisition

CT scanning was performed using a standing craniofacial protocol.[6] The patient was scanned with a spiral CT scanner at an axial plane (120KV, 25 mA, 1.25 mm slice thickness, 1.25 mm slice distance, voxel size 0.3 × 0.3 × 2 mm^3) from below the zygomatic bone to 4 cm above the supraorbital margin. In the present study, a threshold technique was used to control the CT densities for inspection of the craniofacial structures and the osseous defect.

Implant Planning

The CT data were transferred to a personal computer system running EOIPlan software (Fig 3). The planning stage consists of identifying the best locations for implant placement within the orbital bone. The software provides tools and cut views interpolated from the data to optimize this process.

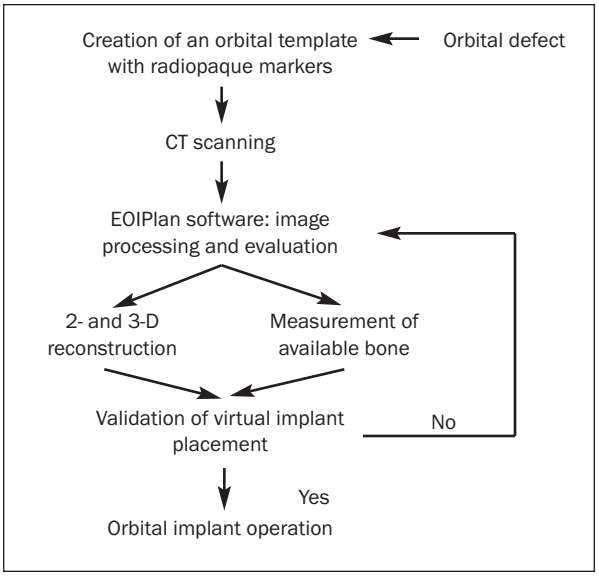

Fig 3 Flowchart of the preoperative planning process for patients with orbital defects.

The main interface of EOIPlan provides 3 views: the 3-dimensional (3D) reconstructed view, the cross-sectional view, and the dissection view (Fig 4). The 3D reconstructed image is the basal reference in CAD procedures (Fig 4c). A threshold technique was used to control the image densities for inspection of the craniofacial structures and the osseous defect. The skull was rotated for evaluation and measurement of the defect using the mouse or keyboard. In the 3D view, the operator could select several points on the surface of the patient's orbital rim to create an orbital curve. For each point, a dissection image was generated perpendicular to the surface of the bone tissues. The dissection view is the key reference in clinical operation (Fig 4a). It is defined as a planar cut

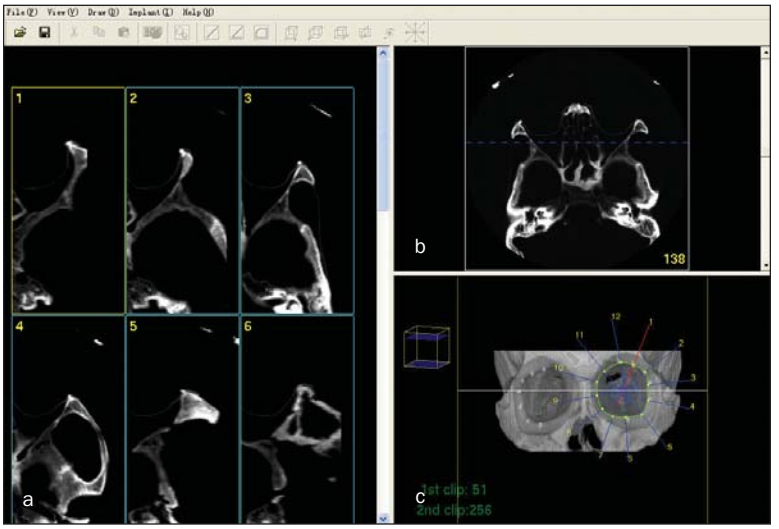

Fig 4 The views shown by the EOIPlan included *(a)* a dissection view, *(b)* a cross-section view, and *(c)* a 3D view constructed using 2D scans.

Table 1 Characteristics of Patients with Orbital Defects

Patient no.	Age (y)	Gender	Indication	Side reconstructed	No. of implants	Implant sites (clock position around orbital defect)	Implant length (n)	
							3 mm	4 mm
1	41	M	Squamous cell carcinoma	Right	3	6:00, 7:00, and 11:00	1	2
2	28	M	Traumatic injury	Right	2	9:00 and 10:00	2	0
3	24	F	Adenoid cystic carcinoma	Left	3	1:00, 4:00, and 5:00	1	2
4	16	M	Neurofibromatosis	Left	3	1:00, 2:00, and 11:00	3	0
5	58	F	Squamous cell carcinoma	Left	3	2:00, 4:00, and 6:00	2	1
6	32	M	Traumatic injury	Left	3	1:00, 4:00, and 5:00	3	0

view positioned along the orbital curve, locally perpendicular to and above the curve. Initially perpendicular to the orbital curve, it can be inclined from the direction perpendicular to the orbital curve with a few degrees (± 15 degrees) to adapt the view to the specific anatomy of the patient and to get more information. The cross-sectional view was defined by the Frankfort plane. Scanner data are usually acquired in planes parallel to the Frankfort plane, so the cross-sectional views were assimilated with these scanner images (Fig 4b).

On the planning software, the surgeon observes the cross-sectional views, defines the orbital curve by setting the control points, and chooses the dissection views. Simulated implant placement is usually performed initially in the dissection views. The position, orientation, length, and diameter of each implant may be defined interactively in each view, with visual feedback in all windows.

RESULTS

The EOIPlan system with preoperative design was performed on 6 patients ranging from 16 to 58 years in age (Table 1). All patients had an orbital defect after enucleation of the globe and 2 patients (patients 2 and 4) had deossification. The neurological status and overall condition of the patients were good. Craniofacial Vistafix System implants (Entific Medical Systems, Göteborg, Sweden) with diameter of 3.75 mm and length of 3 or 4 mm were placed according to the preoperative design in outpatient surgery under local anesthesia.

All 17 implants were successfully and precisely placed as planned with the EOIPlan system. No unexpected complications or injuries were encountered during the surgery. The surgical procedures were uneventful, and the surgical time was reduced compared to conventional methods. The craniofacial implants and prostheses fit the orbital defects well, and consequently, few adjustments were needed. All patients and their families were delighted with the results.

Most implants were placed in the supraorbital and zygomatic regions, ie, in the 1:00, 4:00, 5:00, and 6:00 positions on the left orbital rim and in the 6:00, 7:00, 8:00, and 11:00 positions on the right. In patient 2, 2 implants were placed in the 9:00 and 10:00 positions because of severe deossification caused by traumatic injuries. In patient 4, the 3 implants could be placed only in the 1:00, 2:00, and 11:00 positions because

Fig 5 *The treatment of patient 3.*

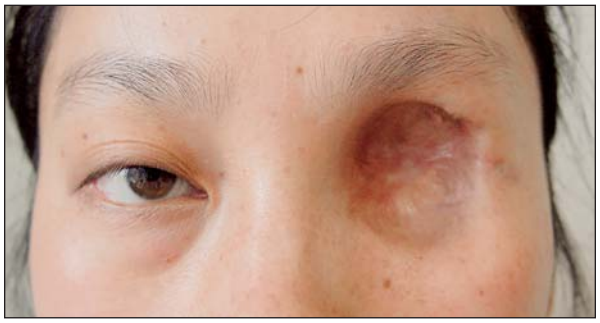

Fig 5a Socket after exenteration.

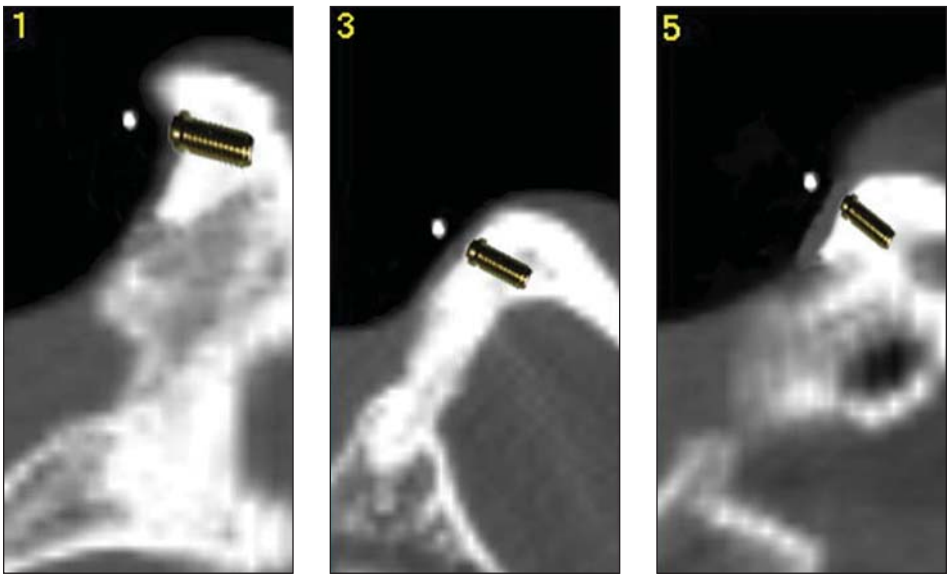

Fig 5b *(right)* Implant planning.

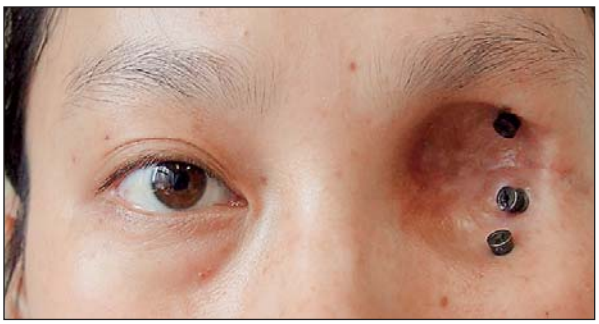

Fig 5c Healed socket with abutments after second-stage surgery.

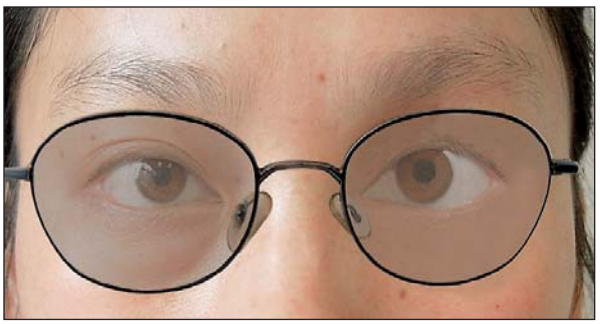

Fig 5d Final appearance with prosthesis.

most of the periorbital bone and the zygoma had been resected, and inferior support was insufficient.

Skin reactions were graded according to the criteria proposed by Tjellström.[7] Six months after second-stage operation, no adverse skin reactions (grade 0) were observed. One year later, only 1 implant showed slight redness (grade 1) of the surrounding skin (the implant in 4:00 position; patient 5). There were no other complications.

The case illustrated in this paper concerns a 24-year-old woman with left orbital defect who underwent enucleation for adenoid cystic carcinoma 3 years ago (patient 3; Fig 5). As described, the template was placed in the orbital defect area during scanning. The placement of 3 implants was planned using EOIPlan software (the dissection views; Fig 5b). The implants were placed in the 1:00, 4:00, and 5:00 positions. The orientation of the implants (both virtual and actual) was perpendicular to the orbital rim. Abutments were attached to the previously placed implants (Fig 5c). The definitive facial prosthesis was fitted 6 months later, with excellent esthetic results (Fig 5d).

DISCUSSION

Orbital defects can be considered a severe social disability. Currently, the artistic skills, materials, and techniques are available to provide patients who have these defects with lifelike facial prostheses supported by implants.

Craniofacial implants have been reported to be successful for use with orbital prostheses. Success rates of 35% to 75% have been reported after 3 to 14 years of observation; success often depends on the sites chosen for implant placement.[4,8–11] Implant placement in orbital sites is challenging because of the limited bone volume and quality. In general, bone sites in the orbital region are thin and irregular. They are often heavily compacted, with little or no marrow, and may lack the blood supply necessary to maintain an adequate bone-implant interface. Thus, optimal positioning and orientation are important to achieve success.

CAD technologies were used for optimal preoperative planning. The commercially available computer-assisted systems can be distinguished according to their different functions and operating strategies. *Navigation systems*[12–14] use preoperative CT scans both for planning and during the operation. Such a system can be an integral part of the surgical procedure. This type of system allows continuous intraoperative coordination of the implantation phase with the preoperative plan, which optimizes the accuracy of implant surgery. These systems require a free line-of-sight between the instrument to be tracked and an external sensor. One disadvantage of these systems is communication delay. *Reconstruction and simulation systems*[15–17] facilitate reconstruction of the craniofacial structure and allow simulation of the surgical procedures. These systems can predict the postoperative appearance of the patient. They give the surgeon the ability to work interactively with craniofacial data of the patient and to simulate different surgical procedures to improve his or her planning process. The medically approved CAD system used in this study belongs to this group.

Because no implant planning tools for working specifically with orbital implants were commercially available, the present planning tool, which works with CT data, was specially developed. EOIPlan software is the first program created for preoperative planning of orbital implant placement.

A trained team that takes all potential sources of error into consideration in advance can deliver esthetic and functional results. The clinical results presented here were achieved by careful optimization of each step of the intervention: template fabrication, image acquisition, preoperative planning, and the actual implant placement surgery. This new process, developed in teamwork by radiologists and surgeons, is easier and more accurate than conventional implant placement. Only with the help of a program such as EOIPlan can optimal implant positioning be realized in surgery.

Before CT scanning, a plastic template with radiopaque markers was fixed to the area of the orbital defect. These markers were visible in both the CT scans and the EOIPlan interface and as reference points for image analysis and implant operation. The template was also used to locate the exact position before drilling. Typical locations for orbital implants were described by Matssura and associates[18]: 1:00, 4:00, and 5:00 for the left eye and 7:00, 8:00, and 11:00 for the right eye. In the present patients, the 1:00 (left eye) and 11:00 (right eye) positions were found to be the most ideal implant positions without deossification. In the study by Matssura and associates,[18] most implants were placed in the 1:00, 4:00, 5:00, and 6:00 positions on the left and in the 6:00, 7:00, 8:00, and 11:00 positions on the right. In the present study, there were only 2 patients with right orbital defects, and pateint 2 had severe deossification. In these 2 patients, implants were placed in the 6:00, 7:00, 9:00, 10:00, and 11:00 positions.

The development and advancement of CT imaging has been very helpful for evaluating craniofacial defects and for surgical planning.[19–21] The EOIPlan system can create a 3D reconstruction of soft or bone tissue based on CT images. A processing segmentation stage is performed to identify the kind of human tissue or material each pixel represents. The CT scans used in the present study included soft tissue, bone tissue, and radiopaque markers. The good sensitivity of CT scans for bone tissues makes it possible to use a threshold technique to segment the raw images after a simple filtering operation (low pass filter) to eliminate the background noise in the measured data. Pixel intensity can be accurately related to universal constants to express the density of the material scanned; this density is expressed in Hounsfield units. Water density (0 HU) and air density (–1,000 HU) are 2 of these constants. Bone generally has a density of 200 to 1,500 HU.

Allen and colleagues[22] suggested an intensive hygiene regimen helped maintain tissue health around implant abutments. The amount of debris on the abutments was much greater in the orbital implant patients than in patients with craniofacial implants placed in the floor of the nose or in the auricular region. There may be several reasons for this. Monocular vision and the associated compromise in depth perception may reduce patients' ability to visualize their defects, manipulate the hygiene aids, and

assess the quality of their hygiene. In the present study, the peri-implant region showed good soft tissue compatibility, which may be attributable to the hygienic instruction given and regular follow-up.

The current series was too small for statistical evaluation. However, no implant failures have been observed since loading (4 to 34 months).

Because of the positive clinical validation and accuracy attained in the present study, it may be worthwhile to use this software for placement of craniofacial implants in other areas of the head as well. Improvements to the software are needed, such as a program feature mirroring the healthy eye into the defect area to facilitate orientation during planning.

CONCLUSIONS

A new method for orbital implant placement has been presented. This new method is based on the use of a radiopaque template, CT imaging, and preoperative planning software. Orbital defects in 6 patients were reconstructed with the aid of CAD software designed specifically for implant placement planning for this region, and satisfactory results were obtained. Improvements to the software and its use in other craniofacial regions may be the subject of future research.

REFERENCES

1. Parel SM, Brånemark P-I, Tjellstrom A, Gion G. Osseointegration in maxillofacial prosthetics. Part II: Extraoral applications. J Prosthet Dent 1986;5:600–606.
2. Tolman DE, Desjardins RP, Jackson IT, Brånemark P-I. Complex craniofacial reconstruction using an implant-supported prosthesis: Case report with long-term follow-up. Int J Oral Maxillofac Implants 1997;2:243–251.
3. Alfano SG, Robinson RF, Webber CM, Erickson KK. Fabrication of a craniofacial implant surgical and treatment planning guide. J Prosthet Dent 2005;1:91–94.
4. Roumanas ED, Freymiller EG, Chang TL, Aghaloo T, Beumer J III. Implant-retained prostheses for facial defects: An up to 14-year follow-up report on the survival rates of implants at UCLA. Int J Prosthodont 2002;4:325–332.
5. Schlieper J, Brinkmann B, Metz HJ. CT-Computer-schablonengestützte Planung der Implantat-und Magnetposition bei der epithetischen Versorgung von Gesichtsdefekten. Mund Kiefer Gesichtschir 2001;5:22–27.
6. Lo LJ, Chen YR. Three-dimensional CT imaging in craniofacial surgery: Morphological study and clinical applications. Chang Gung Med J 2003;1:1–11.
7. Tjellström A. Osseointegrated implants for replacement of absent or defective ears. Clin Plast Surg 1990;2:355–366.
8. Abu-Serriah MM, McGowan DA, Moos KF, Bagg J. Outcome of extraoral craniofacial endosseous implants. Br J Oral Maxillofac Surg 2001;4:269–275.
9. Jacobsson M, Tjellstrom A, Fine L, Andersson H. A retrospective study of osseointegrated skin-penetrating titanium fixtures used for retaining facial prostheses. Int J Oral Maxillofac Implants 1992;4:523–528.
10. Nishimura RD, Roumanas E, Moy PK, Sugai T, Freymiller EG. Osseointegrated implants and orbital defects: UCLA experience. J Prosthet Dent 1998;3:304–309.
11. Toljanic JA, Eckert SE, Roumanas E, Beumer J. Osseointegrated craniofacial implants in the rehabilitation of orbital defects: An update of a retrospective experience in the United States. J Prosthet Dent 2005;2:177–182.
12. Hoffmann J, Westendorff C, Schneider M, Reinert S. Accuracy assessment of image-guided implant surgery: An experimental study. Int J Oral Maxillofac Implants 2005;20:382–386.
13. Meyer U, Wiesmann HP, Runte C, et al. Evaluation of accuracy of insertion of dental implants and prosthetic treatment by computer-aided navigation in minipigs. Br J Oral Maxillofac Surg 2003;41:102–108.
14. Baumann A, Schicho K, Klug C, Wagner A, Ewers R. Computer-assisted navigational surgery in oral and maxillofacial surgery. Atlas Oral Maxillofac Surg Clin North Am 2005;13:41–49.
15. Lo LJ, Chen YR, Tseng CS, Lee MY. Computer-aided reconstruction of traumatic fronto-orbital osseous defects: Aesthetic considerations. Chang Gung Med J 2004;27:283–291.
16. Meehan M, Teschner M, Girod S. Three-dimensional simulation and prediction of craniofacial surgery. Orthod Craniofac Res 2003;6(suppl 1):102–107.
17. Gladilin E, Zachow S, Deuflhard P, Hege HC. Anatomy- and physics-based facial animation for craniofacial surgery simulations. Med Biol Eng Comput 2004;42:167–170.
18. Matsuura M, Ohno K, Michi K, Egawa K. Clinicoanatomic study on the craniofacial bones used for cranio- and maxillofacial implants. Int J Oral Maxillofac Implants 2002;1:121–129.
19. Yu Z, Yang J, Mu X, Yang J. A preoperative planning system for unilateral craniofacial malformation restoration surgery based on the volume measurement of eye sockets [in Chinese]. Sheng Wu Yi Xue Gong Cheng Xue Za Zhi 2005;2:293–296.
20. Zhao L, Patel PK, Widera GE, Harris GF. Development of a computer assisted craniofacial surgery planning system. Stud Health Technol Inform 2003;94:410–412.
21. Sukovic P. Cone beam computed tomography in craniofacial imaging. Orthod Craniofac Res 2003;6(suppl 1):31–36.
22. Allen PF, Watson G, Stassen L, McMillan AS. Peri-implant soft tissue maintenance in patients with craniofacial implant retained prostheses. Int J Oral Maxillofac Surg 2000;2:99–103.