Deformation of Stereolithographically Produced Surgical Guides: An Observational Case Series Report

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ABSTRACT

Background: Template-based computer-guided implant placement holds the promise of more precise and less traumatic placement of dental implants. Errors in the fabrication process of the surgical guide may lead to unfavorable clinical outcomes.

Purpose: This report discusses the potential of unintentional volumetric deformation of stereolithographically (SLA) produced surgical guides (NobelGuide, Nobel Biocare AB, Göteborg, Sweden) compared with the original scan denture.

Materials and Methods: Three-dimensional radiographic data acquired by medical computerized tomography (CT) or cone beam CT (Newtom 3G, AFP Imaging Corporation, Elmsford, NY, USA) can be utilized in specialized software to develop treatment planning for dental implant placement.

This information can then be transferred to the patient via a surgical guide. Stereolithography is a rapid prototyping process that can be used to create such a guide stent. Three cases are shown describing different levels of deformation of SLA-produced surgical guides.

Results: Unintentional deformation of SLA-produced surgical guides is possible. Deformation of surgical guides can create dissimilarity between the virtually planned position and the actual position of the implants.

Conclusion: Incorrect setting of the ISO values for the segmentation of the scan denture has been found to be a factor in the deformation of SLA-produced surgical guides, although more, at this time known but also less understood, issues appear to be involved. Only one manufacturer's product is discussed; further research is warranted to determine if the discrepancies are process or product based. It might be prudent to closely evaluate the volumetric congruence of SLA-produced surgical stents before their clinical use to prevent undesired clinical outcomes.

KEY WORDS: converter, ISO values, misfit, NobelGuide, SLA surgical guide

INTRODUCTION

Historically, dental implants have been placed by creating direct access to the surgical site. This allows the clinician to visualize the bony architecture. Of course this visualization is limited to the exposed area. A broad range of radiographic techniques are used to supplement the available information. These can range from two-dimensional periapical, panoramic, to lateral cephalometric views, either conventionally or in a digital format. In the last decade, three-dimensional radiographic information has become more accessible with the use of computerized tomography (CT) and cone beam CT (CBCT, Newtom 3G, AFP Imaging Corporation, Elmsford, NY, USA) technologies. Implementing this information still requires high surgical skills from the operator who needs to translate the diagnostic information into the correct three-dimensional implant placement.

To aid the clinician during the surgical procedure, a broad range of surgical guides have been developed.[1–8] Design concepts vary, from the simplistic non-limiting, to the partially limiting, and, finally, to completely limiting surgical guides. The non-limiting design, in

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general, provides the surgeon an indication as to where the proposed prosthesis is in relation to the selected implant site. The partially limiting design offers the possibility to have a guide sleeve direct the first drill used for the osteotomy. The remainder of the osteotomy and implant placement is then finished freehand by the surgeon. The completely limiting design restricts all of the instruments used for the osteotomy in a buccolingual and mesiodistal plane. The addition of drill stops limits the depth of the preparation and, thus, the positioning of the prosthetic table of the implant.

The information acquired with CT or cone beam can be used in specialized software to plan the ideal position of dental implants in relation to the prosthetic reconstruction, the available bone, and the vital structures, which need to be avoided. Currently, there are two main technology directions that can be used to transfer the planning to the surgical field: navigated systems and surgical guide stents-based systems. In navigated surgery, the handpiece position in relation to the previously planned osteotomy site is followed live as the surgeon advances the surgical instrumentation.[9–14] With surgical guide stents-based systems, the surgeon follows the information as is encoded in the surgical guide, mostly by means of a guide ring that is embedded in the surgical guide stent. Then, with dedicated instruments, the osteotomy is made through the guide rings, after which the placement of the implant may be guided as well.[15–17] A recent publication by Ruppin and colleagues[18] found both techniques not statically different in the accuracy attained.

Computer-assisted surgical guide stents can be made via a rapid prototyping additive process called stereolithography[19] or through numeric-controlled milling, a subtractive process.[20,21]

In stereolithography, a basin of light-polymerizing resin is illuminated with a laser, polymerizing small areas at a time, much like an ink-jet printer depositing ink on paper. The laser turns on and off based on the information it receives from the computer-aided design model in the computer.

The basin is then moved down over a small distance, and the laser travels over the field again. This process is repeated over a period of time, slowly building the object. In dentistry, the object, historically, was a copy of the patient's anatomy[22] on which then, if desired, conventional surgical guides could be fabricated. The same stereolithographic process can also fabricate surgical stents directly.[23] Although there is great variation in techniques, products, and application, the literature at this time seems to indicate that maximum deviation between planned implants and actual implant position using stereolithographically (SLA)-produced surgical guides is in the range of 1.5 to 2.3 mm linear measured at the apex and 4 to 6° angular.[24–27] It is important to recognize that the maximum deviation is the value that has to be considered if the technology is trusted to place dental implants with confidence, often in a keyhole flapless surgery approach. In addition, this is developing technology where there is a learning curve for the providers of the care as well as for the producers of the products that are used. This article is addressing part of the learning curve, where SLA-produced surgical guides are deformed compared with the shape and form of the original scan denture. Although all cases here discussed are produced via a singular manufacturer, it warrants noting that similar deformations might be possible with other producers and processes. So care should be exercised in the interpretation of these findings. To the author's knowledge, there has not been a report in the dental literature indicating the deformation of SLA-produced surgical guides from the intended shape and form.

MATERIALS AND METHODS

NobelGuide (Nobel Biocare AB, Göteborg, Sweden) is a commercially available specialized software product that allows the importation of CT and CBCT data, the planning of implant therapy, and the subsequent production of an SLA-produced surgical guide, aiming at placing dental implants per the planning in the computer. In addition, because the position of the implants is known before actual surgery, it is possible to generate a dental cast based on the surgical guide, which then allows the prefabrication of a dental prosthesis. This prosthesis can then be placed at the time of surgery if an immediate loading protocol is desired.

As previously mentioned, it appears that, for various reasons, a small deviation between planning and final placement is to be expected. The clinical effects of these deviations are, at this time, less understood. Different authors have reported their experiences with this specific commercial treatment modality and have described a range of satisfaction with the outcome they attained. Very good results have been reported;[28–30] others have reported minor to major complications.[31–33]

Per the protocol, the patient is fitted with a scan denture that, if the patient is fully edentulous, is a well-fitting complete denture, and if partially edentulous, the denture is a partial denture replacing the, to be replaced, teeth and a covering of the remaining dentition. Fiduciary markers of gutta-percha are placed in a zigzag pattern. The computer converter program is set to recognize the size and density of the markers. A scan index is made with a vinyl poly siloxane (VPS), so the patient can compress the scan denture against the tissue in full contact during the scanning procedure. The patient is scanned with the scan denture in place; subsequently, the scan denture is scanned individually, creating two distinct Dicom files. The Dicom files are imported into the converter part of the program. The converter will translate the Dicom files to a software-specific file format. First, the patient's file is converted. The ISO threshold value needs to be set by the operator. The three-dimensional surface is drawn within a volumetric data field, corresponding to points with a specific intensity value. The settings will indicate to the computer which value to assign to a given grayness. To low a setting will give a lot of scatter noise in the computer model, if the threshold is set to high, it will result in a fragmented appearance of the computed model. Second, the scan denture file needs to be converted. Here, too, is setting the threshold value required of the operator. Once the two virtual models have been created, the pairing of these models is next. The computer, in most cases, automatically recognizes the gutta-percha fiduciary markers of both files and, once a match is found, superimposes both files. In such, it is able to have a clear demarcation of the scan denture in relation to the patient's tissue. This file is saved and then imported into the planning module of the software. There, the dental implants can be planned in a virtual environment, considering the prosthesis as well as the bone and vital structures of the patient. The planning module allows for the evaluation of the interrelationship of the surgical guide rings, to each other to prevent collisions and to the surface of the prosthesis to prevent extrusion of the guide rings beyond the surgical guide. Once the planning is confirmed, the computer software is generating a virtual model of the proposed surgical guide. Upon approval by the operator, the guide information is send via the Internet to the production facility. The guide information is based on the scan of the scan denture, superimposed with the information of the guide sleeves that are placed within the duplicated scan denture. The manufacturer offers the option to order a duplicate denture, which is a copy of the scan denture, and a surgical guide, which is the same scan denture, but now with metal guide sleeves incorporated. Once manufactured, the guide and duplicate denture are returned to the clinician for implant placement. The desired outcome of the production of the surgical guide is to have the same shape and volume as the scan denture that was used, as to precisely transfer the planning to the patient. It was found out that this was not always the case. The following cases will describe some minor and major deformation situations.

Case 1

A 55-year-old male presented with full edentulism, desiring implant-supported fixed reconstruction of both maxilla and mandible. The patient was prepared to undergo the above-mentioned protocol in preparation for implant placement and immediate loading provisional prosthesis. The patient was scanned with a CBCT (Newtom 3G, AFP Imaging Corporation). Scan information: 110 kVp, voxel size 0.2 mm, 9 seconds, 27 mA, reconstructed at 0.4 mm interslice distance. The produced Dicom files were imported into the software, and the ISO values were set based on the appearance of the reconstruction model for both the bone as well as for the denture. The planning was performed, and the guide information was sent via the Internet to the production facility. Upon receiving the guides and duplicate dentures, casts were made using the surgical guides, per the manufacturer's protocol. The duplicate dentures fitted the casts well, indicating the congruence between the guides and the duplicate dentures. The duplicate dentures were used to mount the cast in an articulator. At this time, it was noted that the duplicate dentures did not fit the occlusal record as was previously made intraorally using the scan dentures. Dedicated impressions were made with a stiff VPS material (Blu-Mousse, Parkell Inc., Edgewood, NY, USA), from the occlusal aspect of the scan denture as well as from the intaglio (Figures 1–3). The impressions were placed on the corresponding surfaces of the duplicate denture, and gross discrepancies were noted (Figures 4–6). New guides and dentures were ordered based on the same data set. Once the new guides and duplicate dentures were received, it was apparent that the new set was similar to the one previously made, indicating that the discrepancy was

Figure 1 Scan denture in VPS index anterior view.

Figure 4 Duplicate denture in VPS index anterior view, note discrepancy.

within the data set used. Research conducted by the manufacturer indicated that during the conversion process, incorrect threshold values were used for the denture. Once the importance of the threshold settings were realized, the Dicom images were converted correctly, and new duplicate dentures and surgical guides were fabricated. The fit of the new guides was much improved and deemed acceptable for use during surgery.

Figure 2 Scan denture in VPS index lateral view.

Figure 5 Duplicate denture in VPS index lateral view, note discrepancy.

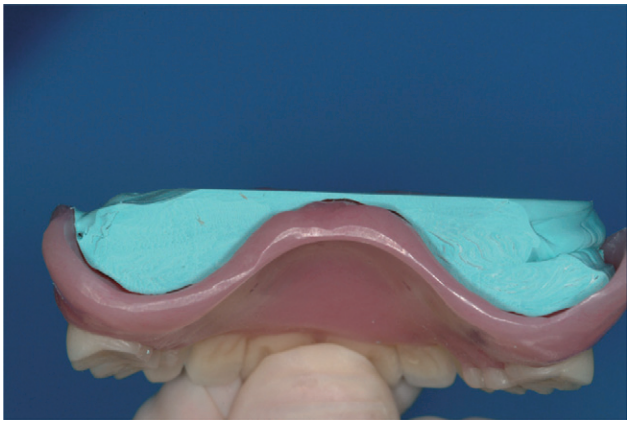

Figure 3 Scan denture with VPS index of intaglio.

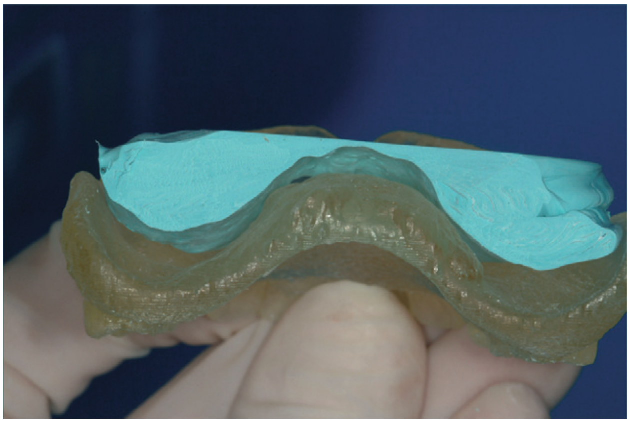

Figure 6 Duplicate denture, note discrepancy between index and intaglio.

Figure 7 Cast fabricated based on the surgical guide.

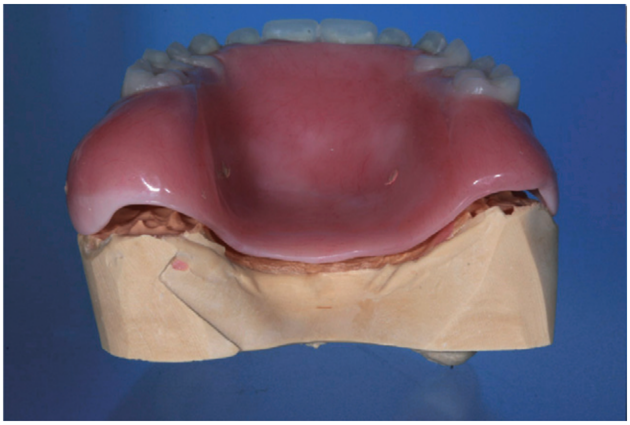

Figure 9 Fitting of scan denture on cast. Soft tissue mask has been removed. Note ill fitting at palatal aspect.

Case 2

A 48-year-old female presented with maxillary edentulism, requesting fixed implant-supported reconstruction. A dedicated scan denture was fabricated per the manufacturer's protocol, and the patient was scanned with a medial CT scanner (Hispeed, GE Healthcare, Buckinghamshire, England). Scan information: 120 kV, gantry tilt 0, gantry speed 0.75 s/rotation, 90 mAS. The Dicom data were imported in the converter program of the NobelGuide software, and the Hounsfield units were set to carefully cover the radiographic information with the orange mask. Loupes with 5× magnification were used to evaluate best coverage. A surgical guide and a duplicate denture were ordered. The surgical guide was used to fabricate a cast that was used to fabricate a provisional restoration for an immediate loading protocol (Figures 7 and 8). The soft tissue material was removed from the cast, and the original scan denture was placed back onto the cast. It was noted that the scan denture did not fit the cast (Figure 9). The scan denture could thus not be used to mount the cast in a dental articulator. When the scan denture was hand articulated in maximum intercuspation, a distance of approximately

Figure 8 Duplicate denture and scan denture.

Figure 10 Scan denture in maximum intercuspation, note relationship of cusp tip to denture material.

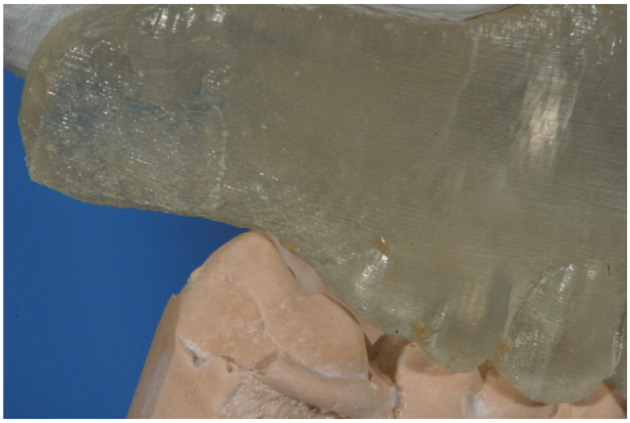

Figure 11 Duplicate denture in maximum intercuspation, note difference in relationship between cusp tip and surface of duplicate denture compared with original scan denture.

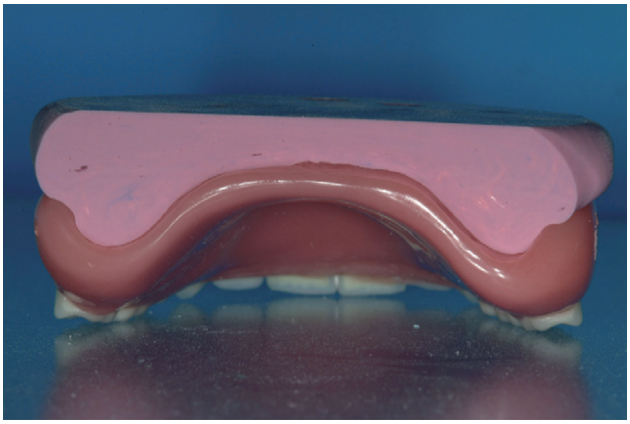

Figure 12 PVS putty index of scan denture.

1 mm was noted between the distal cusps of a lower right molar (Figure 10). When the duplicate denture was hand articulated in maximum intercuspation, this distance was almost eliminated, indicating that the occlusal surfaces of the scan denture and the duplicate denture were dissimilar (Figure 11).

Figure 13 Scan denture in stone index anterior view.

Figure 14 Scan denture in stone index lateral view.

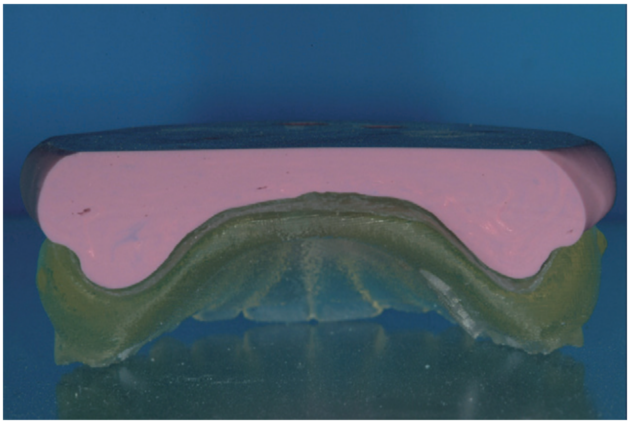

Figure 15 PVS putty index of scan denture now related to duplicate denture, note adequate congruence of fit.

Case 3

A 60-year-old male presented with maxillary edentulism, requesting a fixed implant-supported reconstruction. A dedicated scan denture was fabricated per the

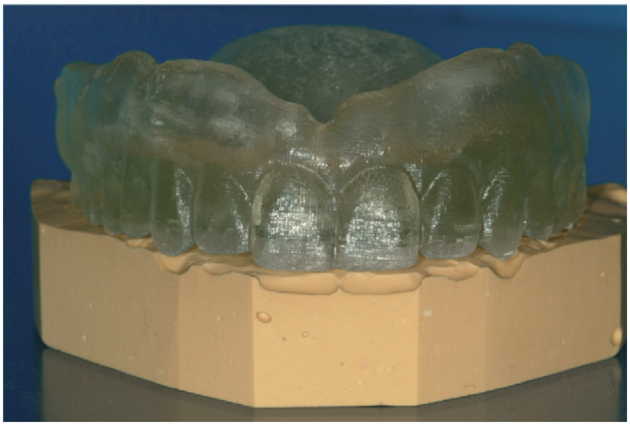

Figure 16 Duplicate denture in stone index anterior view, note discrepancy.

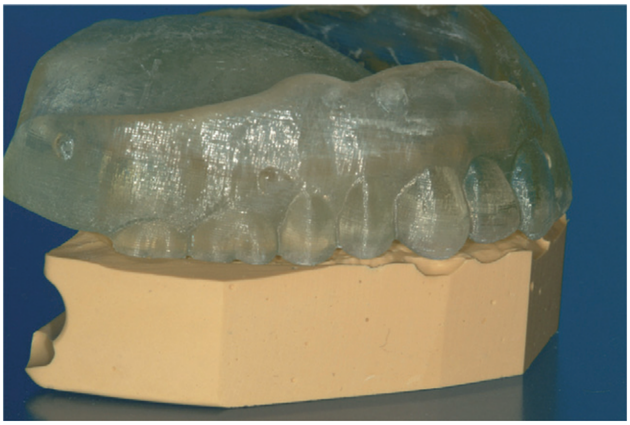

Figure 17 Duplicate denture in stone index lateral view, note discrepancy.

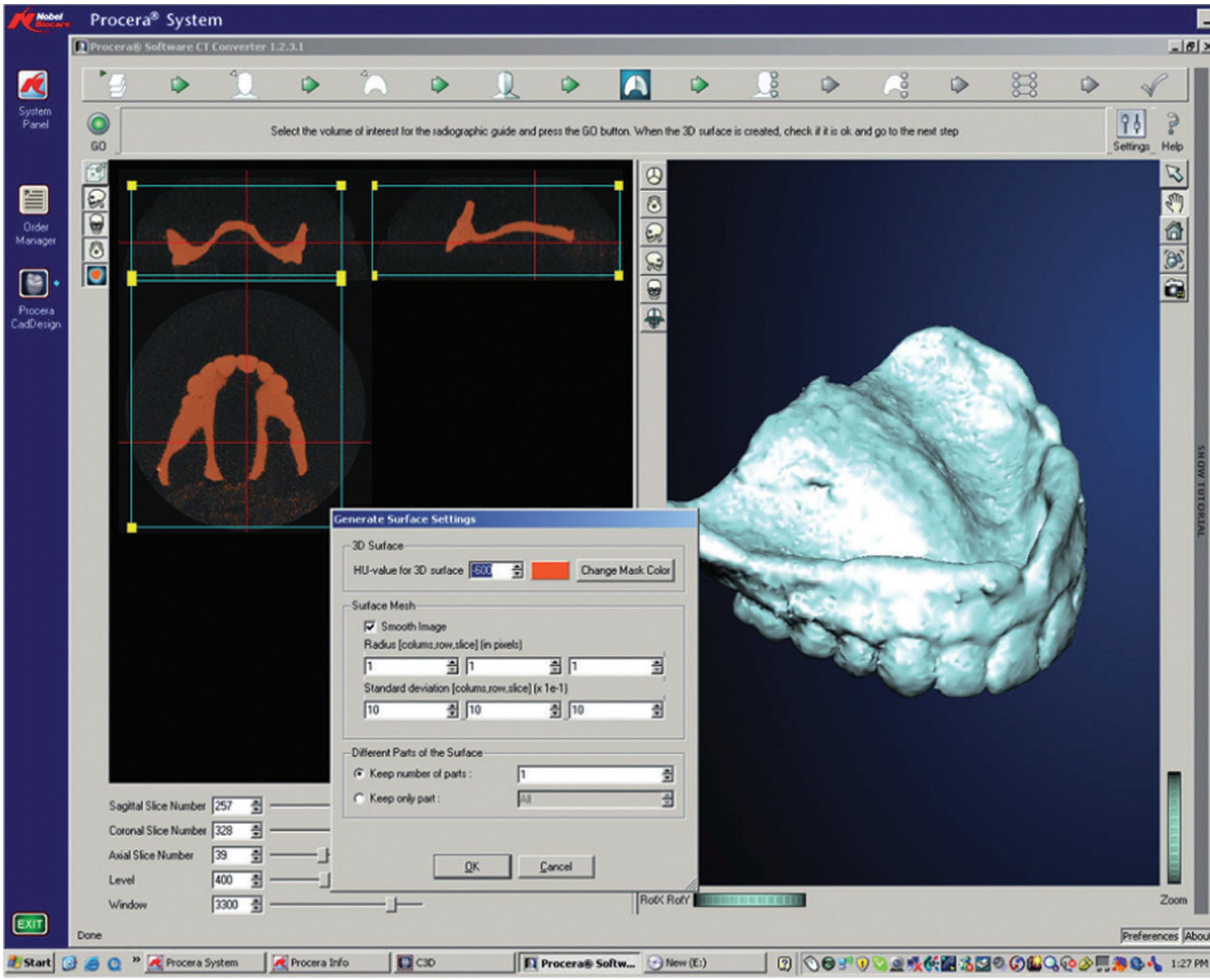

Figure 18 Screenshot of converter set at ISO –600, to low, virtual model appears visually correct.

manufacturer's protocol, and the patient was scanned with a CBCT (Newtom 3G, AFP Imaging Corporation). Scan information: 110 kVp, voxel size 0.2 mm, 9 seconds, 27 mA, reconstructed at 0.4 mm interslice distance. The Dicom data were imported in the converter program of the NobelGuide software. The ISO units were set to carefully cover the radiographic information with the orange mask. Loupes with 5× magnification were used to aid visualization. A duplicate denture and surgical guide were ordered. Impressions were made with a stiff VPS putty material (Coltene lab putty, Coltene/Whaledent Inc., Cuyahoga Falls, OH, USA) of the intaglio of the scan denture, and stone impressions (GC Fujirock, GC Inc., Alsip, IL, USA) were made of the occlusal and incisal aspect of the scan denture (Figures 12–14). The impressions were fitted with the corresponding surfaces of the duplicate denture. It was found that a very acceptable fit was seen for the intaglio of the denture (Figure 15), but that gross deformation had occurred at the occlusal aspect (Figures 16 and 17). Research of the data sets by the manufacturer indicated that the correct threshold values were used to convert the Dicom data. As the original scan denture was no longer available, no conclusions could be drawn as to why this deformation had occurred.

DISCUSSION

Computer-generated surgical guides pose big promise to deliver less-invasive, more-precise surgical placement of dental implants. It is imperative that high precision and fidelity are mandatory requirements if these techniques are to be used in keyhole surgeries. The elimination of

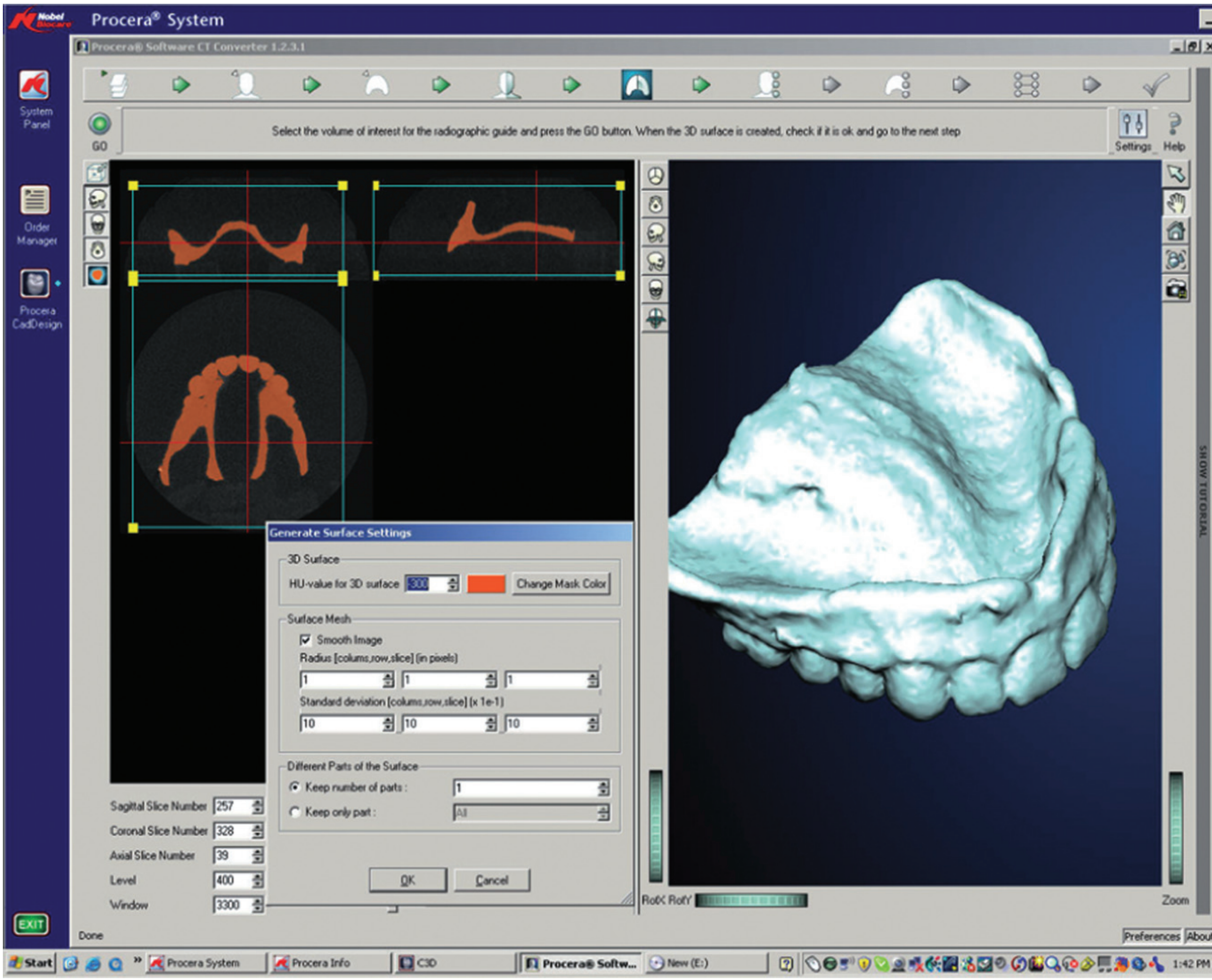

Figure 19 Screenshot of converter set at ISO –300, to low, virtual model appears visually correct.

direct vision makes that the clinician should be able to trust the technology. Of course with any new development, a learning curve is inevitable. This holds true not only for the clinicians delivering the care, but also for the manufacturers developing the technology. It is clear that the desired outcome of the production process of SLA surgical guides is that the guide is similar to the original scan denture. The ISO values as set are used by the computer to build a virtual model of the scan denture (Figures 18–21). Once the model is generated, the operator can visually inspect it. If the value is set to high, then the model is clearly defective (see Figure 21), but if the value is set to low, then visual inspection is not discriminative enough. The virtual model will appear correct for a wide range of values and is thus useless. Instead, what needs to be utilized is the orange mask feature. This indicated which pixels from the radiograph the computer will use for the virtual model. The ISO values need to be set so that the orange mask is exactly covering the data from the scan denture. Set to low, it will grow the surgical guide, set to high, it will shrink the guide. In both cases, creating a deformation compared with the original scan denture. The ISO values are not only specific for the manufacturer, but also for the particular machine used, and will have to be set individually.

If standard values are used, then there is an increase change of introducing incorrect ISO values to the data set. Individual actions of the operator will have an effect on the end product.

As described, we found haphazardly that SLA-produced surgical guides potentially do not conform to the original. Sometimes the deformations were minimal, although sometimes the deformations were gross. The clinical consequences are not yet fully understood but

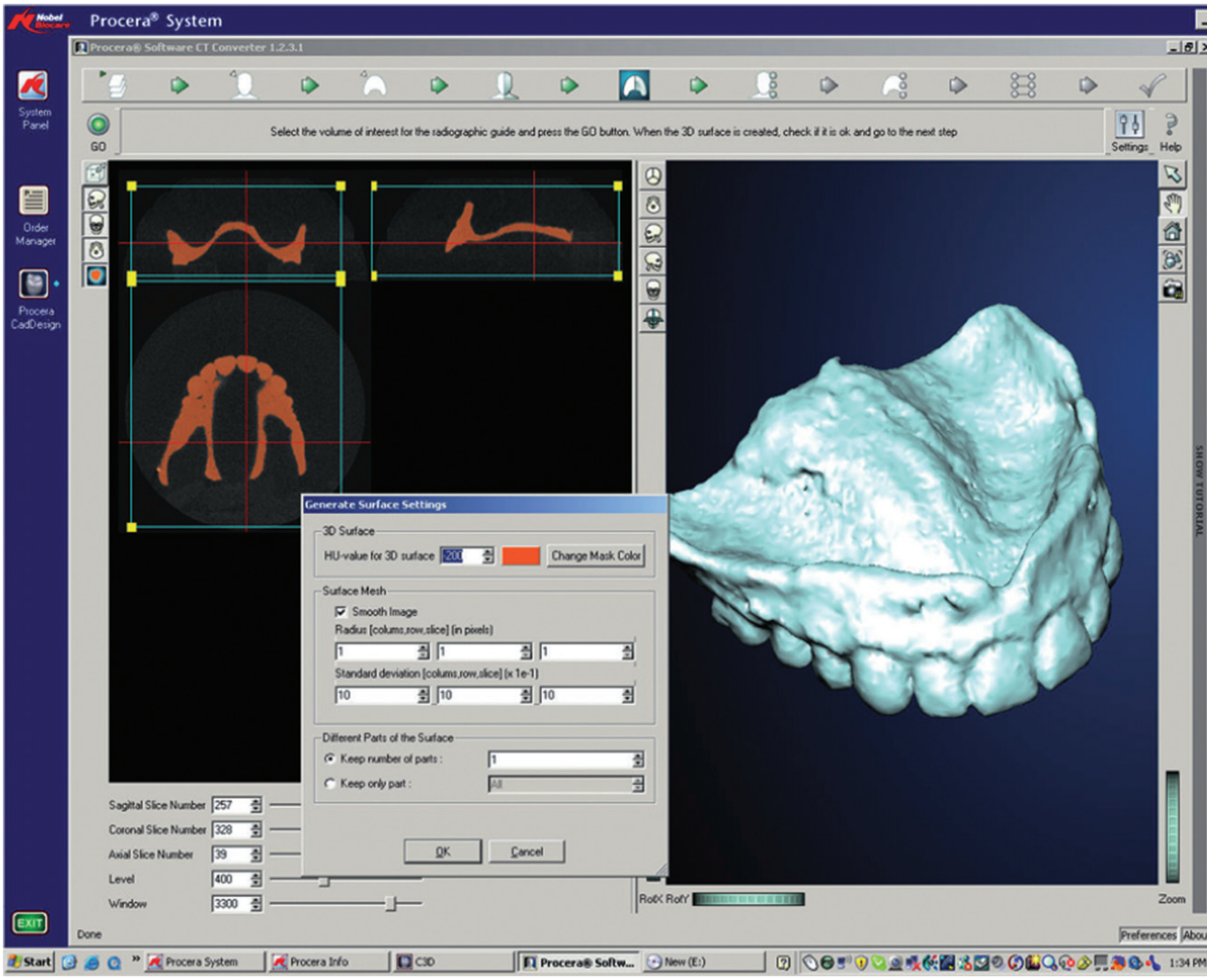

Figure 20 Screenshot of converter set at ISO –200, correct virtual model appears visually correct.

are obviously a decrease in the reliability to place dental implants in the position that was selected in the computer. Case 2 exemplifies how clinical errors could be introduced. A surgical index is used by the surgeon to place the surgical guide at commencement of implant placement. This index is made, per the manufacturer's protocol, by mounting the cast with the duplicate denture. Once mounted, the duplicate denture is replaced with the surgical guide, and a stiff VPS material is injected in the corresponding space. If in this case the scan denture was used per the manufacturer's protocol, then it would have resulted in an incorrect relationship between the mandibular cast and the maxillary cast. To check the correctness of the surgical index, the surgical guide is loaded with a thin-flowing VPS material (Exaflex, GC Inc.) and manually placed in intimate contact. The fit of the surgical guide can then be evaluated as the thickness of the set material indicates space between the guide and the tissue (Figure 22). A similar test is performed with the patient biting on the surgical index. Upon setting of the impression material, the fit can be evaluated (Figure 23). If there is a discrepancy in the thickness of the disclosing material, then the surgical index should be rejected as it would result in the malpositioning of the surgical guide and, hence, in incorrect implant placement.

It would be advantageous if software could be developed that would automate the setting of the ISO values, as this apparently is a very important part of the procedure. This would then maximize the potential precision of this technique. Additionally, the manufacturers should be able to indicate the amount of distortion there is between the produced SLA guide and the original scan denture. This would allow the development of a

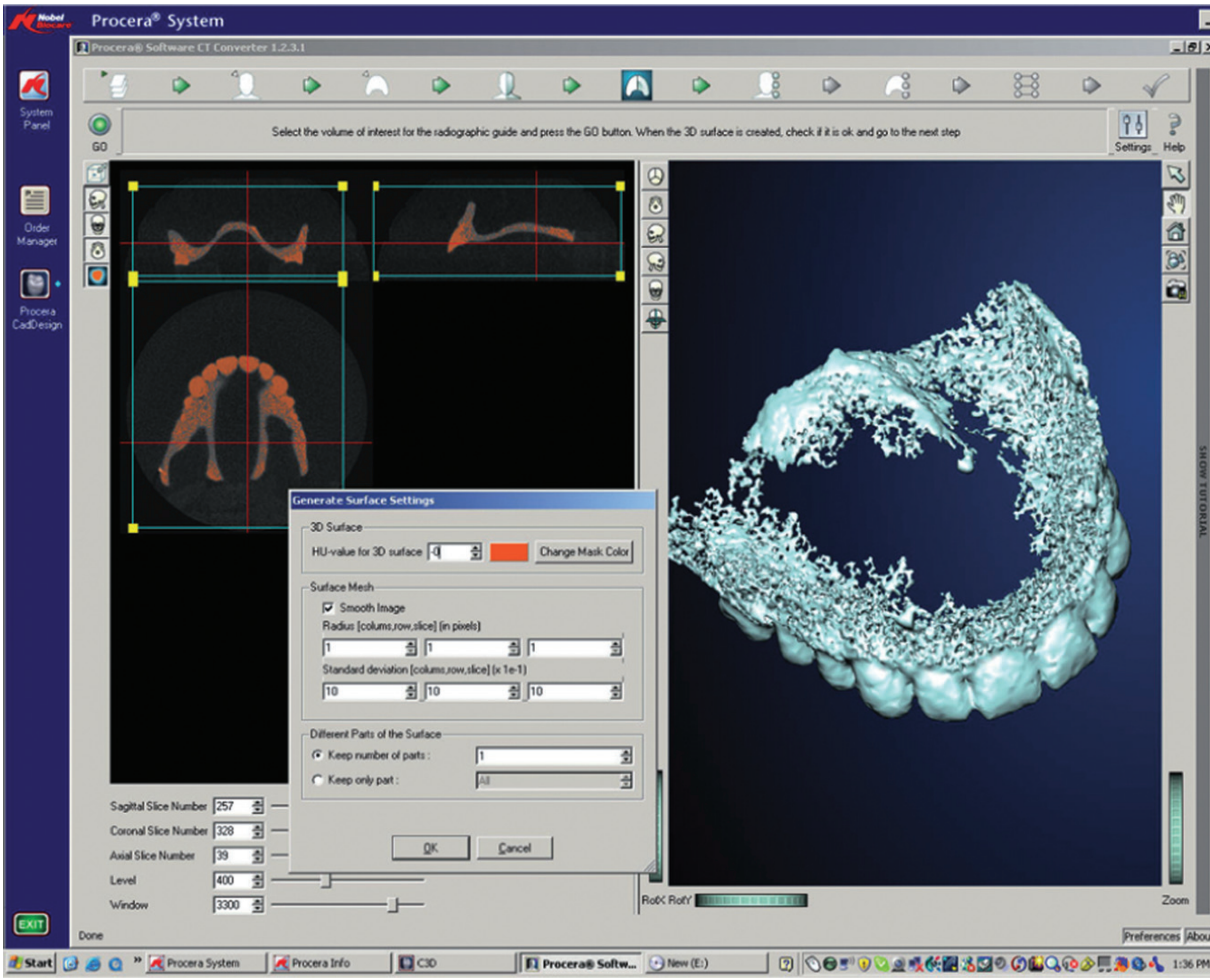

Figure 21 Screenshot of converter set at ISO 0, to high, virtual model appears visually incorrect.

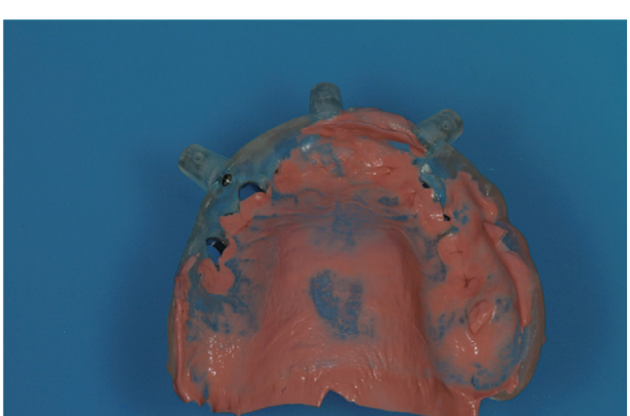

Figure 22 VPS disclosing material indicating intimacy of fit of a surgical guide to soft tissue (photograph of a different case).

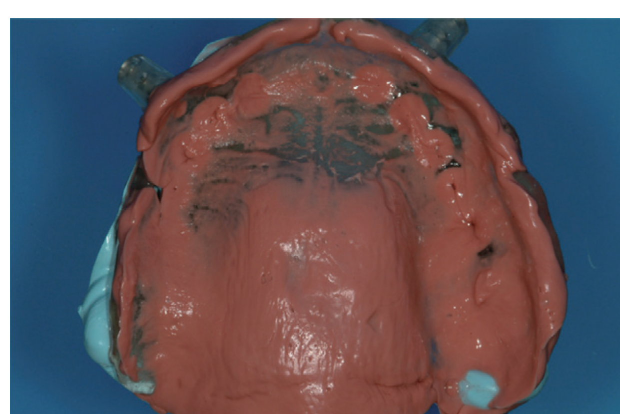

Figure 23 VPS disclosing material indicating intimacy of fit of surgical guide to soft tissue when related with surgical index. Note palatal thickness of VPS, indicating ill fitting of guide, because of incorrect surgical index.

clinically acceptable numerical indicator when a guide can be used for implant placement. For example, a standard set of fiduciary markers in a holder for the scan denture could be scanned together with the scan denture. The marker's size, interrelationship, and location will be known to the software. The marker will follow a similar path within the computer processes as the scan denture, as it is one file. When ultimately the file is created for the duplicate denture, then the marker parameters can be verified to the know markers of the holder and an error recorded. This error would then apply as well to the duplicate denture and could be quantified. At this time, the duplicate denture is used for this purpose. As was shown, the threshold for the ISO values is probably not solely responsible for the discrepancies noted. Case 1 showed a generalized deformation of the surgical guide, with documented incorrect threshold values used for the denture setting. Case 3 showed that even with correct ISO settings, local deformation is still possible. Therefore, a combination of other factors known and unknown maybe involved. Errors in scan parameter setting, interslice distance, and general operator functioning are known to attribute to a less than ideal outcome, but less understood factors may be at play as well. Therefore, more research and development are needed. It should be noted again that although only the experience with one manufacturer's product has been described, careful evaluation of all SLA-produced guides seems to be prudent.

CONCLUSION

SLA-produced surgical guide stents have the potential to be dissimilar from the original scan denture. This will have an effect on the clinical reliability of those guides. The ISO threshold setting in the conversion software is a very sensitive component of the production process. Other, at this time, unknown factors appear to be responsible as well; further research is warranted. Verification of the volumetric congruence of the produced SLA guide and the scan denture is advised.

REFERENCES

1. Quinlan P, Richardson CR, Hall EE. A multipurpose template for implant placement. Implant Dent 1998; 7:113–121.
2. Weinberg LA, Kruger B. Three-dimensional guidance system for implant insertion: part I. Implant Dent 1998; 7:81–93.
3. Atsu SS. A surgical guide for dental implant placement in edentulous posterior regions. J Prosthet Dent 2006; 96:129–133.
4. Shotwell JL, Billy EJ, Wang HL, Oh TJ. Implant surgical guide fabrication for partially edentulous patients. J Prosthet Dent 2005; 93:294–297.
5. Meitner SW, Tallents RH. Surgical templates for prosthetically guided implant placement. J Prosthet Dent 2004; 92:569–574.
6. Windhorn RJ. Fabrication and use of a simple implant placement guide. J Prosthet Dent 2004; 92:196–199.
7. Tsuchida F, Hosoi T, Imanaka M, Kobayashi K. A technique for making a diagnostic and surgical template. J Prosthet Dent 2004; 91:395–397.
8. Stumpel L. Cast-based guided implant placement: a novel technique. J Prosthet Dent 2008; 100:61–69.
9. Wanschitz F, Birkfellner W, Watzinger F, et al. Evaluation of accuracy of computer-aided intraoperative positioning of endosseous oral implants in the edentulous mandible. Clin Oral Implants Res 2002; 13:59–64.
10. Wittwer G, Adeyemo WL, Schicho K, Birkfellner W, Enislidis G. Prospective randomized clinical comparison of 2 dental implant navigation systems. Int J Oral Maxillofac Implants 2007; 22:785–790.
11. Wittwer G, Adeyemo WL, Schicho K, Gigovic N, Turhani D, Enislidis G. Computer-guided flapless transmucosal implant placement in the mandible: a new combination of two innovative techniques. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2006; 101:718–723.
12. Casap N, Tarazi E, Wexler A, Sonnenfeld U, Lustmann J. Intraoperative computerized navigation for flapless implant surgery and immediate loading in the edentulous mandible. Int J Oral Maxillofac Implants 2005; 20:92–98.
13. Kramer FJ, Baethge C, Swennen G, Rosahl S. Navigated vs. conventional implant insertion for maxillary single tooth replacement. Clin Oral Implants Res 2005; 16:60–68.
14. Casap N, Wexler A, Lustmann J. Image-guided navigation system for placing dental implants. Compend Contin Educ Dent 2004; 25:783–784, 786, 788.
15. Di Giacomo GA, Cury PR, de Araujo NS, Sendyk WR, Sendyk CL. Clinical application of stereolithographic surgical guides for implant placement: preliminary results. J Periodontol 2005; 76:503–507.
16. Van Steenberghe D, Malevez C, Van Cleynenbreugel J, et al. Accuracy of drilling guides for transfer from three-dimensional CT-based planning to placement of zygoma implants in human cadavers. Clin Oral Implants Res 2003; 14:131–136.
17. Terzioğlu H, Akkaya M, Ozan O. The use of a computerized tomography-based software program with a flapless surgical technique in implant dentistry: a case report. Int J Oral Maxillofac Implants 2009; 24:137–142.

18. Ruppin J, Popovic A, Strauss M, Spüntrup E, Steiner A, Stoll C. Evaluation of the accuracy of three different computer-aided surgery systems in dental implantology: optical tracking vs. stereolithographic splint systems. Clin Oral Implants Res 2008; 19:709–716.
19. Sarment DP, Al-Shammari K, Kazor CE. Stereolithographic surgical templates for placement of dental implants in complex cases. Int J Periodontics Restorative Dent 2003; 23:287–295.
20. Fortin T, Isidori M, Blanchet E, Perriat M, Bouchet H, Coudert JL. An image-guided system-drilled surgical template and trephine guide pin to make treatment of completely edentulous patients easier: a clinical report on immediate loading. Clin Implant Dent Relat Res 2004; 6:111–119.
21. Fortin T, Champleboux G, Bianchi S, Buatois H, Coudert JL. Precision of transfer of preoperative planning for oral implants based on cone-beam CT-scan images through a robotic drilling machine. Clin Oral Implants Res 2002; 13:651–656.
22. Arvier JF, Barker TM, Yau YY, D'Urso PS, Atkinson RL, McDermant GR. Maxillofacial biomodelling. Br J Oral Maxillofac Surg 1994; 32:276–283.
23. Lal K, White GS, Morea DN, Wright RF. Use of stereolithographic templates for surgical and prosthodontic implant planning and placement. Part I. The concept. J Prosthodont 2006; 15:51–58.
24. Ozan O, Turkyilmaz I, Ersoy AE, McGlumphy EA, Rosenstiel SF. Clinical accuracy of 3 different types of computed tomography-derived stereolithographic surgical guides in implant placement. J Oral Maxillofac Surg 2009; 67:394–401.
25. Ersoy AE, Turkyilmaz I, Ozan O, McGlumphy EA. Reliability of implant placement with stereolithographic surgical guides generated from computed tomography: clinical data from 94 implants. J Periodontol 2008; 79:1339–1345.
26. Van Assche N, van Steenberghe D, Guerrero ME, et al. Accuracy of implant placement based on pre-surgical planning of three-dimensional cone-beam images: a pilot study. J Clin Periodontol 2007; 34:816–821.
27. Vercruyssen M, Jacobs R, Van Assche N, van Steenberghe D. The use of CT scan based planning for oral rehabilitation by means of implants and its transfer to the surgical field: a critical review on accuracy. J Oral Rehabil 2008; 35:454–474 [Epub 2008 April 22].
28. Balshi SF, Wolfinger GJ, Balshi TJ. Guided implant placement and immediate prosthesis delivery using traditional Brånemark System abutments: a pilot study of 23 patients. Implant Dent 2008; 17:128–135.
29. Malo P, de Araujo Nobre M, Lopes A. The use of computer-guided flapless implant surgery and four implants placed in immediate function to support a fixed denture: preliminary results after a mean follow-up period of thirteen months. J Prosthet Dent 2007; 97(Suppl 6):S26–S34.
30. van Steenberghe D, Glauser R, Blombäck U, et al. A computed tomographic scan-derived customized surgical template and fixed prosthesis for flapless surgery and immediate loading of implants in fully edentulous maxillae: a prospective multicenter study. Clin Implant Dent Relat Res 2005; 7(Suppl 1):S111–S120.
31. Yong LT, Moy PK. Complications of computer-aided-design/computer-aided-machining-guided (NobelGuide) surgical implant placement: an evaluation of early clinical results. Clin Implant Dent Relat Res 2008; 10:123–127.
32. Komiyama A, Klinge B, Hultin M. Treatment outcome of immediately loaded implants installed in edentulous jaws following computer-assisted virtual treatment planning and flapless surgery. Clin Oral Implants Res 2008; 19:677–685.
33. Oyama K, Kan JY, Kleinman AS, Runcharassaeng K, Lozada JL, Goodacre CJ. Misfit of implant fixed complete denture following computer-guided surgery. Int J Oral Maxillofac Implants 2009; 24:124–130.