Computer-supported implant planning and guided surgery: a narrative review

The placement of endosseous implants has many pitfalls: movement of the patient while drilling, limited surgery time related to the use of local anesthesia, a restricted visualization of the operation field, mental transfer of two-dimensional radiographs into the three-dimensional surgical environment, esthetics, biomechanics, and functional constraints of the prosthetic treatment. Thus, during a limited time span and with a restricted view, the surgeon has to take numerous decisions while nurturing a conscious patient under aseptic conditions. Therefore, a thorough pre-operative planning of the number of implants to be placed, their size, position, and inclination will free the surgeon’s mind, allowing concentrating on the patient and the tissues handling.

As its development in the mid-nineties, guided implant surgery has quickly gained popularity [Verstreken et al. 1996, 1998; Jacobs et al. 1999]. The introduction of the cone beam computed tomography (CBCT), enabling volumetric jaw bone imaging at reasonable costs and low radiation doses [Guerro et al. 2006; Loubele et al. 2008], facilitated the collection of a large amount of information preoperatively (Jacobs & Quirynen 2014) including: an exact knowledge of the available bone volume and quality, the presence/location of anatomical structures and pathologies, and their relationship with the future restorative rehabilitation. As such the planning can be nearly completed preoperatively [Vercruyssen et al. 2008].

At this moment, different methods are available to transfer the “planned” information to the “clinical” situation. Jung et al. [2009] categorized these methods into “static” and “dynamic”. Static systems apply surgical templates or implant guides, while dynamic systems transfer the selected implant position to the surgical area via visual imaging tools on a monitor. A dynamic system includes surgical navigation and computer-aided navigation technologies, and allows the surgeon to alter the implant position in real time.

The workflow of the static and dynamic guided surgery is summarized in Fig. 1.
details on the differences between static and dynamic guided surgery can, however, be found in a recent review paper by Verbruysen et al. [2014d]. Jung et al. [2009] stated that static systems had a tendency to be more accurate. However, most of the publications on navigation at that time had been clinical studies, whereas the majority of papers on static protocols were preclinical (models or cadaver), with more favorable conditions [Tahmaseb et al. 2014]. Today dynamic systems are not frequently used, primarily due to the initial high costs, even though the technology opens new perspectives.

Static surgical guides are currently most often applied [Jung et al. 2009], and therefore, this review will concentrate on this technology. Between static surgical guiding systems for implant placement, significant variations can be observed [Van Assche et al. 2012]. One can distinguish different modalities regarding the fabrication of the drill guide; some guides are fabricated via rapid prototyping while others are produced via mechanical routing where others are produced via mechanical positioning devices that convert a radiographic scan prosthesis into a surgical guide (model based) [Fortin et al. 2002, 2004]. Some systems use for one patient different templates with sleeves with increasing diameter, while others use removable sleeves in one template and sleeve inserts or sleeve on drills [Koop et al. 2012]. Particular systems foresee special drills or drill stops to allow depth control, while other systems use indication lines on the drills. After the preparation of the implant osteotomy, a number of systems allow a guided insertion of the implant [fully guided implant placement], while for other systems, the template has to be removed to allow free-handed implant insertion. A guide can be tooth, bone, or mucosa supported. The choice is primarily made on the number of remaining teeth for support of the guide and on the need/wish for a flapless approach.

This review has been based on a previous systematic review [Van Assche et al. 2012]. An additional electronic literature search of the PubMed database was performed with the intention of collecting relevant information on computer-supported implant planning and guided surgery. The search included articles published from January 2012 up to December 2014. Following search terms were used dental or oral, implant*, guid*, and compute*. The aim of the present narrative review was to give an overview of the workflow from examination to planning and execution, including possible errors and pitfalls, in order to justify the indications for guided surgery.

Examination
As a prerequisite, every patient should be considered for implant surgery after thorough examination and basic dental treatment. Guided implant surgery should not be considered solely with the flapless approach, as there are indications for flap elevation before guided implant surgery. If the patient is a candidate for computer-supported implant planning and guided surgery, several steps should be carried out.

Guided implant placement requires three-dimensional (3D) imaging of the bone and of the planned prosthesis. In edentulous patients, the ideal tooth position is visualized via a scan prosthesis, so that the implants can be positioned taking both anatomic and prosthetic aspects into account. As a standard resin prosthesis has a density, similar to that of the surrounding soft tissues, it is nearly impossible to segment it from the CT images. Therefore, a special scan prosthesis has to be prepared. This can be performed in several ways.

- A first option in edentulous patients is to prepare a copy of the prosthesis in radiopaque resin. As such only one scan has to be made with the patient wearing this radiopaque prosthesis.
- A double-scan procedure is another option (Fig. 2). First, the patient is scanned with the prosthesis and the index in the mouth. The scan prosthesis is than scanned, with alerted exposure parameters, to visualize the denture and teeth. This procedure requires an integration of the scan prosthesis within the craniofacial model (Verstreken et al. 1996, 1998). Therefore, the scan prosthesis contains for example small gutta-percha spheres (diameter ± 1 mm). The craniofacial images show the gutta-percha markers in relation to the bone, without visualizing the prosthesis itself. As the markers are visible in both sets of scans, they can be transformed and realigned to fuse the prosthesis within the maxillo-facial structures [Jacobs et al. 1999, Van Steenberghe 2005].

In partially edentulous patients, a virtual computerized prosthetic wax-up or digital scanning from an analogue wax-up is usually used to visualize the ideal prosthetic setup. Additional benefit could come from data retrieved from an intra-oral scanner (mucosal tissues) by superimposing these data with the ones obtained with (CB)CT. In fact, by doing so it is possible to visualize hard and soft tissue anatomy and to obtain a more precise segmentation of the residual teeth. A double scanning technique could be applied also in partially edentulous patients, but it is questioned whether this technique is still used.

Some precautions
- When a scanning mucosa-supported prosthesis is used, correct positioning of the scan prosthesis in optimal fit with the patients soft tissues is crucial. The scan prosthesis has to fit well and one has to verify whether air is visible between the scan prosthesis and the soft tissues (Fig. 3). This is especially important for mucosa-supported guides, where the basis of the future surgical guide will be the same as the basis of the scan prosthesis. Furthermore, the prosthesis should have sufficient thickness, to allow a correct segmentation. In case of insufficient thickness, it is not possible to differentiate between the acrylic borders and the

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Fig. 1. Workflow of the static and dynamic guided surgery. Legend: SLA = stereolithography, Labo = laboratory, N = Navigation.
air, and holes will be visible in the scanned prosthesis.

- Motion artifacts during (CB)CT examination are a big concern (Pettersson et al. 2012).
- Metal artifacts can influence the image quality and render the identification of the outline of the alveolar bone and anatomical boundaries more difficult (Dreisdeider et al. 2009).
- A correct tooth setup of the teeth, performed either virtually or with an analogue method, is mandatory.
- The double-scan technique with fiducial marker-based matching (i.e., gutta-percha) can also be a possible source for deviation both in partially edentulous and edentulous patients, for example, if the matching is incorrect (Verhamme et al. 2012). The matching process can include several manual setup parameters, and it is important to choose the optimal settings for segmentation of the markers to obtain a maximum number of registered markers. Furthermore, Pettersson et al. (2012) experienced that the automatic superimposing procedure of gutta-percha markers sometimes proceeded without any notification of errors, while motion artefacts were present. Therefore, the surgeon is responsible for checking the accuracy of the procedure.
- The use of pre-installed reference markers such as mini-implants could increase the accuracy of the scan prosthesis matching process and later positioning of the guide.

Clinical confirmation, however, is still lacking (Tahmaseb et al. 2010; Tahmaseb et al. 2014).

- In case of a tooth-supported guide, it is recommended to take an additional impression of the remaining teeth. The cast is than scanned and integrated with the radiographic images to create a more accurate 3D model of the teeth (Vandenberghhe et al. 2010; Al-Rawi et al. 2011). This extra step is simplified if an intra-oral optical scan is used (Reich et al. 2014).
- Changes in the mucosa and alveolar bone during the time between the assessment and surgical intervention have to be taken into consideration. Resorption of the alveolar crest after recent tooth extraction, immature bone with low density that does not show up in the (CB)CT and changes in thickness of soft tissues will result in an inadequate planning.
- The applied radiographic technique has no influence on the correct imaging of the patient or his prosthesis. Several studies (Arisan et al. 2013c; Poeschl et al. 2013) have shown that there is no difference in the accuracy between MSCT and CBCT, for their use in guided implant surgery. It is thus advisable to use the lowest radiation exposure taking into consideration the ALARA concept.

Planning

There are several planning software packages available to virtually plan implant placement. Planning should always be based on the need to achieve a prosthesis that respects the biological, functional, and esthetic requirements.

Once the planning is completed and approved by the dentist responsible for the treatment, and the digital information is used to produce the stent with either an analogue method or CAM rapid prototyping (milling or 3D printing).

Some publications reported on the use of pre-installed mini-implants that function as fiducial markers and as the retention mechanism for the scanning prosthesis and the drill guide (Tahmaseb et al. 2010). Other systems use fixation screws to stabilize the drill guide which is posited using a bite index (Vercruyssen et al. 2014b).

Some precautions

- Some factors have to be considered before producing the stent. The planned implant

![Fig. 2. The scan prosthesis, which has been scanned separately with more exposure parameters to become visual, can be integrated within the craniofacial model by matching the small gutta-percha spheres which are visible on both scans.](image)

![Fig. 3. Clinical example with air between the scan prosthesis and the soft tissues.](image)
length can be limited, due to insufficient interarch space during surgery (patient limitation). The planning might lead to a stent involving the use of drill lengths that are not directly available. Furthermore, sufficient interimplant or tooth-implant distance should be foreseen to be able to place the sleeves in the guide with sufficient material to prevent fracture of the guide (hardware limitation).

- The overall deviation in the production process of a stereolithographic guide is <0.3 mm (Swaelens & Kruth 1993). The guide production executed in the laboratory with the aid of a coordinate transfer apparatus or with the computer numerical control (CNC) milling machine has a deviation of <0.5 mm (Dreiseidler et al. 2009).

- An additional cumulative deviation error may be caused by either the (CB)CT scan, the image segmentation, and/or the creation of the model itself (Bianchi et al. 1997; Santler et al. 1998; Schneider et al. 2002). For example, if the 3-D reconstruction for the creation of the surgical template is generated with a too low gray value threshold, the surgical template will be thicker than the original radiographic guide, resulting in a higher position toward the alveolar ridge and the implants will be placed to superficially (Verhamme et al. 2012).

**Execution**

Before surgery, the surgical guide needs to be fitting intra-orally. To expose the bone in case of a flapless approach, a punch technique can be used through the guide. The guide may be anchored to the bone with mini-screws (Fig. 4) or temporary implants to improve accuracy of the procedure. To guarantee a good position, the use of a bite index to stabilize the guide is recommended when inserting the mini-screws.

The drilling procedure can involve the use of drill keys inserted in the sleeves within the guide, which guide the consecutive drills with different diameters in the correct position and angulation. For some systems, the drill key can be attached on the drills or can be designed as spoons. The drills can have a physical or a visual stop. Some systems use different guides for each drill diameter. Guidance of the implant during insertion is system specific.

Complications during surgery were reported (Tahmaseb et al. 2014) such as temporary implant fracture (3.6%), change in surgical plan (2.0%), lack of primary stability of implants (1.3%).

The major concern for the transfer of the planning to the operative field is the accuracy, defined as the deviation between the position of the “planned” and the “inserted” implant. The latter is crucial in order to avoid anatomical boundaries and to prevent neurological complications (Jacobs et al. 2014). The inaccuracy is mostly expressed by four parameters: (i) deviation at the entry point, (ii) deviation at the apex, (iii) deviation of the long axis (angulation), and (iv) deviation in depth. More recently, additional attention has been given to deviations in mesio-distal and bucco-lingual direction (Verhamme et al. 2012, 2013; Vercruyssen et al. 2014a).

Several recent systematic reviews have verified the accuracy of guided implant surgery (Van Assche et al. 2012; Tahmaseb et al. 2014). Data from the last systematic review (Tahmaseb et al. 2014) revealed an overall mean deviation at the entry point of 0.9 mm (95% CI 0.7–1.1), with a maximum of 4.5 mm. The corresponding data at the apex were 1.3 mm (95% CI 0.05–1.5), with a maximum of 7.1 mm. The overall mean deviation in angulation was 3.5° (95% CI 3.0–4.1), with a maximum of 21.2. This review included 24 articles, which reported on accuracy. From the included studies, 5 were model based, 5 were human cadaver studies, and there were 14 in vivo patient studies.

In a recent RCT, several static guiding systems have been compared to freehand surgery and the use of a surgical guide, involving one surgeon (Vercruyssen et al. 2014a,b,c). Seventy-two edentulous lower or upper jaws were randomly assigned to one of the following treatment groups (12 jaws/group): Materialise Universal® mucosa-supported guide (flapless approach) (no drill stop and freehanded implant insertion), Materialise Universal® bone-supported guide (no drill stop and freehanded implant insertion), Facilitate® mucosa-supported drill guide (drill stop and guided implant insertion), Facilitate® bone-supported drill guide (drill stop and guided implant insertion), freehand implant placement (software planning, CT images with planning available during surgery, no guide) and a pilot-drill template (radiopaque scan prosthesis converted into a surgical template by drilling holes at planned implant positions). Table 1 summarizes the data on the accuracy, including information on the bucco-lingual and mesio-distal deviation. It became obvious that the differences between the type of guidance (Materialise® or Facilitate®, mucosa, or bone supported) were negligible, but all were significantly superior to freehanded placement or a pilot-drill template (Vercruyssen et al. 2014a,b). Data on partially edentulous patients referring to this type of research are not available up till now.

The literature is not consistent on whether a learning curve is important; one clinical trial observed a learning curve (Vasak et al. 2012).
Deviations may reflect the sum of all errors occurring from imaging to the transformation of data into a guide, to the improper positioning of the latter during surgery. Thus, all errors have a cumulative effect (Fig. 5).

### Some precautions

- The positioning and stabilization of the surgical guide has a major impact on the accuracy. It is important to place fixation pins to avoid rotation of the surgical template [Van Assche et al. 2012; Tahmaseb et al. 2014]. To this extent, the stabilization of drill guides on mini-implants has also been advised [Tahmaseb et al. 2010].

- Tooth-supported surgical guides have been described as being stable when used in guided surgery.

- A bite index is often used to fix the surgical guide in the correct position before placing the fixation pins. Because of the resilience of the mucosa, the surgical guide can easily be fixated in a rotated position, resulting in an inaccurate position of all the implants [D'haese & De Bruyn 2013; Verhamme et al. 2013].

- When using a bite index possible production inaccuracies in the occlusal surface of the surgical guide must be assessed as they can jeopardize a good fit with the bite index [Stumpel 2012]. In addition, the mucosa might be swollen after local anesthesia, which could cause small changes in fit between the guide and the mucosa [Sun et al. 2013].

- During the drilling process, one has to be aware of a certain tolerance of the drills within the sleeves [Van Assche & Quirynen 2010]. Therefore, one has constantly to check that the correct direction is followed during the entire drilling sequence.

- To reduce errors due to this tolerance, different solutions have been proposed. By increasing the drill key height and/or the guiding sleeve height, and decreasing the distance between the sleeve and the bone the accuracy could be improved in *vitro* (Koop et al. 2012). However, longer sleeve inserts could require a larger mouth opening and the apical position of the sleeve is limited due to possible interference of the sleeve with the mucosa or the alveolar bone. Reduction of the tolerance between drills and the drill keys is difficult due to mechanical friction and the formation of metal debris, but resulted in a higher accuracy [Schneider et al. 2014]. Tahmaseb et al. (2010) described a specific drill design avoiding the use of drill keys or drills with different sheath diameters.

- Recent publications [Farley et al. 2013; Vercruyssen et al. 2014a] have shown that the most significant error with guided surgery is made in vertical direction (depth). Horizontal inaccuracies are clearly less. The vertical inaccuracy can be explained by: The presence of debris in the implant cavity so that the implant cannot reach its final position, the resilience of the mucosal tissues [compression of the tissues could result in a more subcrestal implant position], the setting of the gray values during segmentation and surgical guide reconstruction [a guide reconstruction with too low gray values will be too thick and will be positioned too high on the alveolar process, resulting

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**Table 1. Summary of data from RCT comparing different static guides (either mucosa or bone supported) with freehanded implant placement and the use of a pilot-drill guide (12 jaws and ± 55 implants per group) (Vercruyssen et al. 2014a,b)**

<table>
<thead>
<tr>
<th>Deviation</th>
<th>Materialise</th>
<th>Facilitate</th>
<th>Mental Navigation</th>
<th>Surgical Template</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mucosa</td>
<td>Bone</td>
<td>Mucosa</td>
<td>Bone</td>
</tr>
<tr>
<td>Entry</td>
<td>1.23</td>
<td>1.60</td>
<td>1.38</td>
<td>1.33</td>
</tr>
<tr>
<td>SD</td>
<td>0.60</td>
<td>0.92</td>
<td>0.64</td>
<td>0.82</td>
</tr>
<tr>
<td>Max.</td>
<td>2.65</td>
<td>3.73</td>
<td>2.68</td>
<td>3.58</td>
</tr>
<tr>
<td>Angulation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>2.86</td>
<td>3.79</td>
<td>2.71</td>
<td>3.20</td>
</tr>
<tr>
<td>SD</td>
<td>1.6</td>
<td>2.36</td>
<td>1.36</td>
<td>2.70</td>
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<tr>
<td>Max.</td>
<td>7.60</td>
<td>10.05</td>
<td>6.36</td>
<td>16.03</td>
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<tr>
<td>Apex</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>1.57</td>
<td>1.65</td>
<td>1.60</td>
<td>1.50</td>
</tr>
<tr>
<td>SD</td>
<td>0.71</td>
<td>0.82</td>
<td>0.70</td>
<td>0.72</td>
</tr>
<tr>
<td>Max.</td>
<td>2.99</td>
<td>3.66</td>
<td>3.27</td>
<td>3.56</td>
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<tr>
<td>Depth</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Mean</td>
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<td>0.74</td>
<td>1.00</td>
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<tr>
<td>SD</td>
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<td>0.94</td>
<td>0.65</td>
<td>0.69</td>
</tr>
<tr>
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<td>3.65</td>
<td>3.32</td>
<td>3.00</td>
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<tr>
<td>Subparameters deviation at entry</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Lateral</td>
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<tr>
<td>Mean</td>
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<td>1.04</td>
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<td>0.50</td>
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<td>2.10</td>
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<td>2.46</td>
<td>2.49</td>
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<tr>
<td>Mesio-distal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>0.61</td>
<td>0.54</td>
<td>0.69</td>
<td>0.68</td>
</tr>
<tr>
<td>SD</td>
<td>0.48</td>
<td>0.5</td>
<td>0.56</td>
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<tr>
<td>Max.</td>
<td>1.69</td>
<td>2.07</td>
<td>2.41</td>
<td>2.45</td>
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<tr>
<td>Bucco-lingual</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
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<td>0.5</td>
<td>0.59</td>
<td>0.31</td>
</tr>
<tr>
<td>SD</td>
<td>0.45</td>
<td>0.59</td>
<td>0.47</td>
<td>0.22</td>
</tr>
<tr>
<td>Max.</td>
<td>2.08</td>
<td>2.88</td>
<td>1.92</td>
<td>1.10</td>
</tr>
</tbody>
</table>
in an too superficial implant position] (Stumpel 2013; Verhamme et al. 2013), the blockage of the implant holders in the sleeves or by the crestal bone or deformation of the guide during surgery [Tahmaseb et al. 2010]. Tahmaseb et al. also designed a drill stop that prevents inserting implants at the incorrect depth.

- Guided implant insertion, when compared to freehanded placement after guided osteotomy, shows a higher accuracy [Tahmaseb et al. 2014].
- A mucosa-supported approach seems to offer higher accuracy than a bone-supported procedure [Van Assche et al. 2012; Tahmaseb et al. 2014]. The literature included in these systematic reviews, however, did not report on bone-supported guides fixed with mini-screws to the underlying bone, in a recent RCT (Vercruyssen et al. 2014b), no difference could be observed between bone- and mucosa-supported guides, when both were stabilized with fixation screws.
- Tooth-supported guides tend to be slightly more accurate than mucosa-supported guides, but the differences are small [Van Assche et al. 2012; Tahmaseb et al. 2014].
- No overall significant differences were observed for the accuracy of guided surgery in the mandible compared to the maxilla [Tahmaseb et al. 2014].

Indications

Indications for guided surgery may include need for minimal invasive surgery or flapless approach, optimization of implant placement and positioning and immediate restoration. This approach could also be useful for geriatric patients and patients with compromised medical conditions. The use of only the computer-supported planning could also be beneficial for both the patient and the clinician.

Guided surgery offers a number of advantages. When during the planning of the implants in the software program, the prosthetic superstructure is included, the most optimal position of the implants (depth, mesio-distal, bucco-lingual as well as inclination) in relation to the future reconstruction can be designed. As such the implants can be planned to support a prosthesis that provides the “biological, functional, and esthetic” requirements and at the same time the morphology of the jawbone as well as anatomical boundaries can be taken into account. These factors can of course contribute to a long-term success of the implants, although long-term data to prove this statement are unfortunately not available at this moment. A systematic review by Tahmaseb et al. (2014) indicated a mean failure rate of 2.7%, using a static guide and after an observation period of at least 12 months.

Moreover, the need for bone regeneration as well as for prosthetic modifications (e.g., angulated abutments, removable instead of fixed, …) can be anticipated. The latter can prevent disappointment of the patient, because the final outcome is easier to predict. Finally, if the planning is discussed between surgeon and prosthodontist, a better mutual understanding can be reached.

Up to now, it remains unclear how much inaccuracy can be accepted. This does, however, influence the final impact of such deviation depends on the anatomic situation (bone volume, the presence of neuro- logical structures), interimplant/tooth distance, future prosthetic rehabilitation, etc. (Schneider et al. 2014). The literature seems to indicate that one has to accept an inaccuracy of ±1.5 mm [Van Assche et al. 2012; Tahmaseb et al. 2014] which is clearly less than for nonguided surgery [Vercruyssen et al. 2014b].

A recent systematic review indicated that flapless implant placement will reduce patient morbidity (Hultin et al. 2012). A later study confirms the latter findings (Pozi et al. 2014), while another study could not demonstrate a better patient centered outcome [Vercruyssen et al. 2014c].

The duration of a surgical intervention can influence the morbidity for the patient. Arisan et al. (2010) compared the duration for implant placement in fully edentulous jaws (flapless guided surgery vs. open flap guided surgery vs. conventional surgery) and reported that the first mentioned approach took half the time of the other two approaches (24 min. vs. more than 60 min.). In another trial, the same researchers compared conventional (n = 29) with computer-assisted stereolithographic template-guided surgery (n = 34) in fully edentulous jaws (Arisan et al. 2013b), and again indicated a significant reduction in surgical time for the guided approach (63 vs. 33 min, respectively).

The improved accuracy obtained with guided implant surgery may provide a better platform for the final prosthetic restoration. Guided implant surgery might also provide a more predictable esthetic outcome, if the preplanned implant positions are transferred precisely into the surgical environment. Arisan et al. (2013a) evaluated seven positioning error criteria by a blinded examiner at the stage of prosthesis delivery in fully edentulous patients treated with freehanded or computer-guided surgery. They found that the interproximal emergence (OR = 2.82, P < .0001), insufficient interimplant distance (OR = 1.42, P < .0001), and improper parallelism (OR = 1.24, P = .001) errors were significantly higher in implants placed by the freehand method. Fühauser et al. (2014) conducted a clinical study using stereolithographic guided surgery to insert single-tooth implants for the replacement of upper incisors. The inaccuracy was assessed and an evaluation of implant esthetics [Pink Esthetic Score] was performed after a mean follow-up of 2.3 years. Even though guided, a mean deviation at the implant shoulder of 0.84 mm was recorded. The authors also observed that deviations ≥0.8 mm resulted in significantly worse implant esthetics [median PES: 9.5] compared with more accurate implant positions [median PES: 13, P = 0.039].

Guided implant placement also facilitates treatments involving immediate restoration. It even allows the use of a prefabricated restoration which can be delivered immediately after implant placement to improve patient satisfaction including comfort, function, and esthetics (Pozi et al. 2014). The application of prefabricated restorations resulted in acceptable survival rates, ranging from 91% to 100% [Jung et al. 2009; Papaspyridakos et al. 2014].

The cost-effectiveness of different guided surgery protocols is difficult to judge as no information regarding this parameter could be found in the scientific literature.

An interesting clinical question is if these techniques can be used as an alternative to bone augmentation. Unfortunately, only one article addresses this question. Fortin et al. (2009) used the guided technique in partially edentulous cases with severely resorbed maxilla’s and reported a 98% implant survival rate after 4 years, without any augmentation procedure. As of yet we cannot state that guided surgery can be used as an alternative for augmentation procedures.

Future

Digital technology and computer-aided design/computer-aided manufacturing systems are rapidly progressing. Today, in a conventional workflow, the CBCT is taken with a scan prosthesis, which means intra-oral impression taking, fabrication of a plaster cast, a wax-up of the desired tooth position and finally the production of the scan pros-
thesis, the basis for the later surgical guide. If an exclusively digital workflow is chosen, intraoral digital impressions are taken. On these digital models, the desired prosthetic suprastructures are designed, taking into consideration the intra-oral soft tissues (Flügge et al. 2013). The entire datasets are virtually superimposed by a “matching” process on the corresponding structures [teeth] in the CBCT (only possible today in partially edentulous cases). Thus, both the osseous and prosthetic structures are visible in one single 3D application and make it possible to consider surgical and prosthetic aspects. After having determined the implant positions on the computer screen, a drilling template is designed digitally. According to this design (CAD), a template is 3D printed or milled in a CAM process. This template is than the first physically extant product in the entire workflow (Reich et al. 2014). The ultimate integration would be a full three-dimensional data matching of radiographic, optical, and potential clinical images creating the virtual patient (Jacobs & Quirynen 2014).

Conclusion

The digital technology is rapidly evolving and new developments will enable further improvements in reducing the inaccuracy. A crucial factor for the improvement of the accuracy seems to be to reduce the number of steps needed from the preoperative examination to the actual execution of the guided surgery. The implementation in the near future of optical scans and 3D printing will facilitate this process. If the predictability of the treatment can be increased, the number of clinical applications can also be further expanded.

References


Pettersson, A., Komiyama, A., Hultin, M., Næström, K. & Klingen, B. (2012) Accuracy of virtually planned and template guided implant sur-
gery on edentate patients. *Clinical Implant Dentistry and Related Research* **14**: 527–537.


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