3D planning in the reconstruction of maxillofacial defects
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Free flap reconstruction of oncology patients

At the start of this PhD project knowledge about 3D reconstructive planning of maxillofacial defects was rather limited. A pubmed search on 3D planned fibula reconstructions of the jaw yielded 4 results. While commercial software to plan fibula reconstructions was already available in 1988, only one study reported about accuracy of graft position using this method. The aim of this thesis is to add on knowledge about the accuracy of 3D planned fibula graft reconstructions of maxillofacial defects. Because dental implants have proven to favor chances of dental rehabilitation we included immediately placed dental implants in the planning and measurements on accuracy.

In chapter 2 we performed a systematic review on the functional outcome of fibula grafts of the jaw. We learned that the overall survival rate of dental implants, placed in a osteocutaneous Free vascularized Fibula Flap (FFF) is high with an survival rate of 95% (662 implants in 210 patients). The oral function in head and neck oncology patients after cancer treatment is better when they receive an implant-retained denture than a conventional denture. However, though implant-retained oral rehabilitation is favorable in head and neck cancer patients, implant placement in a FFF is often not straightforward and may result in non-used implants or even a failure of the prosthodontist of being able to make a functioning implant-retained overdenture. The problem with implant placement in FFFs is that proper positioning of the implants in a FFF is not easy due to loss of anatomical landmarks after tumor resection, especially when immediate placement is strived for. When implants are placed as a second stage surgery, scarification of mucosa, a bulky mucosa and/or a tender mucosa contribute to this problem. E.g., due to the resection of soft tissues a deficit of peri-implant soft tissue and often absence of a buccal sulcus remains. The latter conditions difficult the creation of healthy peri-implant soft tissues. These circumstances agree with the observation that more peri-implantitis is observed around implants placed in the often bulky, mobile soft tissues that are present in the reconstructed area. For these reasons either implants are not placed in FFF or cannot be used for retaining prosthetics in case it was attempted to place implants in these unfavorable soft and hard tissue conditions. As a result the implants become infected or are left buried as sleeping implants. The sum of the reported problems regarding implant-retained prosthodontics in oncology cases and our experience made us realize that proper planning of the reconstruction might be on the basis of optimal positioning of the graft and implants favoring a functional oral rehabilitation. Also combining efforts by involving both the surgeon who performs the reconstruction, the surgeon who places the implants (if not the same) and the prosthodontist who has to make the prosthodontic rehabilitation in composing the virtual reconstructive treatment plan, will to our opinion result in a viable, anatomical and clinical plan.

When focusing on planning of FFFs and its functional outcome the concept introduced by Dennis Rohner is promising, but in need of refining. The first step is to gain more anatomical insight and to reduce or even omit the multiple laborious steps of his method. The technique described in chapter 3 shows that the planning can be executed virtually as well as that the guides can be fully designed virtually thus overcoming the multiple, often time consuming and expensive, laborious steps. The in chapter 3 described cases also learned us that the errors between the virtual planning and the final result are rather small. This, however, does not necessarily mean that the error of the implant placement or cutting in itself is also small. But as we scan the actual implant position in the fibula with the Lava COS intra oral scanner and import the obtained data into the virtual plan, the result is an inherent correction of the implant position with regard to the final prosthodontics where after an rather accurate CAD-CAM bar or bridge can be milled. This way, there is an inherent compensation for surgical inaccuracies during implant placement. We tested this favorable outcome from our first cases in a case series (chapter 4). As expected the accuracy of the combination is larger than fibula reconstruction or implant placement alone. However, what was rather unexpected was the occlusal freedom the prefabricated prosthetics allowed the surgeon to place the segmented FFF without resulting in an improper occlusion. Thus the surgeon had the freedom to place the graft and denture entity as a whole in occlusion and even allowed for slight movement of the
graft to maximize bony contact at key-points in the donor area of the bony graft edges to the jaw. On the other hand we also noted that placing the prefabricated graft, including the implants and prosthetics, was sometimes difficult due to scar tissue as a result of previous surgery or radiotherapy. Hence reconstruction of large defects in these patients remains to be complex surgery. Authors who perform 3D planning of their reconstructions, noted that planning helped them to perform more complex reconstructions. Though the surgery can be complex, this does not mean that every FFF has to be planned digitally. The more straightforward a reconstruction is, meaning less fibula segments and easy positioning and landmark recognition, the less there is a need for 3D planning to our opinion.

As with every new technique, 3D planning and guided reconstruction also has a learning curve. Not only a surgical learning curve on how to manage guided surgery, but also a planning learning curve to efficiently perform a clinical viable plan. One can discuss who has to perform the 3D planning? It can be done by the surgeon or by someone with a technical background and sufficient medical knowledge to interpreted the clinical possibilities and limits. Also the 3D planning does not have to be performed in the hospital, it can also be performed outside the hospital and results and fine-tuning can be discussed in a web-meeting with the clinical team. Literature shows this variety of options well and there seems to be no golden standard or strong argument to choose one over the other.

Fixating the graft in occlusion and at the same time placing osteosynthesis plates is probably a limiting step in obtaining the maximum end result. Roser et al. (2010) mentioned already that adapting the osteosynthesis is a key factor with regard to a proper positioning of a 3D planned fibula grafts, especially when large reconstruction plates have to be shaped to match the planned position of the segments. Thus, the next logical step was to integrate a custom 3D shaped reconstruction plate into the virtual plan and fixate the graft using this CAD-CAM milled reconstruction plate (chapter 5). The same virtual treatment planning method was adopted as in the previous chapters to present a functional virtual reconstructive plan. The difference is that now the reference for placement of the graft is not the occlusion but the plate and the pre-drilled screw-fixation holes. Therefore this method is suitable to apply to immediate reconstruction after tumor ablation. This approach resulted in a higher accuracy compared to the approaches used in chapters 3 and 4. There are two major reasons underlying this favorable outcome, viz. primary wound closure is possible (the implants in the fibula that is transplanted to the oral cavity are buried which is necessary to bear post operative radiotherapy), and second; the time frame for the planning and fabrication of the guides an plate is less than 4 weeks, so the tumor resection and reconstruction can be performed within the time frame of 30 days according to the guidelines of the Dutch head and neck cancer taskforce which are based on international publications. Our clinical studies are focused on mathematical outcome compared to the virtual plan. Our time frame was relatively short to address the functional outcome of our patients. Besides this there is gross heterogeneity in the groups of patients. In total we treated 18 patients in total in 2 studies, 13 had a mandibula defect and 5 a maxilla defect. Six patients had osteoradionecrosis due to primary radiotherapy treatment. Nine patients had a primary diagnosis of squamous cell carcinoma, three had an ameloblastoma, the other 4 had varying other types of tumors. This heterogeneity can also influence functional outcome and the timeframe in which dental rehabilitation can be executed. We believe that our patients benefit of 3D planning and guided reconstruction and more patients receive a prosthetic and they receive the prosthesis earlier, compared to our traditional staged reconstruction. This is coherent with the paper of Avram et al. (2014) who reported about unprecedented rates of dental rehabilitation. It is known that prosthetic concepts may be changed during the treatment due to unfavorable soft tissue conditions which can lead to sleeping implants. One of our patients received 6 planned implants in the reconstructed mandible and due to the lack of a labial vestibule the 2 ventral implants could not be used to retain the denture (Fig. 1). This case illustrates that the soft tissue problems we encountered before 3D planning are as expected are not all overcome, but by planning more implants in a functional position we can probably compensate for the majority of technical problems that arise in these complex patients. One of the major advantages of the Rohner procedure for secondary reconstruction is the transplantation of a fixed peri-implant layer of soft tissue. We noted that in this group we
Figure 1. Fibula reconstruction of the mandible. In a one stage procedure 6 implants were inserted in the graft in an immediate reconstruction using 3D planning and a CAD-CAM reconstruction plate. The orthopantomogram (A) and the intra oral image (B) shows the lack of a buccal vestibule anterior, for this reason 2 anterior implants were not used for retention of the prosthesis and left as sleeping implants. The remaining 4 implants were used to retain a well-functioning denture.

Conclusions and suggestions for future research

As described in the previous paragraph, virtual treatment planning and guided surgery in FFF reconstructions combined with dental implants of maxillary and mandibular defects offers sufficient accuracy for a predictable outcome as well as that image fusion of MRI and (CB)CT provides proper resection margins determination, contributing to safe planning of immediate reconstructions of the resection of malignant oral tumors. Virtual planning of primary implant placement in FFFs is currently the standard treatment in our department for patients who are reconstructed for a large maxillary or mandibular defect.

had substantial less problems with the peri-implant soft tissues (Fig. 2). We hope to provide insight into the functional outcome of our 3D planned reconstructions in the future.

When the virtual planning method is applied to primary malignant cases, the risk of incorrect determination of the resection margins is a substantial clinical problem.\textsuperscript{23,24} The potential discrepancy between planned and actual surgical margins is caused by a lack of 3D information concerning bony infiltration and tumor spread that can be learned form CT imaging. When combining CT data with MRI data, allowing for a more detailed image of the soft tissue, this clinical issue can be surpassed as is shown in chapter 6. The true clinical value of data fusion and the resulting virtual planning still has to be proven. We expect this will lead to improvement of the amount of tumor free margins after resection of large tumors. MRI tends to moderately overestimate the tumor size. Pathology reports will clear this out and hopefully give enough consistent data to provide an algorithm for safe resection margin determination and prohibit excessive overresection.
Virtual treatment planning offers a good anatomical insight and therefore can be of great help to plan tumor resections and complex reconstructions. The resulting optimal anatomical virtual treatment plan might not be the most realistic clinical plan, however. To convert the optimal anatomical plan into the optimal executive plan needs the involvement of a multidisciplinary team. This team should assess the virtual plan and make an estimation for the virtual plan to be clinically applicable regarding the patient’s local situation. Open, mutual collaboration between all team members, including the person who does the virtual treatment, facilitates a steep learning curve of the whole team and helps to prepare a realistic best virtual treatment plan, foresee surgical problems and get the best outcome for the patient. Moreover, virtual treatment plans are only as good as the scanning data is, so optimizing scanning protocols to obtain (CB)CT data that facilitates 3D planning best is therefore important.

Introducing the CAD-CAM reconstruction plate into the 3D workflow has proven to be a valuable step in controlling the translation of a virtual treatment plan to the surgery. This reconstruction plate is yet a bulky plate, which is only applicable in the mandible. The planning of smaller individual tailored osteosyntheses with a sufficient strength might be valuable in the reconstruction of the maxilla to use the same principle in translation pathway. Also in the mandible smaller plates might be of benefit. It also has to be tested whether indeed a rigid large reconstruction plate is needed or that smaller osteosyntheses can also do the job, e.g., two smaller plates at each osteotomy line, like is done in the treatment of mandibular fractures. Besides being easier to apply, less bulky plates also will reduce the risk on developing dehiscence’s of the osteosynthesis as is not uncommon for large reconstruction plates.

Figure 2  Fibula reconstruction of the lower jaw. The fibula was prefabricated with a split skin graft and dental implants, note the good aspect and amount of peri-implant split skin graft.
References