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The fitting accuracy of pre-bend reconstruction plates and their impact on the temporomandibular joint

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ABSTRACT

Background: Various causes for bone defects of the lower jaw have been described. As a result, patients often suffer from compromised aesthetics and a loss of, or reduction in, important physiological functions, such as swallowing, breathing, and speaking. A change in the shape of the lower jaw can impair the natural occlusion and leads to an atypical or modified position of the temporomandibular joint. Titanium reconstruction plates are the standard approach to jaw reconstruction, and are used for temporary bridging of a jaw defect or fixation of a bone graft. Conventionally these plates are intraoperatively adjusted to the mandible by the surgeon. Computer-aided manufacturing, computer-aided design, and rapid prototyping have gained increasing importance in the field of medicine, as they allow the production of individual models of the lower jaw, with the possibility of preoperatively bending the reconstruction plates. In this retrospective study, the accuracy of pre-bent titanium plates and their effect on the temporomandibular joint situation in comparison with intraoperatively curved plates will be discussed.
Materials and Methods: Patients who attended our department for lower jaw reconstruction between March 2013 and February 2015 were included in this retrospective study. Within that time 20 patients were treated with pre-bent reconstruction plates (group 1). 20 comparable patients were selected with reconstruction and conventional intraoperative bending (group 2). To evaluate the accuracy of the plates and the condylar position, postoperative cone beam computed tomograms and computed tomograms were used to assess the bone–plate distance at 12 defined points and four angles in axial reconstruction. The results were compared, statistically evaluated, and discussed.
Results: Regarding the maximum bone–plate distances and the sum of distances, there was a significant difference between the accuracy of the pre-bent and the conventionally bent reconstruction plates ($p = 0.022$, $p = 0.048$). Regarding the condylar position, there was no significant difference between both methods ($p = 0.867$).
Conclusion: The results of this study show that a better fitting accuracy can be achieved using pre-bent plates. Preparation of the plates proves to be advantageous and meaningful, especially in complex bone defects and deformations of the lower jaw. Nevertheless, concerning the position of the temporomandibular joint, no significant difference could be ascertained between the shown methods, contradicting several studies.

1. Introduction

Various causes for bone defects of the lower jaw have been described. Benign or malignant tumours, cysts, trauma, and acute or refractory chronic infections are the most common reasons for extensive bone defects in the head and neck region (Spencer et al., 1999; Hausamen et al., 2003). Malignant tumours of the oral cavity represent the most common cause for extensive bone defects of the

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mandible (Lindstrom et al., 1981; Lukash and Sachs, 1989). As a result, patients often suffer from compromised aesthetics, and a loss of, or reduction in, important physiological functions, such as swallowing, breathing, and speaking (Freeman, 1948; Wolfgang J. Spitzer 1991; Kumar et al., 2016). A change in the shape of the lower jaw can impair the natural occlusion and lead to an atypical or modified position of the temporomandibular joint (Azuma et al., 2014). In addition to these somatic consequences, such defects can lead to psychosocial impairment. As a result, jaw reconstruction is a complex, time-consuming, and challenging task for the surgeon (Cohen et al., 2009; Rahimov and Farzaliyev, 2011; Lethaus et al., 2012). Typically, titanium plates are used in reconstructive surgery. Good contouring and adaptation of these reconstruction plates, as well as stability, are essential for the healing of the graft, and the postoperative aesthetic and functional result (Schmoker, 1983; Freitag et al., 1991). Conventionally, the adjustment of plates on the lower jaw is made intraoperatively by the surgeon. Multiple bending is needed to accurately shape the plate, which can lead to fatigue of the material (Freitag et al., 1991; Maurer et al., 2010). In addition, valuable operating time is needed, especially in larger defects (Rahimov and Farzaliyev, 2011).

Computer-aided manufacturing (CAM), computer-aided design (CAD), and rapid prototyping (RP) have gained increasing importance in the field of surgery. These techniques open new possibilities in the field of mandibular reconstruction (Succo et al., 2015; Wang et al., 2016). With RP, it is possible to produce individual models of the mandible and preoperatively bend the reconstruction plates (Cohen et al., 2009; Lethaus et al., 2012). Medical rapid prototyping (MRP) allows the creation of anatomically correct models, derived from medical imaging data (computed tomography, magnetic resonance imaging, ultrasound) (Winder and Bibb, 2005). Some studies have examined the use of pre-bent titanium plates for jaw reconstructions, especially when compared with conventional curved reconstruction plates (Lukash and Sachs, 1989; Cohen et al., 2009; Lethaus et al., 2012; Hanasono and Skoracki, 2013; Azuma et al., 2014). According to those studies, this method allows precise adjustment of the plates on the lower jaw, a shortening of operation time, and improved postoperative aesthetic and functional results. Other benefits highlighted in the context of the investigations were: reduced bone plate distance and thus reduced scarring; reduced metal fatigue; and protection of root tips, nerves, vessels, and (if present) tooth germs.

Although these models bring many benefits, MRP creates additional costs — a barrier to its widespread use and acceptance in clinical practise (Sinn et al., 2006). Nonetheless, previous studies emphasize the reduction in operation time (Kammerer et al., 2014), costs (Azuma et al., 2014), and aesthetics (lower jaw and facial symmetry) (Hanasono and Skoracki, 2013; Succo et al., 2015).

The aim of this retrospective study was to clarify the fitting accuracy of pre-bent plates and their impact on the position of the temporomandibular joint in comparison with intraoperatively bent plates.

2. Materials and methods

This study was approved by the ethics committee of the University Erlangen-Nuremberg (35A_16 Bc).

The retrospective study included patients visiting our department between March 2013 and February 2015 for reconstruction of extensive lower jaw defects.

Group 1 was treated with pre-bent reconstruction plates and consisted of 20 patients. The patients were aged between 27 and 81 years, and comprised 17 men and three women.

Group 2 (control group) included 20 patients who had been treated with plates that were bent by the surgeon during the operation. It comprised 15 men and 5 women, aged between 33 and 78 years. The patients were considered comparable if a partial resection of the mandible, followed by primary or secondary reconstruction using a reconstruction plate made of titanium, had been done.

The diagnosis was confirmed in all cases prior to surgical resection by biopsy. Diagnoses can be seen in Table 1.

2.1. Data acquisition and processing

CTs of the head/neck regions (thickness $\geq$1 mm) were carried out and archived in DICOM (digital imaging and communications in medicine) format. The DICOM datasets were segmented and converted into virtual 3D models using Mimics software (Mimics 14.1, Materialise, Belgium). The records were largely narrowed, and artefacts were virtually removed. With an additional software program (3-matic 6.1, Materialise, Belgium) the virtual jaw was edited and prepared for 3D printing. Data were then exported to ZPrintTM (ZPrintTM software 7.6.7, Z Corporation).

2.2. The printing process

3D Printing was carried out by Sektrum ZTM510 (Z Corporation). The starting material was a gypsum powder (zp® 131 powder, Kisters AG). For binding we used 60 clear (Kisters AG). Dry time was at least an hour. As the lower jaw model was very porous and unstable, it was carefully lifted from the pit and then infiltrated with thin, fast-setting cyanoacrylate (ColorBondTM, Z Corporation).

2.3. Pre-bending of the reconstruction plates

The expected resection margins were drawn on the model (Fig. 1) and the titanium reconstruction plate was bent with pliers. The plates were cropped three or four holes cross the resection margins, for later fixation. Leibinger plates (Leibinger, Stryker Howmedica GmbH) were used in 38 cases, and a Martin plate (MARTIN, Tikom GmbH) in two cases. In the preoperative assessment, all plates could be adapted without any gap on the lower jaw. Then, the plates were sterilised.

2.4. Resection

The resections were categorized according to the classification by Jewer et al. [44] (Table 2).

2.5. Reconstruction

Transplant type was dependent on the extent and location of the defect, as well as the general and vascular condition of the patient.

Table 1
Diagnoses within the two groups: OSCC — oral squamous cell carcinoma; rOSCC — relapse OSCC; ORN — osteoradionecrosis; KCOT — keratocystic odontogenic tumour; AB: ameloblastoma; rAB — relapse AB.

	Diagnosis	n
Group 1	OSCC	11
	rOSCC	1
	ORN	2
	KCOT	3
	Other	3
Group 2	OSCC	7
	rOSCC	2
	ORN	6
	AB	1
	rAB	1
	Other	3

Fig. 1. Preoperative model of the lower jaw, with drawn resections lines and plate dimensions.

The type of reconstruction (primary or secondary) was planned before the resection. Transplant and reconstruction types are shown in Table 3.

2.6. Surgery

The planned osteotomy lines were drawn, the pre-bent plate was attached to the bone and fixation was performed with three screws anterior and three screws posterior to the defect. In this way, correct positioning of the jaw stumps was guaranteed. Partial resection was carried out according to the planned osteotomy lines. Positive tumour margins required further resection. The surgeon did not adjust, or only slightly adjusted, the pre-bent titanium plates intraoperatively. Primary or secondary reconstruction followed routine protocols (Fig. 2).

In contrast to group 1, plates were bent intraoperatively in group 2. The planned osteotomy lines were drawn, the plate was attached to the bone and bending was performed until an optimal fitting was achieved. The plate was fixed with three screws anterior and three screws posterior to the defect. The remaining surgery was equivalent to group 1.

2.7. Scan settings

2.7.1. Accuracy of reconstruction plates

Digital volume tomography (DVT) was performed post-operatively to evaluate the reconstruction. Measurements were performed with eXam Vision (V1.9.3, KaVo Dental, Germany). The fitting accuracy of the reconstruction plates was determined by measuring the distance between bone and plate. Six locations were selected (Fig. 3). Distances were measured cranially and caudally to the six locations (Fig. 4).

2.7.2. Temporomandibular joint position

The temporomandibular joint position was determined on the basis of preoperative and a postoperative CT or DVT with axial layering. A straight line was drawn through the two rearmost points of both fossae. This line is called fossa line. Another straight line was drawn through the condyle at the point of maximum extension. This was done for both condyles. Then the angles between the fossa line and the right and left condyle-line were determined using the software Magic Web (Magic Web VA60C_0212 client, Visage Imaging) (Fig. 5).

Table 2
Sites of defects, according to the classification by Jewer et al. (1989)

	L	LC	LCL	CH
Group 1	5	4	8	1
Group 2	4	7	9	–

Table 3
Type of reconstruction: IC — iliac crest; fibula — vascularized fibula flap; scapula — scapula bone flap; radialis — radial forearm flap; NR — no reconstruction.

	IC	Fibula	Scapula	Radialis	NR
Group 1	2	4	7	5	2
Group 2	-	1	11	8	–

2.7.3. Statistical evaluation

A Shapiro–Wilk test was carried out to verify normal distribution. In this case a two-sample *t*-test was used. Otherwise, a Wilcoxon rank sum test was used. Statistical significance was considered at *p*-values less than 0.05.

3. Results

For this study, 24 distances and four angles were collected per patient. For assorted reasons, this was not possible in some cases. In three cases, the reconstruction plate was not fully captured. One patient died before postoperative imaging. In two cases, the temporomandibular joint was not sufficiently captured to perform an angle determination.

3.1. Analysis of accuracy of reconstruction plates

The mean plate–bone distance in group 1 was 0.45 ± 0.67 mm ($n = 238$). In group 2 the distance was 0.62 ± 0.67 mm ($n = 236$). Table 4 shows the mean values. In consideration of the sum of all values in a group, the increased fitting accuracy found for group 1 was statistically significant ($p = 0.048$) (Fig. 6). The Wilcoxon rank sum test confirmed a significant difference between the two groups regarding maximum displacement ($p = 0.022$) (Fig. 7).

3.2. Analysis of the temporomandibular joint

The Wilcoxon rank sum test confirmed no significant difference between the two groups regarding the sum of differences ($p = 0.867$). Group 1 showed a change of 11.44 ± 10.23° ($n = 18$); group 2 showed a difference of 9.63 ± 6.49° ($n = 19$).

Fig. 2. Optimal fitting, pre-bent reconstruction plate with vascularized fibula flap for lower jaw reconstruction.

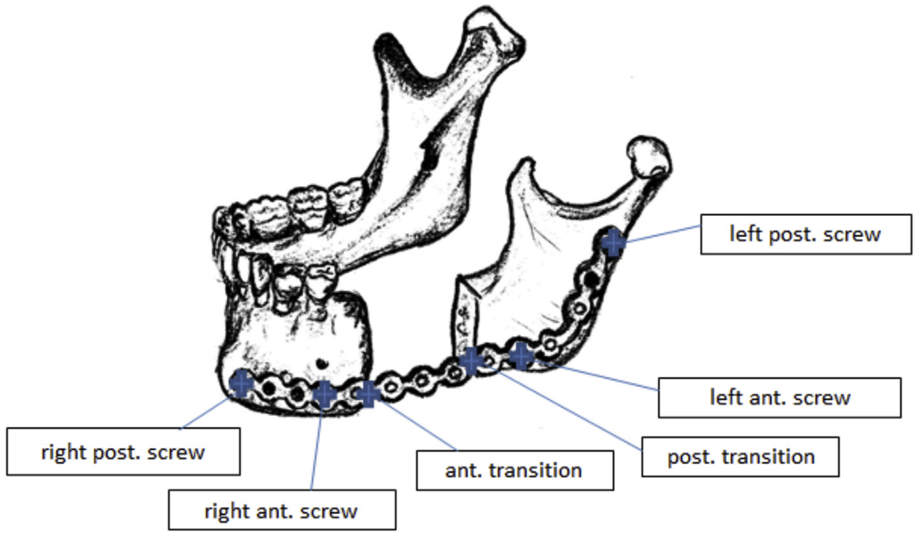

Fig. 3. Selected measurement locations.

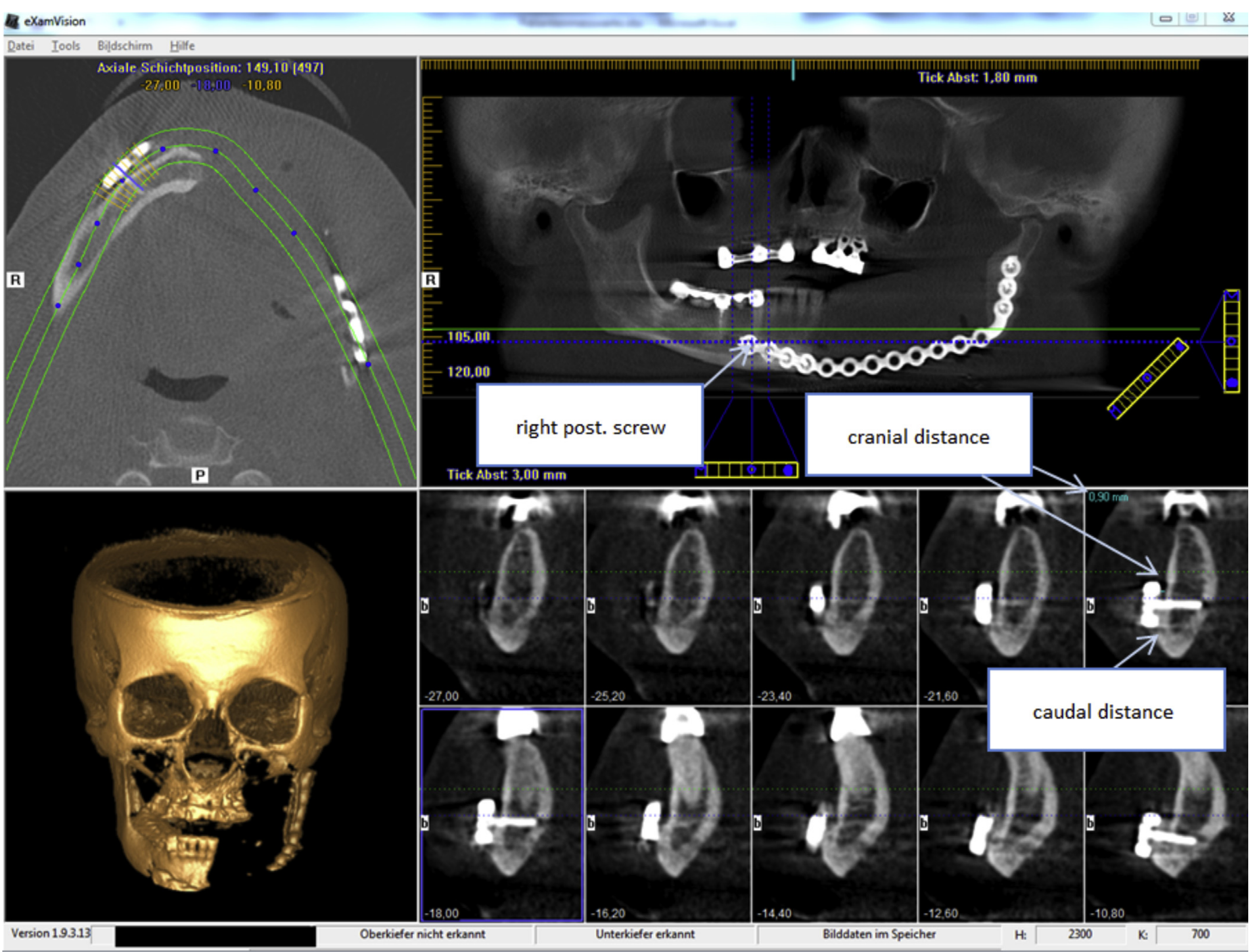

Fig. 4. Measurement was performed using eXam Vision software (V1.9.3, KaVo Dental, Germany), cranially and caudally to the selected measurement locations.

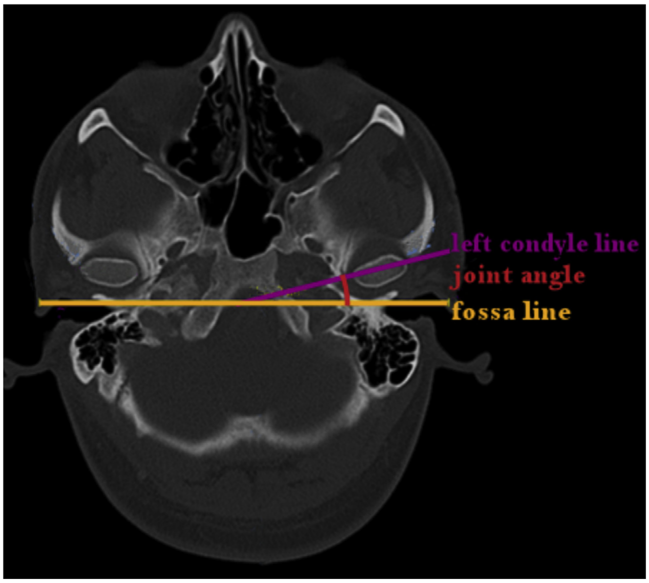

Fig. 5. Construction of the joint angle.

4. Discussion

In this study, pre-bent reconstruction plates were compared with conventional, intraoperatively bent reconstruction plates in the context of lower jaw reconstruction. The primary objective of the study was to determine the fitting accuracy of the titanium plates. In addition, the study should also provide information about their influence on the position of the temporomandibular joint.

There are several studies dealing with MRP-based, pre-bent titanium plates, and numerous factors have been analysed so far (Chang et al., 2003; Bill and Reuther, 2004; Silva et al., 2008; Cohen et al., 2009; Lethaus et al., 2012). Crucial and repeatedly analysed factors are operation time and the costs involved. Some of the studies report a reduction in operation time. According to some studies, improvements in aesthetic and functional results were achieved using pre-bent plates, thus resulting in an increased quality of life (QOL) of patients. Our study did not aim to analyse the aesthetic outcome or QOL. Nonetheless another study by our group is analysing operation time and cost/benefit ratio, and so might contribute to that topic.

Our results showed that pre-bending increased fitting accuracy. A slightly smaller bone–plate distance could be measured. When comparing the sum of distances and the maximum distance, there was a statistically significant difference from the intraoperatively

Table 4
Bone plate distances as means. The titanium plates in both groups have the best fit at the transition zone and the worst at the outermost screws.

Point of measurement	Mean in mm	SD in mm	Min; max	n
$A_{cranial}$	0.79	±0.81	0; 2.4	39
A_{caudal}	0.53	±0.64	0; 2.4	39
$B_{cranial}$	0.57	±0.7	0; 3.05	40
B_{caudal}	0.45	±0.65	0; 2.53	39
$C_{cranial}$	0.43	±0.7	0; 2.28	40
C_{caudal}	0.29	±0.65	0; 2.42	40
$D_{cranial}$	0.38	±0.74	0; 3.6	39
D_{caudal}	0.48	±1	0; 4.08	39
$E_{cranial}$	0.57	±0.74	0; 2.7	40
E_{caudal}	0.68	±1.63	0; 9	40
$F_{cranial}$	0.64	±0.76	0; 2.42	40
F_{caudal}	0.62	±0.71	0; 2.56	39

bent plates. Several studies classify a bone-plate spacing below 1 mm as 'very good' or 'normal or precise' (Probst et al., 2016; Wang et al., 2016). As in our study, Wang et al. achieved worse results with the conventional bending. The comparability of the studies, however, is limited due to the lack of information on measurements from Wang et al. Probst et al. noticed that the best fitting accuracy was obtained in areas close to the defect. This is supported by our results, which might derive from the mandibular mobility evident after resection.

The accuracy of the 3D models plays an important role in the reconstruction plate pre-bending process — the anatomy of the lower jaw needs to be reproduced in detail to achieve the best results. Numerous studies address this topic (Choi et al., 2002; Chang et al., 2003; Wilde et al. 2015a, 2015b). At each stage of the MRP process (imaging, data collection, processing, transfer) errors can lead to inaccuracies in the model (Winder and Bibb, 2005; Ibrahim et al., 2009). Increasing the CT resolution allows greater precision, but this is a time-consuming approach, because every layer has to be edited individually. This virtual editing can also influence the precision of the models (Winder and Bibb, 2005); nonetheless, we obtained satisfactory results. It should be noted that a sufficiently precise model can still be created using a lower resolution. Not only the radiation dose, but also the duration of printing is reduced in this way, which in turn is associated with a reduction in costs (Winder and Bibb, 2005).

The size of the plate depends on the defects' dimensions. Longer plates impede the bending process and are more time consuming. When comparing the sum of distances and the maximum distance in our study, there was a statistically significant difference from the intraoperatively bent plates. As also described in the study by Lethaus et al., pre-bending was faster and easier than intraoperative bending (Lethaus et al., 2012). This approach also reduces the risk of plate exposure and material fatigue (Martola et al., 2007).

To maintain chewing function and face shape, a physiological jaw relation plays a decisive role. This is determined by the correct positioning of the two condyles, as well as by good occlusion and articulation (Urken et al., 1991; Li et al., 1996; Bak et al., 2010). Vertical interference by only 0.1 mm can cause pain in the joints and the muscles, and affect the entire patient. Therefore, preservation of the temporomandibular joint position during reconstruction is crucial. Our investigations showed no significant difference between using pre-bent plates and conventional plates in relation to the temporomandibular joint. In a similar study to ours, Wang et al. examined changes to the condylar position (Wang et al., 2016). However, no information was given about the exact measuring method. Succo et al. compared CAD/CAM-fabricated reconstruction plates with pre-bent plates (Succo et al., 2015). The condylar position was assessed using several measurement points. Both methods allowed more precise reconstruction compared with the conventional procedure. Laser-modelled plates achieved an even better aesthetic and functional result than manually bent plates, but this method was much more expensive.

It is unknown how tumour growth can influence the position of the lower jaw. Changing an already altered position could result in even larger angle differences. The same applies to previous procedures, which also complicate the contouring of the reconstruction plate regardless of the bending method. Software-based corrections of the fossa–condylus relation are possible, in order to achieve physiological positioning. A completely intact preoperative mandibula can be used for the MRP.

In summary, in this study there were strong differences between the pre- and postoperative joint positions, and no significant differences between the two groups. Nonetheless, a preoperative 3D model can contribute to better planning and preparation.

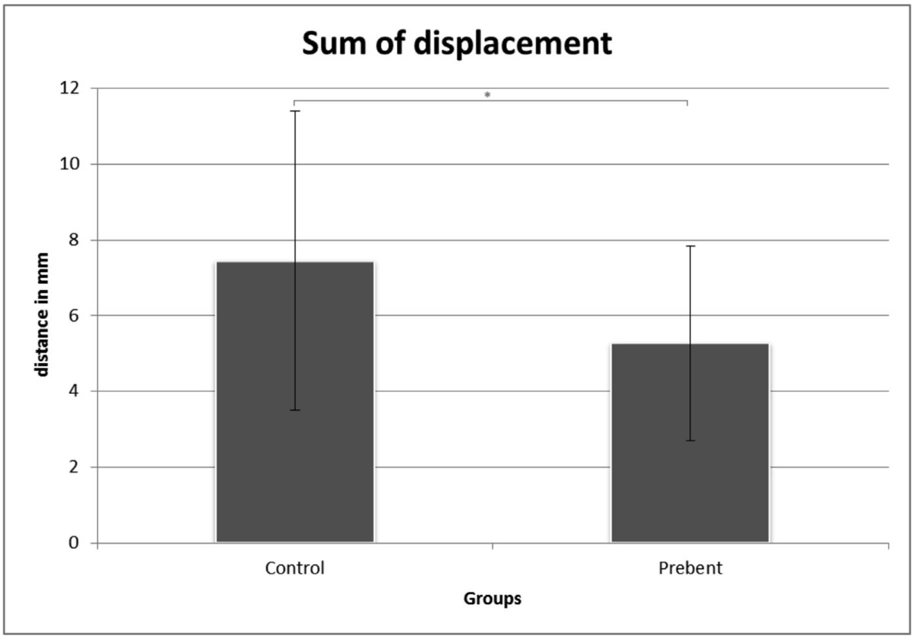

Fig. 6. Sum of distances in mm. *The increased fitting accuracy found for group 1 was statistically significant ($p = 0.048$): group 1: 5.27 ± 2.58 mm ($n = 20$); group 2: 7.44 ± 3.95 mm ($n = 20$).

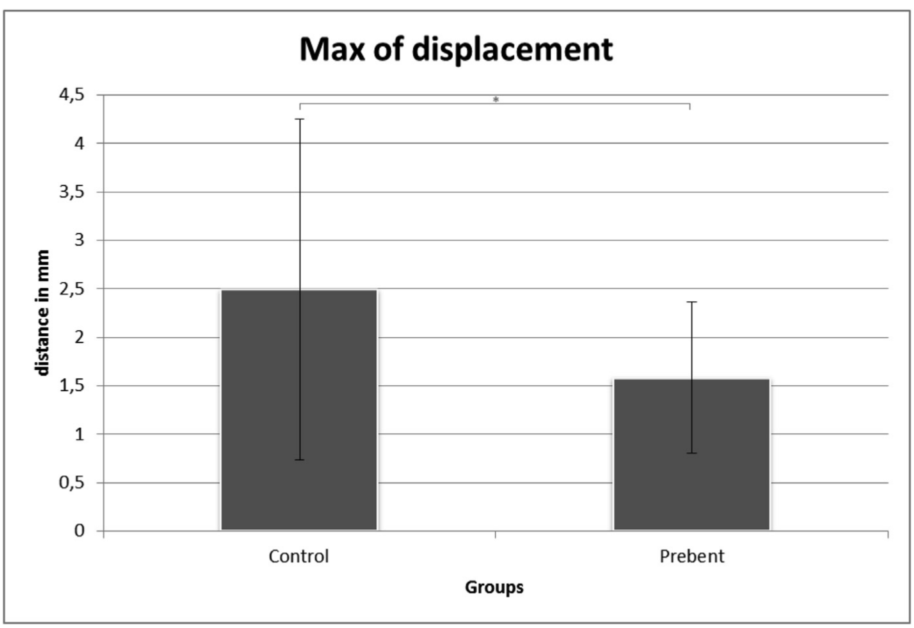

Fig. 7. Group 1 showed a maximum displacement of 1.58 ± 0.78 mm ($n = 20$); group 2 showed a maximum displacement of 2.49 ± 1.76 mm ($n = 20$). *A Wilcoxon rank sum test confirmed a significant difference ($p = 0.022$).

Surgeons can familiarize themselves with the anatomical situation. Pre-bent plates save surgery time that can be used otherwise.

Measurement errors are inevitable. These include human errors in measurement as well as the accuracy and resolution of measuring instruments. Human errors can occur at any point, for example when drawing lines or modifying the model. Choi et al. confirm that selecting locations for measurement is troublesome (Choi et al., 2002). The definition of maximum expansion of the temporomandibular joint head was not easy, and left open some room. In this way, it may have come down to deviations and human errors. The magnification ability and resolution of the DVT was limited, resulting in limited accuracy of digital measurement.

5. Conclusion

A lot of work can be avoided by the surgeon by pre-bending reconstruction plates. Time can be saved intraoperatively and used elsewhere. The results of this study show that a better fitting accuracy can be achieved with pre-bent plates. Preparation of the plates proves to be advantageous and meaningful, especially in complex bone defects and deformations of the lower jaw. Nevertheless, concerning the position of the temporomandibular joint, no significant difference could be ascertained between the shown methods, in contradiction with several studies.

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References

Azuma M, Yanagawa T, Ishibashi-Kanno N, Uchida F, Ito T, Yamagata K, et al: Mandibular reconstruction using plates prebent to fit rapid prototyping 3-dimensional printing models ameliorates contour deformity. Head Face Med 10: 45, 2014
Bak M, Jacobson AS, Buchbinder D, Urken ML: Contemporary reconstruction of the mandible. Oral Oncol 46: 71–76, 2010
Bill JS, Reuther JF: Rechnergestützte Modellbauverfahren zur Planung ausgedehnter Rekonstruktionseingriffe im Schädelbereich. Mund Kiefer GesichtsChir 8: 135–153, 2004
Chang PS, Parker TH, Patrick Jr CW, Miller MJ: The accuracy of stereolithography in planning craniofacial bone replacement. J Craniofac Surg 14: 164–170, 2003
Choi JY, Choi JH, Kim NK, Kim Y, Lee JK, Kim MK, et al: Analysis of errors in medical rapid prototyping models. Int J Oral Maxillofac Surg 31: 23–32, 2002
Cohen A, Laviv A, Berman P, Nashef R, Abu-Tair J: Mandibular reconstruction using stereolithographic 3-dimensional printing modeling technology. Oral Surg Oral Med Oral Pathol Oral Radiol Endodontology 108: 661–666, 2009
Freeman BS: The use of vitallium plates to maintain function following resection of the mandible. Plast Reconstr Surg 1946(3): 73–78, 1948
Freitag V, Hell B, Fischer H: Experience with AO reconstruction plates after partial mandibular resection involving its continuity. J Craniomaxillofac Surg 19: 191–198, 1991
Hanasono MM, Skoracki RJ: Computer-assisted design and rapid prototype modeling in microvascular mandible reconstruction. Laryngoscope 123: 597–604, 2013
Hausamen J-E, Becker J, Neukam FW, Reichart PA, Scliephake H, Schmelzeisen R: Curriculum Mund-, Kiefer- und Gesichtschirurgie, Chirurgie Band III. Q. Verlags-GmbH, 2003
Ibrahim D, Broilo TL, Heitz C, de Oliveira MG, de Oliveira HW, Nobre SM, et al: Dimensional error of selective laser sintering, three-dimensional printing and PolyJet models in the reproduction of mandibular anatomy. J Craniomaxillofac Surg 37: 167–173, 2009
Kammerer PW, Klein MO, Moergel M, Gemmel M, Draenert GF: Local and systemic risk factors influencing the long-term success of angular stable alloplastic reconstruction plates of the mandible. J Craniomaxillofac Surg 42: e271–e276, 2014
Kumar BP, Venkatesh V, Kumar KA, Yadav BY, Mohan SR: Mandibular reconstruction: overview. J Maxillofac Oral Surg 15: 425–441, 2016
Lethaus B, Poort L, Böckmann R, Smeets R, Tolba R, Kessler P: Additive manufacturing for microvascular reconstruction of the mandible in 20 patients. J Cranio-Maxillofacial Surg 40: 43–46, 2012
Li KK, Cheney ML, Teknos TN: The importance of mandibular position in microvascular mandibular reconstruction. Laryngoscope 106: 903–907, 1996
Lindstrom J, Branemark PI, Albrektsson T: Mandibular reconstruction using the preformed autologous bone graft. Scand J Plast Reconstr Surg 15: 29–38, 1981
Lukash FN, Sachs SA: Functional mandibular reconstruction: prevention of the oral invalid. Plast Reconstr Surg 84: 227–233, 1989 discussion 234–225
Martola M, Lindqvist C, Hänninen H, Al-Sukhun J: Fracture of titanium plates used for mandibular reconstruction following ablative tumor surgery. J Biomed Mater Res Part B: Appl Biomater 80B: 345–352, 2007
Maurer P, Eckert AW, Kriwalsky MS, Schubert J: Scope and limitations of methods of mandibular reconstruction: a long-term follow-up. Br J Oral Maxillofac Surg 48: 100–104, 2010
Probst FA, Metzger M, Ehrenfeld M, Cornelius C-P: Computer-assisted designed and manufactured procedures facilitate the lingual application of mandible reconstruction plates. J Oral Maxillofac Surg 74: 1879–1895, 2016
Rahimov C, Farzaliyev I: Virtual bending of titanium reconstructive plates for mandibular defect bridging: review of three clinical cases. Craniomaxillofac Trauma Reconstr 4: 223–234, 2011
Schmoker RR: Mandibular reconstruction using a special plate. J Maxillofac Surg 11: 99–106, 1983
Silva DN, Gerhardt de Oliveira M, Meurer E, Meurer MI, Lopes da Silva JV, Santa-Barbara A: Dimensional error in selective laser sintering and 3D-printing of models for craniomaxillary anatomy reconstruction. J Craniomaxillofac Surg 36: 443–449, 2008
Sinn DP, Cillo Jr JE, Miles BA: Stereolithography for craniofacial surgery. J Craniofac Surg 17: 869–875, 2006
Spencer KR, Sizeland A, Taylor GI, Wiesenfeld D: The use of titanium mandibular reconstruction plates in patients with oral cancer. Int J Oral Maxillofac Surg 28: 288–290, 1999
Succo G, Berrone M, Battiston B, Tos P, Goia F, Appendino P, et al: Step-by-step surgical technique for mandibular reconstruction with fibular free flap: application of digital technology in virtual surgical planning. Eur Arch Otorhinolaryngol 272: 1491–1501, 2015
Urken ML, Buchbinder D, Weinberg H, Vickery C, Sheiner A, Parker R, et al: Functional evaluation following microvascular oromandibular reconstruction of the oral cancer patient: a comparative study of reconstructed and non-reconstructed patients. Laryngoscope 101: 935–950, 1991
Wang YY, Zhang HQ, Fan S, Zhang DM, Huang ZQ, Chen WL, et al: Mandibular reconstruction with the vascularized fibula flap: comparison of virtual planning surgery and conventional surgery. Int J Oral Maxillofac Surg 45: 1400–1405, 2016
Wilde F, Hanken H, Probst F, Schramm A, Heiland M, Cornelius C-P: Multicenter study on the use of patient-specific CAD/CAM reconstruction plates for mandibular reconstruction. Int J Comput Assist Radiol Surg 10: 2035–2051, 2015a
Wilde F, Winter K, Kletsch K, Lorenz K, Schramm A: Mandible reconstruction using patient-specific pre-bent reconstruction plates: comparison of standard and transfer key methods. Int J Comput Assist Radiol Surg 10: 129–140, 2015b
Winder J, Bibb R: Medical rapid prototyping technologies: state of the art and current limitations for application in oral and maxillofacial surgery. J Oral Maxillofac Surg 63: 1006–1015, 2005
Wolfgang J, Spitzer HJP: Tierexperimentelle Untersuchungen über den Einfluss des Distalbisses auf die Kiefergelenke. Dtsch Zahnärztl Z 46: 585–588, 1991