This thesis describes ways to optimize the treatment of fractures of the mandible by investigating several steps in fracture diagnosis and treatment.

**Fracture reduction techniques**

Anatomic reduction is an essential step in the treatment of fractures. Especially when the load-sharing principles according to Champy are used, interfragmentary stability is an important factor for uneventful healing as the combination of fracture reduction and plate fixation in the tensile zone (=upper border) provides the stability of the fracture.

Intermaxillary fixation (IMF) is historically used to reduce the fracture fragments and to restore occlusion. However, in some mandibular fractures, IMF is not enough to achieve adequate reduction of fracture fragments. In chapter 2 several other methods to improve alignment of fracture fragments were proposed. It appears that the use of reduction forceps makes the treatment quicker and easier. Clear evidence that reduction forceps have an advantage over other fracture reduction techniques is lacking. The study described in chapter 3 provided extra knowledge regarding this topic.

The results of this chapter indicate that a fracture of the mandible reduced with the aid of reduction forceps resulted in better fracture alignment and less postoperative complications than those reduced without the help of the reduction forceps. The scoring of the postoperative fracture alignment (assessed on panoramic and Towne) in the study is somewhat counterintuitive in case of angle fractures because mandibular angle fractures often do not show a perfect alignment of the fracture fragments in the initial postoperative radiographic and adjusts over time by muscle action. On the other hand, to overcome this limitation we assessed fracture alignment on postoperative radiographs along with the occlusal state of the patients. Another limitation of the study was the retrospective design. Standardization of the surgeon or reduction technique selection was not possible. The group of mandibular fractures studied was a representative sample of the mandibular fractures treated during the inclusion period. As these fractures are treated by several surgeons during out of office hours the surgeons could not select patients or fractures. Therefore, the results of this study can be generalized to other surgeons as well.
The results of Chapter 2 and 3 clearly indicate that there is a need for further development of reduction forceps of mandibular fractures. Therefore, after careful analysis of existing techniques and reduction forceps, we have produced a set of three reduction forceps, one for the anterior part and a left and a right one for the posterior part of the mandible and tested their feasibility clinically (Chapter 4). The feasibility test revealed that these two designs are suitable for the reduction of most mandibular fractures. However, this initial feasibility test showed that a reduction forceps is not always suitable for the reduction of oblique, flat fractures of the mandible. Further adjustments and testing of the forceps designed for the angle region is planned to overcome these drawbacks.

*The use of locking plate systems.*

After sufficient reduction of mandibular fractures is achieved by either reduction forceps or other techniques, fixation is performed using osteosynthesis materials. Osteosynthesis is nowadays achieved by either lag screws or different plates and screws, depending on the fracture characteristics, location, and surgeons’ preferences. Besides the dimensions of the plates and screws, the osteosynthesis may vary in a locking and non-locking mechanism. It is presumed that the locking plates system is superior to the non-locking plate system with regard to stability, and postoperative complications. However, the meta-analysis described in Chapter 5 demonstrated that a locking plate system is only superior to a non-locking plate system concerning the postoperative need for IMF in the early and intermediate period after treatment. The cause for this finding is not obvious and may be explained by subjective choices of the surgeon instead of the locking or non-locking system. Moreover, the quality of the included studies was moderate and even low, because they did not report randomization, concealment of allocation and blinding of participants, surgeons and outcome assessors. Although blinding of the surgeons is not possible when these two plate systems are compared, other quality characteristics could be improved in future studies.

Furthermore, most of the included studies in the review described in Chapter 5 do not take into account plate dimension, number of plates, plate design, and fracture fixation principles (Champy vs. AO) when comparing the locking and non-locking plate systems. This means that, besides locking and non-locking characteristics of the plate systems, other potential confounders are not considered in these studies. Consequently, the meta-analysis included
only studies which compared plates as similar as possible with regard to plate dimensions and design, and fixation principles.

Treatment of fractures of the edentulous mandible

While a variety of treatment protocols for fractures of the edentulous mandible have been suggested, a generally accepted consensus has not been reached, particularly not for the treatment of severely atrophic mandibles with a bone height of equal or less than 10 mm. The study described in Chapter 6 demonstrates a practically applicable clinical flowchart/protocol for the fracture of the edentulous mandible. The protocol was developed according to the best evidence available, but due to the low number of included patients and diversity of fractures, the level of evidence is low. On the other hand, if others would start to use this a guideline, and evaluate outcomes there will be hopefully stronger evidence in the future.

The protocol cannot be extrapolated to all patients. For instance, most edentulous patients are seniors, which tend to have a variety of systemic diseases and health-related complications. From this perspective, conservative or closed treatment is preferable in geriatric patients with health issues which could decrease the chance of morbidity and mortality. One should bear in mind that this issue is not taken into account in the protocol. Moreover, in general, the treatment protocol is one of the options for improving the quality of care. Yet, following the protocol does not prevent each and every complication that could occur. The bottom line is that the "Groningen protocol" significantly reduces postoperative complications and reoperations in the treatment of the fractures of the edentulous mandible.

3D measurements of condylar process fractures of the mandible

A comprehensive classification scheme for fractures should meet several requirements\(^1\). It must have a logical and systematic structure, and provide an accurate demonstration of the possible complexity of the fracture, as well as provide therapeutically relevant information about the fracture. The widely known mandibular condylar fracture classification by Loukota and Spiessl & Schroll are logically structured and differentiate the lower regions (viz. base) and higher condylar neck regions, but somewhat lack to fulfill the above-stated requirements. The displacement and dislocation of the condylar fractures which demonstrate the fracture extent and severity are not considered
in Loukota’s classification whereas it is included in the Spiessl & Schroll classification. According to the Spiessl & Schroll classification, dislocation is diagnosed in case the condylar head is out of the fossa while displacement is diagnosed in case the condylar head is within the fossa while there is displacement at the fracture site. However, the displacement extent is vaguely defined. The difference between fractures with (type II and III) or without (type I) considerable displacement is not clear, and the outcome may likely differ from surgeon to surgeon. Moreover, these classifications do not give enough information on which the choice for one or another treatment can be based. Clinical decision making is also often based on unreliable 2D measurements such as ramus height loss (measured in OPT) and deviation of the fractures (measured in Towne)\textsuperscript{2,3}. The 2D measurements are user dependent and have low reproducibility. Therefore, there is need for improvement of the measuring method in order to get to a correct classification.

The study described in Chapter 7 aimed to develop a standardized quantitative 3D measurement method for mandibular condylar fractures and to correlate the obtained results with the Loukota and Spiessl & Schroll classification. The obtained results from the 3D measurements provide additional quantitative information about fracture extent and severity of the condylar fractures with excellent reproducibility. Due to the retrospective design of the study, we are not able to compare the 3D measurements of the condylar fractures with the outcome of the treatment chosen. At this point, the 3D measurements cannot dictate which therapy should be chosen. There is ongoing debate on which fractures should be treated open or closed. Decision making seems to be based mainly on surgeons opinion, surgeons experience, and facilities for treatment. Despite several attempts to set up randomized clinical trials in order to prove which fractures should be treated closed or open, there still is discussion. The great variation in fracture presentation introduces so many confounding factors influencing the outcome of treatment that, to our honest knowledge, there is no scientific evidence for any treatment protocol so far except absolute indications as given by Zide and Kent\textsuperscript{4}. Possibly and hopefully, an exact classification based on reproducible 3D measurement will provide criteria to choose objectively for surgical or non-surgical treatment in an individual case.
Future perspectives

This thesis tries to contribute to optimization of the mandibular fracture treatment, although the outcome of the treatment is generally appreciated as favorable and relatively uncomplicated. In addition to the subjects in this thesis, there is abundant room for further research to enhance the treatment of mandibular fractures as suggested below. As long as there is room for improvement, the time needed for treatment may be reduced, duration of hospitalization may be reduced, and time from trauma to resuming daily activities of the patient may be reduced.

As for the open treatment, a plate should be adapted to the surface of the underlying bone when used to fix fractures at varying anatomical positions. This process may take some time when the surgeon is unexperienced. In addition, repeated bending of the plate can fatigue the plate and increases the chance of a fracture of the plate. Therefore, a pre-bent (pre-shaped) plate could help to overcome these issues. A pilot study was conducted in our department to test the feasibility of pre-bent plate for mandibular angle fractures. To do that, first, manually bent plates were postoperatively segmented and reconstructed from postoperative CBCT scan (7 patients). Second, the anatomical shape of healthy (non-fractured) mandibular angles were analyzed using 3D models which were manufactured from CBCT scans as well (19 patients). The preliminary results of this study showed that the variation of the manually bent plates was very large and it was not feasible to use these data to determine average contouring of a pre-bent angle plate. Conversely, the anatomical shape of the intact mandibular angle turns out to have less variation which made it feasible to design a pre-bent angle plate. Further studies should prove the clinical relevance of this development.

Biodegradable osteosyntheses generally have less mechanical properties than titanium ones. The mechanical demand for the osteosynthesis may theoretically be lower after a very precise reduction which enhances interfragmentary stability. Reduction with reduction forceps will help in the precise reduction. It is worthwhile to test degradable osteosyntheses for mandibular fracture fixation after precise reduction with reduction forceps, especially when using sonic weld fixation as measured by Buijs et al. Sonic weld fixation provides considerable more rigidity in comparison with a combination of degradable plate and screw fixation.
The treatment protocol for fractures of the edentulous mandible (Chapter 5) illustrated the importance of compiling/developing a protocol. Also, quantitative 3D analyzes of fractures of the condylar process (Chapter 6) provide accurate information about the fracture extent allowing a reliable classifications. The results of these studies support the idea to define a protocol for fractures of the condylar process in reference to the quantitative characteristics of the fracture. Clinical results may bring the ongoing discussion on open vs. closed treatment to an end. For now it seems that the outcome of treatment of condylar process fractures is more a problem for some surgeons than for most of the patients.

Last but not least, an alternative approach to improve mandibular fracture care is to pay more attention to the patients’ appreciation of proposed treatment and treatment outcome. A patient will hardly be able to determine for open or closed treatment protocols. He/she is depended on the information the surgeon provides him/her or which the patient gathers in other way. It is well known that patients can be very content with the treatment and the treatment outcome while the surgeon is not, vice versa. It seems worthwhile to measure the quality of life (QOL) of mandibular trauma patients. These measurements may help in determining the best treatment option for individual patients. A patient seems more concerned about the ability to chew and speak without complaints after the treatment; his/hers least concern is how the fracture is reduced or fixated. Therefore, the treatment outcome may be improved by learning from patients’ expectations6,7.
REFERENCES


