

## Summary, conclusions, address to the aims and future perspectives

This study aims to contribute to the knowledge of the adaptation of the jaw muscles after surgical mandibular advancement in short-face and long-face patients. The different results achieved after surgical mandibular advancement, using a bilateral sagittal osteotomy (BSSO), between short-face and long-face patients, has been subject to extensive research over the last decades. Apart from different relapse tendencies, an increased risk for condylar resorption is obviously apparent in the long-face group. Until recently, no information was available on changes of jaw muscle size and direction and the possible effect of these changes on condylar loading and, thus, condylar resorption. In an effort to provide some of this information a study with the following aims was designed.

- To calculate and to compare the cross-sectional area and the volume of the masseter muscle, the medial pterygoid muscle, the lateral pterygoid muscle and the anterior belly of the digastric muscle in a group of patients before treatment and at least one year after surgical mandibular advancement.
- To assess and to compare the direction of the masseter muscle, the medial pterygoid muscle, the lateral pterygoid muscle and the anterior belly of the digastric muscle in a group of patients before treatment and at least one year after surgical mandibular advancement.
- To compare the differences of the pre- and postoperative data on cross-sectional area and volume of these jaw muscles between a group of class II patients with a short face and a group of class II patients with a long face.
- To compare the differences of pre- and postoperative jaw muscle direction between the two groups.
- To assess the sagittal and the axial rotation of the proximal segments (condyles) that occurs as a consequence of mandibular advancement surgery and to compare the results between the two groups.
- To estimate the change of the loading of the condyles as a consequence of surgical advancement procedures in class II short-face and class II long-face patients.

**Chapter 2** describes the adaptation of the masseter and medial pterygoid muscles after bilateral sagittal split osteotomies (BSSO) to advance the mandible in five short-face and seven long-face patients with mandibular hypoplasia. A significant decrease of cross-sectional area and volume was found postoperatively in both muscles. Although not significantly, the decline tended to be larger in long-face patients. The decline in muscle size is in keeping with the assumed, improved biomechanics of the masticatory system. It is also in accordance with an impairment of function of these jaw closing muscles after surgical mandibular advancement.

**Chapter 3** deals with the adaptation of the lateral pterygoid muscle and the anterior belly of the digastric muscle after advancement BSSO. The sample consisted of 18 patients. Seven of them had a short face and 11 a long face. Eight of the long-face patients were treated with a Le Fort I intrusion osteotomy in combination with a bilateral sagittal split osteotomy. The volume of the lateral pterygoid muscles increased significantly in the short-face patients, as measured at least one year after surgery. The cross-sectional area of the lateral pterygoid muscle decreased significantly in the patients treated with a

bimaxillary osteotomy. The choice of the surgery, therefore, seemed an important factor in determining the degree of adaptation of this muscle. The anterior digastric muscles showed a highly variable adaptation without a consistent pattern.

**Chapter 4** reports on the changes of the direction of the masseter and the medial pterygoid muscles after advancement BSSO. The direction of these muscles was studied in a sample of 16 patients, consisting of eight short-face and eight long-face patients. All long-face patients were treated with a bimaxillary osteotomy, i.e. Le Fort I intrusion osteotomy and a BSSO. A line through the centroids of the muscle's cross sections was calculated to represent the muscle's direction. This line was projected on a sagittal and a frontal plane, perpendicular to the axial scan plane, to calculate the sagittal and the frontal direction and the moment arms of the muscles pre- and postoperatively. Sagittal and frontal moment arms were calculated from the right condyle. The postoperative direction of both muscles in the sagittal plane became  $9^\circ$  more vertical in the long-face patients, which was significant. This change was attributed to the  $6^\circ$  counterclockwise rotation of the proximal segments in this group. The direction of the masseter and the medial pterygoid muscles in the frontal plane tilted slightly medially after surgery and the angle between the muscles increased, though not significantly. No significant changes in the length of the moment arms were found. The significant changes suggested that biomechanical changes occur in the masticatory system of long-face patients with mandibular hypoplasia, treated with bimaxillary surgery.

**Chapter 5** discusses the changes of the static and dynamic loading of the condyles that may follow the advancement of the occlusal plane and the changes in direction of the jaw-closing muscles. Postoperative rotations of the proximal segments (condyles) in the sagittal and the axial plane are presented. For this study, the muscular and skeletal data of the eight short-face and eight long-face patients, described in the previous studies, were used. Measurements of the moment arms of the bite force and measurements of the rotations of the condyles were added. The expected postoperative increase of the static joint force appeared limited, in particular in the long-face group. This was because of the unexpected modest decrease of the mechanical advantage of the masseter and the medial pterygoid muscles in the long-face group. The dynamic joint reaction force during mouth opening decreased in both groups. Sagittal rotation of the proximal segments appeared to expose only a very small previously unloaded surface of the condyle to articulation. Rotations of the condyles in the axial plane were modest. The outcome of this study does not support the notion that increased loading of the condyle and counterclockwise rotation of the condyle are the cause for condylar resorption and relapse.

**Chapter 6** describes the skeletal and muscular changes of advancement BSSO and attempts to explain their relation to postoperative condylar changes and relapse. The decrease of the cross-sectional area and volume of the masseter and medial pterygoid muscles in the intermediate to long term after advancement BSSO suggests that these muscles have adapted to the new situation and that this is no disuse atrophy. It is not likely to assume that the adapted jaw-closing muscles generate more bite force and, thus, increase the forces on the condyle. The jaw-closing muscles, therefore, do not appear to contribute to the process of condylar resorption. The chewing capacity is not improved by the surgery and the accompanying orthodontics, which makes it likely that the ef-

iciency of the chewing has increased.

### **Address to the aims**

*To calculate and to compare the cross-sectional area and the volume of the masseter muscle, the medial pterygoid muscle, the lateral pterygoid muscle and the anterior belly of the digastric muscle in a group of patients before treatment and at least one year after surgical mandibular advancement.*

*To compare the differences of the pre- and postoperative data on cross-sectional area and volume of these jaw muscles between a group of patients with a short face and a group of patients with a long face.*

It was not difficult to motivate the patients to participate in the study. Due to different reasons, however, a few patients were lost. One patient proved to be claustrophobic and did not dare to enter the MRI for the second time. Others objected to the removal of C-C bars before MRI and the replacement of the retaining wires after the examination. For some patients, the indication was changed in the course of the orthodontic treatment. A few patients had moved to another city and were unable to return for the postoperative MRI. Nevertheless, it was possible to include patients to compose a short-face and a long-face group, large enough for statistical compilation. The muscles were properly identifiable on the images and could be segmented reliably with the software. The findings described in Chapter 2 and 3 show that significant changes of cross-sectional area and volume of the jaw muscles occurred in short-face and in long-face patients.

*To assess and to compare the direction of the masseter muscle, the medial pterygoid muscle, the lateral pterygoid muscle and the anterior belly of the digastric muscle in a group of patients before treatment and at least one year after surgical mandibular advancement.*

*To compare the differences of pre- and postoperative jaw muscle direction between short-face and long-face patients.*

The customized software to assess the muscle direction worked well and had a reproducible output. It took some effort to align the pre- and postoperative images as to be able to compare the direction of the muscles before and after treatment. The results reported in Chapter 4 demonstrate that significant changes of the direction of masseter and medial pterygoid muscles occurred in long-face patients treated with bimaxillary surgery.

*To assess the sagittal and the axial rotations of the proximal segments (condyles) which occur as a consequence of mandibular advancement surgery and to compare the results between short-face and long-face patients.*

*To estimate the change of the loading of the condyles as a consequence of surgical advancement procedures in these two groups.*

The different directions of the MRI sequences made it possible to assess the rotation of the condyles in the sagittal and the axial planes. Rotation of the condyles in the sagittal plane was comparable to the results of other studies. Rotations in the axial plane were modest. It was possible to estimate the effect of the change of direction of the masseter and the medial pterygoid muscle after surgical advancement of the mandible on the loading of

the condyles. The simplified two-dimensional static model however, could not consider the effect of the other jaw muscles.

Preoperative and postoperative dynamic loading of the condyles was estimated by importing the coordinates of the masseter, medial and lateral pterygoid and anterior digastric muscles in three-dimensional dynamic models of the human masticatory system. It was not possible to estimate the loading of the condyles during chewing.

### **Future perspectives**

It could add to the understanding of jaw muscle adaptation if MRI could be taken: before orthodontic treatment, directly before surgery, six weeks after surgery and two and five years after surgery. This would require orthodontic appliances that do not disturb the images and above all, it would increase the expenses. It seems more realistic to extend the present research protocol with an MRI five years after surgery to assess long term changes. The use of titanium retention wires is recommended, because it avoids the need for temporary removal of these appliances for imaging purposes.

For comparable research projects on a larger scale, segmentation software that can automatically segment a muscle in an entire stack of images could reduce the amount of manual work considerably.

The software to match the preoperative and postoperative images, which is available at present, could add to the accuracy of the comparisons and is, therefore, recommended for use in future research.

For better understanding of the direction of the muscles, it would be of importance to be able to calculate lines of action at different jaw positions during chewing. This will require dynamic, in vivo imaging devices.

A prospective study on the changes of the biomechanical properties of the masticatory system of short-face and long-face patients is suggested. In this study, preoperative and postoperative bite force, preoperative and postoperative chewing performance and preoperative and postoperative cross-sectional area, volume and direction of the masticatory muscles should be compared, in combination with the preoperative and postoperative moment arms of the jaw muscles and the bite force. The preoperative and postoperative position and form of the condyles should also be compared. The preoperative and postoperative diet and the effect of preoperative and postoperative training of jaw-closing muscles could be studied in the same group of patients. A multicenter study will probably be necessary to include a sufficient number of patients.

In addition, an in vitro study on the pressure on the temporomandibular joints, which is generated by stretching the soft tissues surrounding the chin (i.e. the myo-fascial envelope), could be conducted.

To assess the possible role of the disc position in patients prone to develop condylar resorption after orthognathic surgery, a prospective double blind study could be set up.

This would entail a protocol in which patients are randomly assigned to two treatment groups. All should undergo the same type of orthognathic surgery. Preoperative MRI's should be made to assess the position of the discs in all patients. Surgical disc repositioning, if necessary, should precede the BSSO in one group, whilst in the other group no disc surgery should be done. Long-term follow-up will be necessary of a fairly large group of patients to come to meaningful conclusions.