Do the changes in muscle mass, muscle direction, and rotations of the condyles that occur after sagittal split advancement osteotomies play a role in the aetiology of progressive condylar resorption?


Abstract. Changes in cross-sectional area (CSA), volume (indicating muscle strength), and direction of the masseter and medial pterygoid muscles after surgical mandibular advancement were measured, along with the rotation of the condyles after bilateral sagittal split osteotomies (BSSOs) to advance the mandible. Measurements were done on magnetic resonance images obtained before and 2 years after surgery. CSA and volume were measured in five short-face and seven long-face patients (five males, seven females). Muscle direction was calculated in eight short-face and eight long-face patients (eight males, eight females). Short-face patients underwent BSSO only; long-face patients underwent combined BSSO and Le Fort I osteotomies. The CSA and volume decreased significantly (mean 18%) in all patients after surgery. The postoperative muscle direction was significantly more vertical (9°) in long-face patients. Rotations of the proximal segments (condyles) were minimal after 2 years. The results of this study showed that, after BSSO advancement surgery, changes in the masseter and medial pterygoid muscles are not likely to cause increased pressure on the condyles and nor are the minimal rotations...
of the condyles. It is concluded that neither increased muscle traction nor condylar rotations can be held responsible for progressive condylar resorption after advancement BSSO.

Keywords: Bilateral sagittal split osteotomy; Condylar position; Masseter muscle; Medial pterygoid muscle; Magnetic resonance imaging; Muscle direction; Muscle size; Progressive condylar resorption; Relapse; Surgical mandibular advancement.

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Introduction

Progressive condylar resorption (PCR) can be defined as a progressive, extreme pathological change in the structure of the condyle leading to a loss of vertical height \(^1\) (Fig. 1). It commonly presents as a bilateral condition, but unilateral presentation does occur. There is a clear predilection for females, as is borne out in several studies.\(^1,4\) The condition usually occurs after bilateral sagittal split osteotomy (BSSO) to advance the mandible,\(^7\)-\(^12\) although it may occur after conventional orthodontic treatment and can even be idiopathic, albeit rarely.\(^1,13\)-\(^15\) The authors are not aware of any published case in which PCR has occurred after a BSSO carried out to set the mandible back.

Several theories have been put forward to explain this phenomenon. It is generally accepted, however, that systemic factors may play a role, including conditions such as rheumatoid arthritis, osteodystrophy, autoimmune disease, endocrine disorders, and nutritional and metabolic disorders.\(^2\),\(^6\),\(^14\),\(^16\) Since in most cases surgery has preceded the presentation of PCR, it is very tempting to blame factors associated with the surgery. One may think of vascular impairment of the condyle because of the sagittal bone cut being not far from the condylar neck, although little evidence exists that this may be the case.\(^7\)-\(^10\),\(^20\) or inflammatory disease because of increased loading of the condyle.\(^3\),\(^21\) This may be due to increased muscle traction or to a change in position of the condyle in relation to the disc and/or capsule. Since PCR predominantly occurs in females, it is thought that oestrogen receptors, which are present in the synovial membrane of the joint, contribute to its occurrence.\(^22\)-\(^24\) Last but not least, several studies have shown that patients with a high mandibular plane angle (MPA) are prone to develop PCR, with patients suffering from anterior open bite being the most susceptible.\(^5\),\(^10\),\(^23\),\(^26\) They are particularly at risk when they have slender, backwards bending condyles.\(^10\),\(^27\)

Whatever the cause may be, the fact remains that a BSSO is almost always the initiating factor and, therefore, it is reasonable to assume that the change in condylar position in relation to the disc and capsule is a determining factor, as well as possible increased loading of the joint because of changed muscle traction. The increased loading and/or changed position of the condyle may cause increased pressure on the disc and/or capsule. Torque or just a rotational movement may also contribute to this pressure and thus result in an inflammatory reaction within the joint. This may lead to adaptive remodelling or in the worst case scenario to PCR.\(^10\)

The aim of this study was to investigate the changes that occur in the main jaw-closing muscles after a BSSO, both in terms of mass and direction. At the same time it was planned to monitor the long-term rotational movement of the condyles. The research hypothesis was that the change in muscle direction and possibly the increase in muscle mass would contribute to increased loading of the joint, which could also be the case because of a persisting rotation of the condyles.

Materials and methods

The patient groups included in this study have been described in two previous articles.\(^28\),\(^29\) In short, 12 patients (five males and seven females) were included to determine changes in cross-sectional area (CSA), and 16 patients (eight males and eight females) were included to measure directional changes in the masseter muscle and medial pterygoid muscle. The average age of the patients at the time of surgery was 27 years (range 16–45 years).

None of the patients showed marked facial asymmetry or had signs or symptoms of temporomandibular joint (TMJ) dysfunction. Of the 16 patients in whom the directional changes were measured, eight had an MPA (sella–nasion (S–N) to gonion–menton (Go–Me)) of <39° (group I). They were considered to be short-face patients. The other eight patients had an MPA of ≥39° (group II). They were classified as long-face patients. All patients underwent orthodontic treatment before and after surgery. A BSSO with the modifications as suggested by Hunsuck and Dal Pont was carried out to advance the mandible in all patients. Fixation was done with three bicortical position screws on each side. Postoperative intermaxillary fixation was not used at all. All patients were allowed to open and close the jaw immediately after surgery. In group II patients, a Le Fort osteotomy with posterior intrusion was carried out in order to avoid counter-clockwise rotation of the
mandible. An additional advancement genioplasty was done in five of these patients. All surgical procedures were carried out in one hospital by the same team of surgeons. Informed consent for participation in this study was given by all patients.

The advancement achieved at surgery was recorded with lateral cephalograms and has been presented in prior publications.28,29 The positional changes of the proximal segments/condyles and the muscular changes were calculated from magnetic resonance images (MRIs).28–30

**Magnetic resonance imaging protocol**

MRIs were taken prior to orthodontic treatment and after completion of treatment (i.e. after removal of the orthodontic appliances). The mean time elapsed between surgery and the post-treatment scans was 28 months (range 10–63 months). MRI examinations were performed with a 1.0-T MR system (Siemens, Erlangen, Germany). The patients were scanned in a supine position with the Frankfort horizontal plane oriented perpendicular to the scan table. The patients were instructed to close their teeth but to avoid clenching. Axial images were made with a multi-slice T1 spin-echo sequence (repetition time (TR)/echo time (TE) 700 ms/15 ms) with 5-mm thickness and 1.25-mm inter-slice gap. Sagittal and coronal imaging was performed in the same sequence with 4-mm thickness and 1-mm inter-slice gap. Images parallel to the right and left ascending rami of the mandible were made with oblique sagittal multi-slice T1 spin-echo sequences (TR/TE 400 ms/15 ms) with 3-mm thickness and 1-mm inter-slice gap. The masseter muscle and medial pterygoid muscle were segmented in these images using individualized software to compute the largest CSA (Fig. 2), the volume, and the direction of these muscles. Sagittal and axial rotations of the condyles, i.e. proximal segments, and the distance between the mandibular angles in the axial plane (intergonial distance) were also calculated from these images.

**Results**

The results of the calculation of the changes in CSA and volume of the masseter and medial pterygoid muscles and the postoperative changes in the direction of these muscles have been reported previously.28,29 In short, the CSA and volume of the jaw-closing muscles decreased by 18% in the short-face and the long-face patients (Fig. 3). The muscle direction became 9° more vertical in the long-face patients. This occurred along with upward rotation of the proximal segments. In short-face patients, no significant changes in muscle direction were observed. The decrease in the mechanical advantage (the ratio between the moment arm of the muscle and the moment arm of the bite force)31 of the masseter muscle and medial pterygoid muscle after surgery was about the same in both groups.30 The static joint reaction force (opposite to the resultant of all of the jaw muscle vectors) increased minimally and the dynamic joint reaction force decreased after surgery in both groups.30 Postoperative axial rotation (torque) of the condyles and the ramus was modest in the present sample.30 The mean intergonial distance, as measured in the axial plane between the angles of the mandible, increased from 88 to 90 mm, which was not significant.

**Discussion**

The main reason for investigating the muscular changes that occur after BSSO to advance the mandible was to study their possible role in the pathogenesis of condylar resorption after surgery. The hypothesis was that because of these changes, the loading on the condyles would increase.
The results of our studies clearly indicate that the muscle strength had not increased, because the CSAs had decreased considerably in long-face and short-face patients. The change in direction in the long-face group probably contributed to a more efficient action to achieve the same bite force as compared to the preoperative situation. This is because the increase in the vertical component of the force of these muscles in long-face patients would be approximately 5%. However, the somewhat increased efficiency of the main closing muscles is likely to be completely neutralized by the decreased strength of these muscles, and thus increased loading of the joint is not to be expected. Based on these observations it may, therefore, be concluded that the change in direction and CSA of the closing muscles, as studied in this series of patients, does not contribute to the development of PCR. Even though the study sample was rather small, the results were statistically relevant.29 Thus, this part of the hypothesis has to be refuted.

A component that has not been investigated concerns the action of the temporalis muscle. This muscle is, due to its shape, difficult to measure with the method used. In the segmentations, the strong anterior part of the muscle would have to be ‘separated’ from the thin, fan-like posterior part to compute the main direction of the muscle. This separation procedure was rejected by the authors as being arbitrary and therefore not reproducible. It is assumed that the temporalis muscle hardly changes its direction after a BSSO. The authors have to admit that the action of this muscle could affect the loading of the condyle, although this cannot be substantiated. The rotational movements of the condyle, as measured on average 28 months postoperatively, were minimal. It should be emphasized, however, that no measurements were done immediately postoperatively. It could very well be that remodelling had taken place in the period between the operation and when the MRI was taken to adapt the contour of the condyles to their new position. Condylar resorption was not observed in any of the patients treated.

Because increased pressure on the condyles as a result of the treatment remains an attractive hypothesis, a different explanation has to be found. The length of the digastic muscles had not changed either, and neither had their volume or their CSA.32 Hence, the role of this muscle appears to be negligible. The stretched soft tissue drape consisting of skin and subcutaneous tissues remains to be considered. This stretching could be the cause of an increased reciprocal force on the condyles.33 At present, much effort is put into three-dimensional imaging of the changes to the facial surface after surgical mandibular advancement. Once an inventory of these changes has been drawn it may become possible to develop a reliable algorithm to quantify the pressure of the stretched skin and subcutaneous tissues on the joint.

Another explanation may be found in the technique of seating the condyles in the fossa. Surgeons tend to push the condyles backwards when applying fixation in order to avoid condylar sag. In this context, the hypothesis as put forward by Wolford and Cardenas3 – that an anteriorly dislocated disc might predispose to PCR – becomes relevant.3,36-39 A condyle pushed posteriorly against a stretched posterior ligament may cause a sterile inflammatory reaction.39 To assess the role of an anteriorly displaced disc, a randomized prospective study will be necessary. This will take much effort from the profession because of the large number of patients needed for a study of this type, due to the relative rarity of the at-risk group, i.e. young female patients with a long face combined with mandibular hypoplasia, an anterior open bite, and small, reclining condyles.

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## Competing interests
None.

## Ethical approval
This study received ethical approval from the Medical Ethics Review Committee of the VU University Medical Centre Amsterdam (2014.056).

## Patient consent
Not required.

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BSSO and progressive condylar resorption 631