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Changes in the temporomandibular joint position depending on the sagittal osteotomy technique and extent of mandibular movement

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Abstract. The bilateral sagittal split osteotomy (BSSO) and high oblique sagittal split osteotomy (HSSO) are common techniques for mandibular movement in orthognathic surgery. The aim of this study was to evaluate the influence of both techniques, as well as movement distances and directions, on the position of the temporomandibular joint (TMJ). A total of 80 mandibular movements were performed on 20 fresh human cadaver heads, four on each head. Pre- and postoperative cone beam computed tomography was used to plan the surgical procedure and analyse the TMJ. Reference measurements included the anterior, superior, and posterior joint spaces, intercondylar distances and angles in the axial and coronal planes, and the sagittal, coronal, and axial angulations of the proximal segment. Only minor differences were found between the BSSO and HSSO techniques, particularly in terms of the intercondylar angle in the axial plane ($P < 0.03$) and the condylar angle of the proximal segment in the sagittal plane ($P < 0.011$). Observed changes in the TMJ were mostly opposite when moving the mandible forwards and backwards and increased with increasing movement distance. BSSO and HSSO result in similar changes in TMJ position. The extent of the movement distance influences the position of the condyle more than the osteotomy technique.

Keywords: bilateral sagittal split osteotomy; high oblique sagittal split osteotomy; temporomandibular joint.

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Introduction

The traditional bilateral sagittal split osteotomy (BSSO) was first introduced by Obwegeser[1] and was later modified by Dal Pont[2]; it is amongst the most popular surgical techniques used to treat mandibular movement due to skeletal malocclusions of the jaw. Various modifications of the traditional BSSO technique have been reported, such as those by Hunsuck and Epker[3,4]. Further modifications may be based on the extent of the osteotomy cut and device used[5,6].

Another increasingly popular technique, namely the high oblique sagittal split osteotomy (HSSO), is based on an osteotomy localized cranial to the mandibular foramen[7]. Compared with the classical BSSO, the HSSO is believed to lead to fewer injuries to the inferior alveolar nerve, a reduction of the exposed bone surface, and minimal possible bad splits[8–10]. However, this technique also results in a reduction of the bone contact area between segments[11]. Other limitations and concerns related to potential complications include alterations in condylar position and complicated handling of the short proximal segment[12–16].

Kuehle et al. evaluated changes in the position of the condyle in the glenoid fossa and its angulation before and after orthognathic surgery with HSSO using cone beam computed tomography (CBCT)[17] and reported that the joint space increased significantly relative to the baseline immediately postoperative. However, no differences were found after a 9-month follow-up. The authors thus concluded that this technique allows free-hand condylar positioning into the fossa safely without any clinically relevant dislocations.

Although Kuehle et al. distinguished between mandibular advancement and setback, neither an investigation of the extent of movement nor a comparison with a traditional BSSO technique was conducted. Therefore, the aim of the present cadaveric investigation was to evaluate changes in the temporomandibular joint (TMJ) position according to the sagittal osteotomy technique applied (HSSO vs BSSO) and the distance and direction of mandibular movement.

Materials and methods

The Ethics Committee of the Medical Faculty of RWTH Aachen (EK 219/16) reviewed and approved the study design, and the Institute of Molecular and Cellular Anatomy of the University Hospital of RWTH Aachen gave institutional approval. A total of 80 mandible movements were performed on 20 mandibles possessing at least a molar dentition in fresh cadaver heads (11 female and nine male; mean age 72 years, range 55–86 years). The same osteotomy technique was performed on the left and right ascending ramus, and two mandible advancements and setbacks were done per head. The BSSO group consisted of five females and five males with a mean age of 70 years (range 55–81 years), while the HSSO group consisted of six females and four males with a mean age of 74 years (range 65–86 years).

Surgical planning

Before surgery, CBCT scans (Galileos CBCT; Sirona, Bensheim, Germany) of all heads were performed in maximum intercuspation, and super-hard plaster models of the maxilla (Alpenrock; Amann Girrbach AG, Koblach, Austria) based on impressions were manufactured using Impregum Penta (3 M ESPE, Neuss, Germany). Afterwards, all models were transferred to virtual reality using digital scans generated by a three-dimensional (3D) model scanner (orthoX scan; Dentaurum, Ispringen, Germany). Subsequently, the CBCT scans and virtual models were transferred in DICOM format to Dolphin 3D Surgery software (Dolphin Imaging & Management Solutions, Chatsworth, CA, USA). After superimposition of the model casts and upper and lower jaws, 3D segmentations of the mandible and maxilla were performed and surgical cuts were defined. 3D surgery was subsequently performed on each cadaver head. Four movements corresponding to mandible advancements and setbacks of 4 mm and 8 mm were planned in each head. Orthognathic surgery was conducted on 10 heads using traditional BSSO and on another 10 heads using a modified HSSO (Figs. 1 and 2). Surgical splints with a vertical occlusion opening of approximately 3 mm were designed for each movement distance (Figs. 3 and 4) and manufactured using a 3D printer (Form 2; Formlabs, Somerville, MA, USA).

Surgical procedure

In the BSSO group, a lingual osteotomy was performed according to Hunsuck, as described above, and just posterior to the mandibular foramen through the cortical bone using a traditional burr (Lindemann Drill; Hager & Meisinger GmbH, Neuss, Germany). A buccal osteotomy through the cortical bone was performed in the region between the first and second molars. The two osteotomies were combined with a third osteotomy along the oblique line. Subsequently, the distal and proximal segments were separated under continuous spreading using a spreader and chisel.

In the HSSO group, the osteotomy was performed using a reciprocating saw (GC615R, reciprocating; Microspeed Aesculap AG, Tuttlingen, Germany). The cut was started on the lingual side of the ascending ramus approximately 3 mm above the mandibular foramen and ran downwards to the vestibular side of the ascending ramus of the mandible. The bone cut was then completed with a chisel.

Mandibular movement

Four splints were manufactured for each head to displace the mandible forward or backward by approximately 4 mm or 8 mm. After intermaxillary fixation (IMF) into the operation splint using IMF screws and metal wires, osteosynthesis was performed using plates. To provide rotational stability of the proximal and distal segment, the fixation was performed on each side using one plate and four screws after BSSO and one plate and six screws after HSSO by oral approach (Modus 2.0 fixation plates: BSSO, M-4051C; HSSO, M-4055C; Modus 2.0 screws M-5243.07C/4; Medartis GmbH, Umkirch, Germany). In the course of the mandibular setbacks after BSSO, the bone excess on the proximal segment was removed until tension-free bony contact between the distal and proximal segments could be achieved.

Radiological measurements

Postoperative CBCT scans were performed after each movement, and the IMF screws, osteosynthesis plates, and surgical splints were removed. The next four splints were then inserted, and IMF and osteosynthesis were repeated in the new position. Postoperative CBCT images were taken after all movements, four in each cadaveric head.

Radiological measurements were performed using iPlan CMF software (Brainlab, Munich, Germany) after adjustment according to Kuehle et al.[17], with the definition of reference points and corresponding planes, including the most cranial points of the glenoid fossa in the coronal plane, the Frankfort horizontal

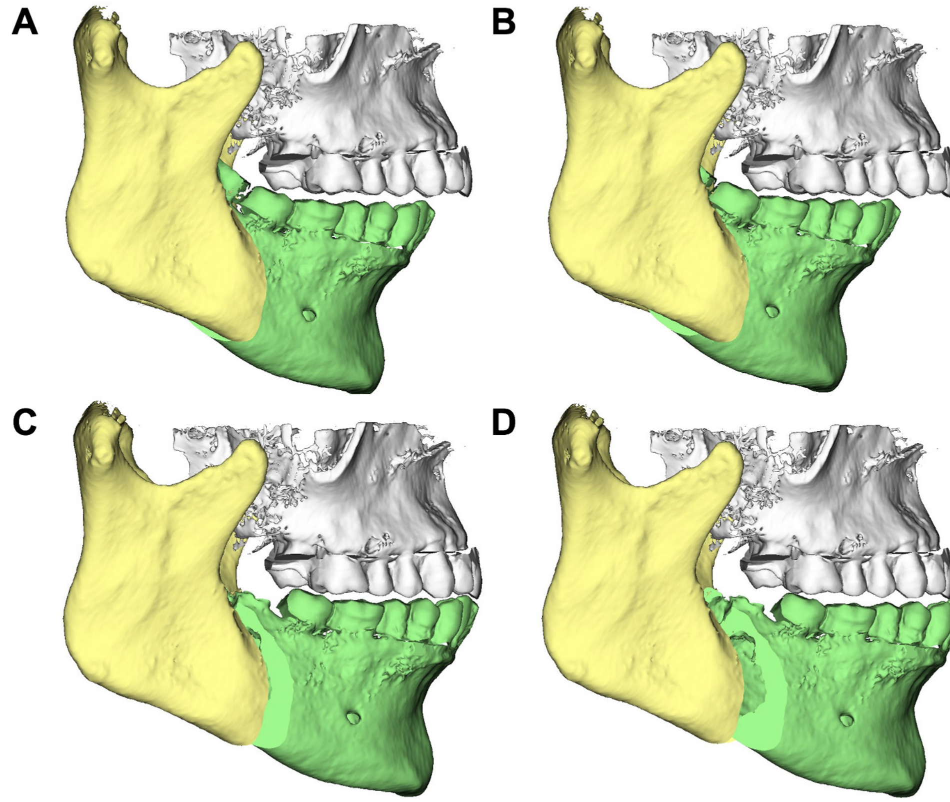

Fig. 1. Virtual planning of mandibular movement based on bilateral sagittal split osteotomy (BSSO): (A) −4 mm setback, (B) −8 mm setback, (C) 4 mm advancement, and (D) 8 mm advancement.

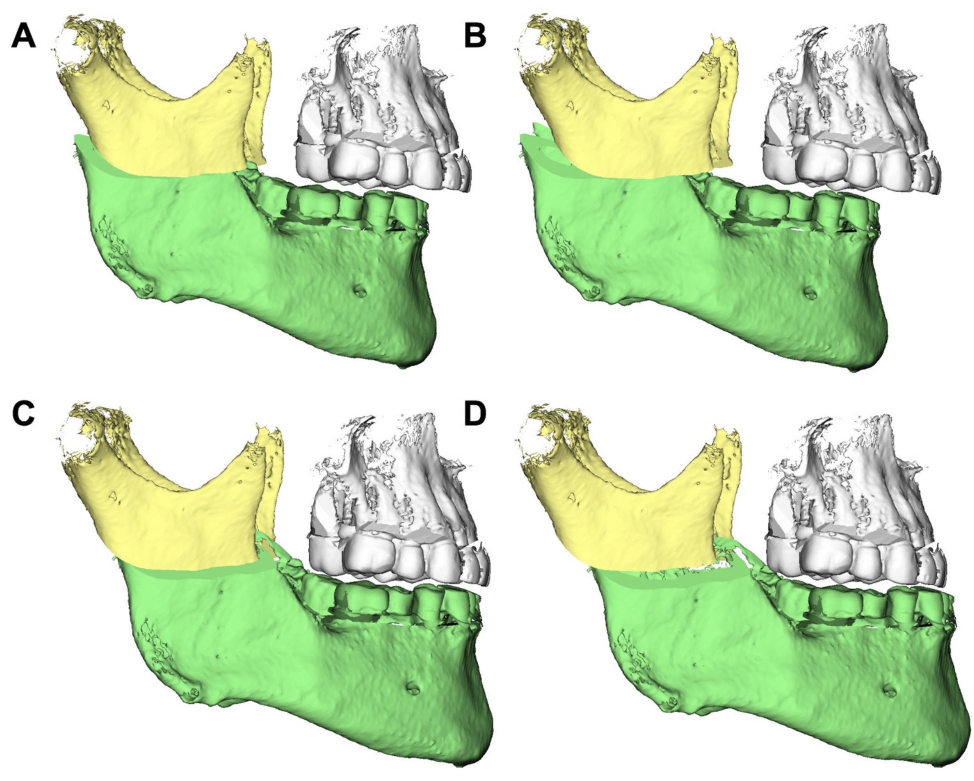

Fig. 2. Virtual planning of mandibular movement based on high oblique sagittal split osteotomy (HSSO): (A) −4 mm setback, (B) −8 mm setback, (C) 4 mm advancement, and (D) 8 mm advancement.

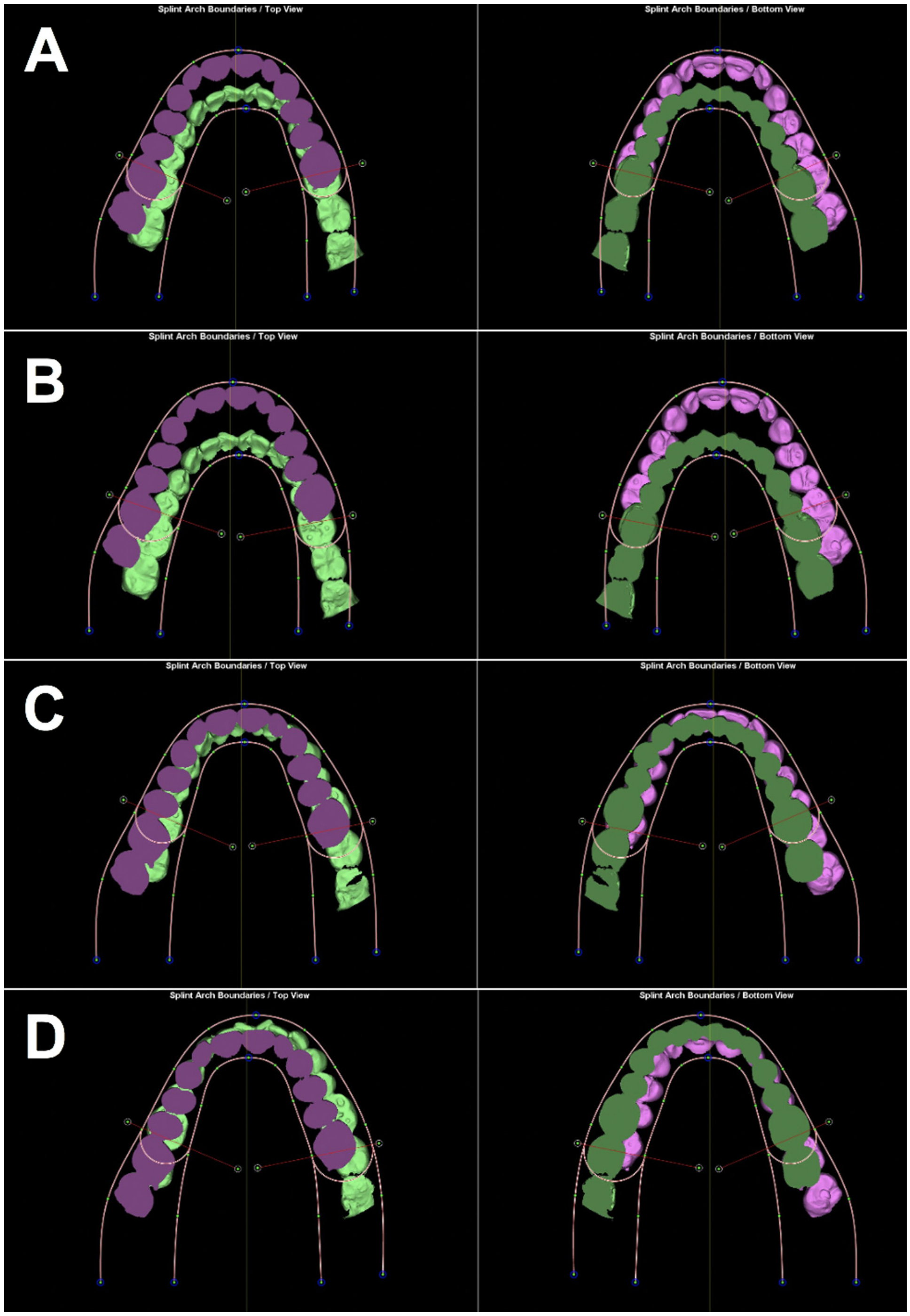

Fig. 3. Occlusal view of the virtual splint planning based on bilateral sagittal split osteotomy (BSSO): (A) −4 mm setback, (B) −8 mm setback, (C) 4 mm advancement, and (D) 8 mm advancement.

in the sagittal plane, and a multiplanar reconstructed line from the lower nasal spine to the most anterior portion of the foramen magnum in the axial plane. This procedure ensured reliable measurements of the condylar angulations.

The positions of the condyles were investigated in the sagittal, coronal, and axial planes, including the anterior, superior, and posterior joint spaces, the sagittal, coronal, and axial condylar angulations, the axial and coronal intercondylar angulations, and the outer and inner intercondylar distances (Figs. 5 and 6).

Statistical analysis

All measurements were repeated after 2 weeks by the same investigator. Calibration was assessed with the intra-class correlation coefficient (ICC); the ICC results were consistently higher than 0.85 for all variables. Overall, the ICC ranged between 0.91 and 0.96. Due to the small sample size, non-parametric tests were applied to the data for analysis. The Wilcoxon matched-pairs signed rank test was employed to compare movement distances (4 mm vs 8 mm) for mandibular advancement and setback, and the Mann–Whitney

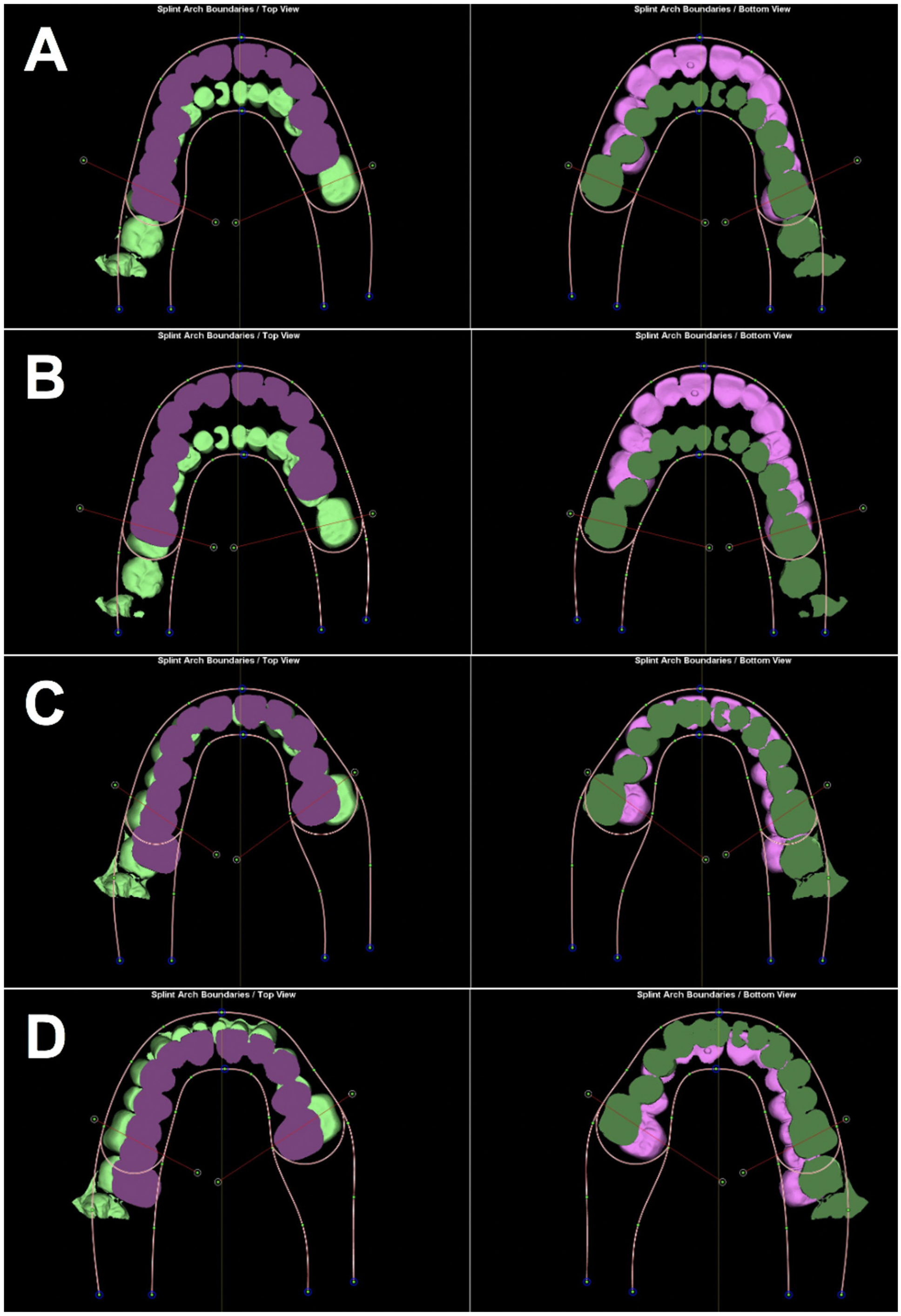

Fig. 4. Occlusal view of the virtual splint planning based on high oblique sagittal split osteotomy (HSSO): (A) −4 mm setback, (B) −8 mm setback, (C) 4 mm advancement, and (D) 8 mm advancement.

test was used to analyse differences between surgical techniques (HSSO vs BSSO) for each movement (−8 mm, −4 mm, 4 mm, and 8 mm). The level of significance was set to $P \leq 0.05$ using the statistical programme Prism version 8 (GraphPad Software Inc., La Jolla, CA, USA). All results are expressed as the mean ± standard deviation (SD).

Results

The absolute mean and SD values of the measured distances and angles before and after surgery within (anterior, superior, and posterior joint spaces; axial, coronal and sagittal condylar angles) and between TMJs (outer and inner intercondylar distances and axial and coronal intercondylar angles) are presented in Supplementary Material Table S1. Figs. 7–10 demonstrate average changes (T0–T1) and the corresponding *P*-values of comparisons between HSSO and BSSO and between 4 mm versus 8 mm mandibular setback and advancement. Positive values reflect a decrease, whereas negative values indicate an increase compared with the initial value (T0).

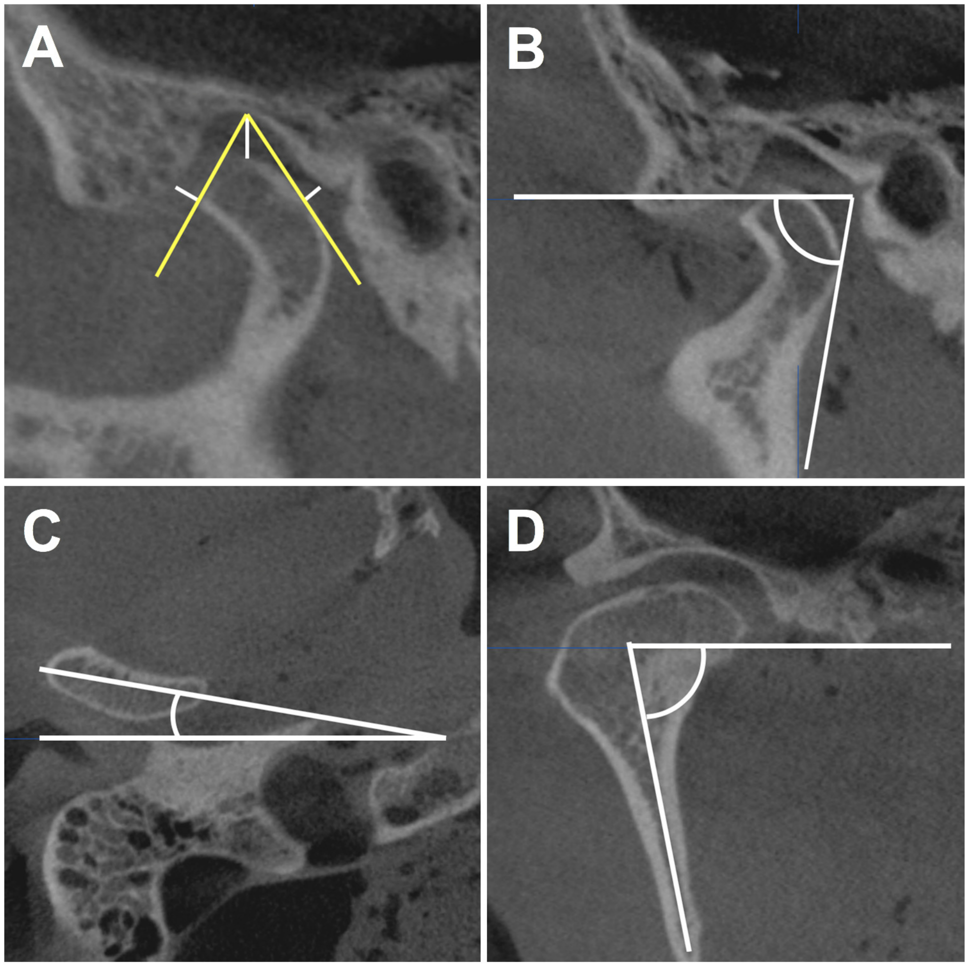

Fig. 5. Condylar measurements of the temporomandibular joint (TMJ) position: (A) anterior, superior, and posterior joint spaces (yellow supporting lines are used to measure the joint space in three areas); (B) sagittal, (C) axial, and (D) coronal condylar angulation of the TMJ.

HSSO and BSSO similarly resulted in an extension in the anterior portion and a compression in the posterior portion after mandibular setback; by contrast, both techniques resulted in a compression in the anterior portion and an extension in the posterior portion after mandibular advancement. No statistically significant difference was found between the splitting techniques, but statistically significant differences were found between the 4 mm and 8 mm movements in both directions ($P < 0.008$) (Fig. 7A, C).

Furthermore, compression of the superior joint space increased during forward and backward movement (Fig. 7B). In addition, whilst no statistically significant difference was observed between BSSO and HSSO, the extent of mandibular movement ($P < 0.006$), except for mandibular advancement on the right side after HSSO ($P = 0.432$), showed statistically significant differences between the techniques.

A statistically significant increase was observed for both intercondylar distances after mandibular advancement (4 mm vs 8 mm; $P < 0.004$), and a statistically significant decrease was noted after mandibular setback (−4 mm vs −8 mm; $P < 0.004$). No statistically significant differences in outer and inner intercondylar distances were found between the two osteotomy methods, even though the intercondylar distances were less descriptive after HSSO compared with BSSO for setback and the outer intercondylar distances were less descriptive after BSSO compared with HSSO after advancement (Fig. 8).

Changes in the axial and coronal intercondylar angles were measured (Fig. 9). Backward movement led to a significant decrease ($P < 0.004$), whereas forward movement resulted in a significant increase ($P < 0.004$) in both angles. In the axial plane, significant differences were found between the osteotomy techniques for the −4 mm and −8 mm setbacks, as well as for the 4 mm advancement ($P < 0.030$).

Average changes in condylar angulation in the sagittal, coronal, and axial planes were similar between the left and right TMJ (Fig. 10A–C). In the sagittal plane, the mandibular movement mainly led to an increase in condylar angulation, except after advancement based on conventional HSSO (Fig. 10A). Whilst a statistically significant increase in sagittal angulation in the right and left TMJ was found between the −4 mm and −8 mm setbacks after both split techniques and between the 4 mm and 8 mm advancement after BSSO ($P < 0.004$), a significant decrease between the 4 mm and 8 mm advancements was measured after HSSO ($P = 0.002$). Significant differences between the two osteotomy methods were found for all comparisons ($P < 0.006$, except for the comparison regarding the right condyle at 8 mm advancement ($P = 0.093$).

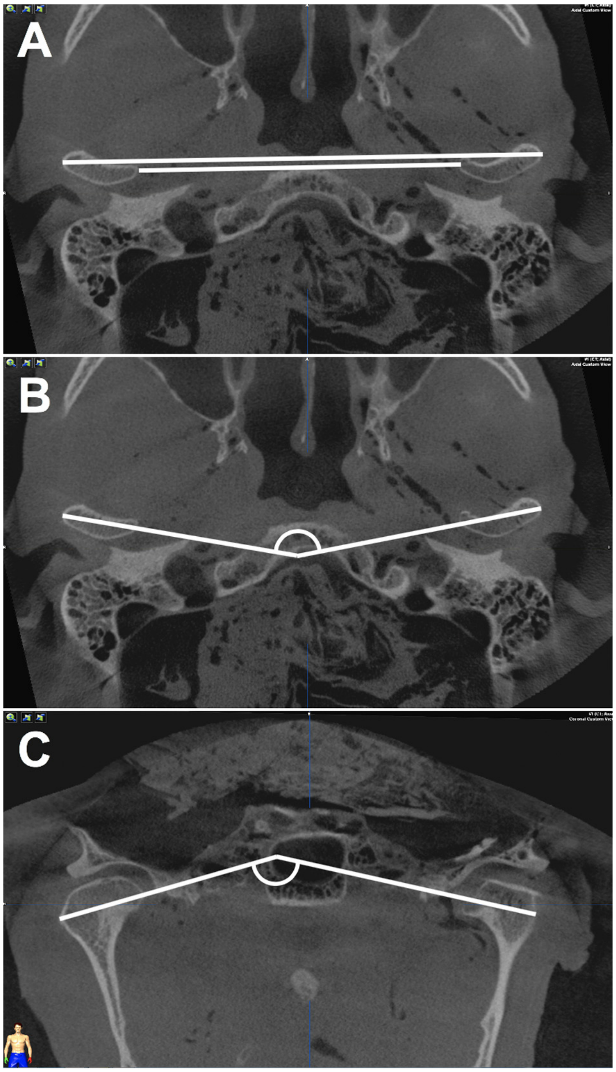

Fig. 6. Intercondylar measurements of the temporomandibular joint position: (A) outer and inner condylar distances, (B) axial intercondylar angulation, and (C) coronal intercondylar angulation.

In the coronal plane, only slight changes in condylar angulation were observed (Fig. 10B). Coronal angulation in both surgical groups increased between both advancements ($P < 0.004$) and decreased between both setbacks ($P = 0.002$). Statistically significant differences between splitting techniques were observed only for the −4 mm setback in the right TMJ ($P = 0.032$).

Condylar angulation in the axial plane corresponds to the axial intercondylar angle. A significantly lower angulation was found with increasing setback (−4 mm vs −8 mm) ($P = 0.002$), and a significantly larger angulation was determined after increasing advancement (4 mm vs 8 mm) ($P = 0.002$) (Fig. 10C). These results reveal that the condyle rotates inwards when moving backwards and rotates outwards when moving forwards. No differences between the two surgical techniques were detected for any of the comparisons.

Discussion

Several studies investigating HSSO of the ascending ramus of the mandible to achieve mandibular movement during orthognathic surgery have been published[7,10,11,16–18]. These studies cite the optimal location and orientation of the osteotomy cut, fixation of the bone segments to prevent injury to the inferior alveolar nerve, and disorders of the TMJ as major challenges that must be addressed to improve the long-term stability of skeletal movements and bone healing conditions. The development of postoperative disorders of the TMJ has been well investigated[19,20] and the risk is much higher in patients with preoperative dysfunction of the TMJ than in those without such dysfunction[21].

Seeberger et al. investigated the function of the TMJ after HSSO in a study evaluating this technique as an alternative method in orthognathic surgery and reported stable postoperative bites and no dysfunction of the TMJ[7]. The authors also suggested that their results using HSSO were comparable to those obtained using BSSO[22,23], and reported that lateral excursion and protrusion improved significantly after the operation. Thus, the group concluded that the results of HSSO are nearly identical to those of BSSO as far as the function of the TMJ is concerned[24]. In a follow-up investigation, Seeberger et al. demonstrated that an adequate condylar position can be achieved even without a condylar-positioning device[16]. Here, positional control of the condylar segment was achieved in 22 patients treated by HSSO for mandibular advancement or setback during and after surgery by mobile CBCT. Whilst no significant difference in the proximal segment positions was observed in the axial and coronal planes, a significant difference was noted in the sagittal plane. The authors concluded that fewer positional changes can only be expected when HSSO is performed in the absence of postoperative TMJ dysfunction or an unstable occlusion and, therefore, the intercondylar distance should not be a critical factor in selecting the most suitable osteotomy technique. However, neither a BSSO control group nor movement distances or directions were considered in that study.

In a study using CBCT, Kuehle et al. assessed the positions of the mandibular condyles after HSSO in orthognathic surgery immediately postoperative and before removal of the osteosynthesis plates at 9 months postoperative[17]. The position of the TMJ changed after mandibular advancement by an average of 6.51 ± 2.41 mm amongst 24 patients with class II malocclusion and after mandibular setback by an average of 4.16 ± 2.77 mm amongst 26 patients with class III malocclusion. These investigators found a slight increase in both groups relative to the baseline immediately postoperative, but no significant increase at the 9-month follow-up. Changes in position in the sagittal, coronal, and axial planes were comparable. In addition, condylar centralization by the spatial approximations tended to occur. The group thus concluded that BSSO allows free-hand condylar positioning into the fossa safely without any clinically relevant disloca-

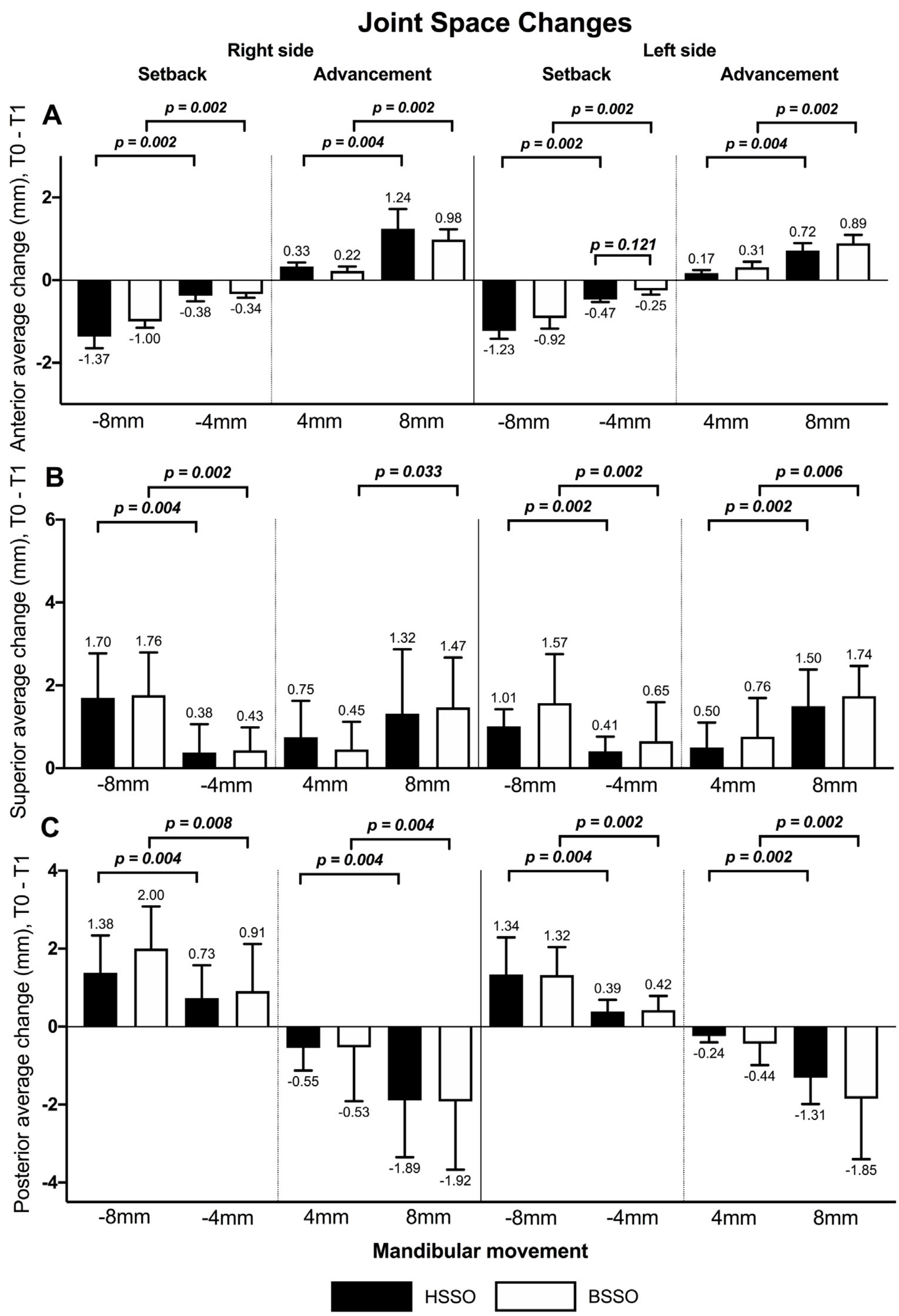

Fig. 7. Mean changes in the (A) anterior, (B) superior, and (C) posterior joint space of the left and right temporomandibular joint depending on the sagittal split osteotomy technique (high oblique sagittal split osteotomy (HSSO) vs bilateral sagittal split osteotomy (BSSO)) and movement distance of mandibular setback (−4 mm vs −8 mm) and advancement (4 mm vs 8 mm).

tions. However, in this work, only changes in joint space and proximal segment angulation were determined; no information about intercondylar changes was provided.

Movement of the TMJ after HSSO and BSSO has also been investigated in a computer-simulation study[11]. An increase in intercondylar distance during mandibular advancement and a reduction during mandibular setback were found, which were already appreciable from a mandibular movement distance of 3 mm in both osteotomy groups. However, no significant differences between HSSO and BSSO were noted. Thus, the surgical technique appears to be of minor significance regarding TMJ position; however, possible segment rotation could not be determined in this simulation.

In the present investigation, a study design based on the use of fresh human cadaver heads was applied to generate results close to clinical reality. The pur-

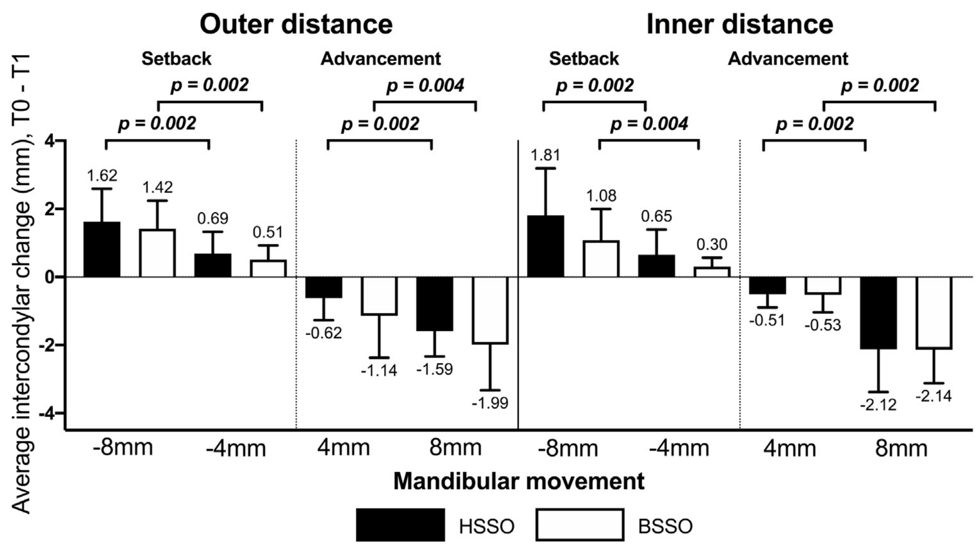

Fig. 8. Mean changes in the outer and inner intercondylar distance between the left and right temporomandibular joint depending on the sagittal split osteotomy technique (high oblique sagittal split osteotomy (HSSO) vs bilateral sagittal split osteotomy (BSSO)) and movement distance of mandibular setback (−4 mm vs −8 mm) and advancement (4 mm vs 8 mm).

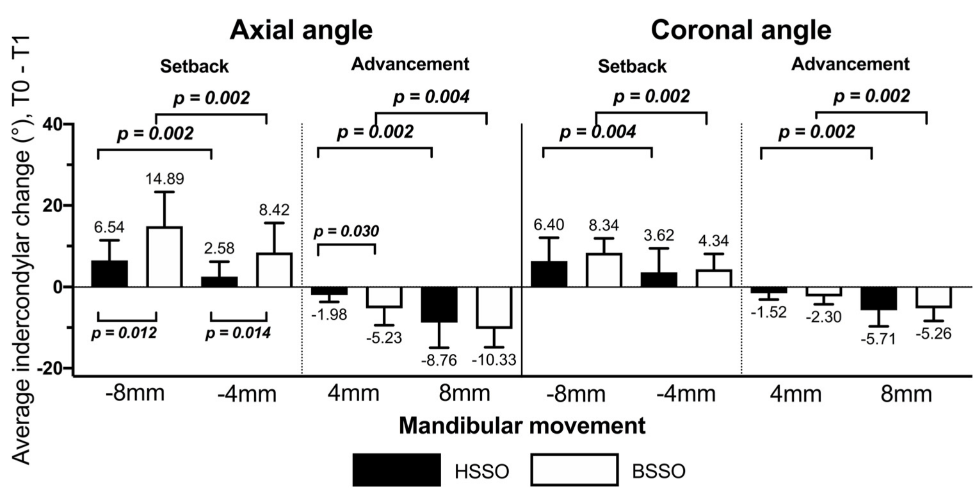

Fig. 9. Mean changes in the axial and coronal intercondylar angle between the left and right temporomandibular joint depending on the sagittal split osteotomy technique (high oblique sagittal split osteotomy (HSSO) vs bilateral sagittal split osteotomy (BSSO)) and movement distance of mandibular setback (−4 mm vs −8 mm) and advancement (4 mm vs 8 mm).

pose of this study was to compare changes in the position of the condyle in the glenoid fossa and its angulation after orthognathic surgery using HSSO and BSSO with different movement distances for mandibular advancement and setback by CBCT. The maxillary occlusal plane was not taken into account in the operative planning in this investigation, although the mandibular movement could be influenced in the vertical directions. However, the alterations of the condyles caused by the vertical component of the mandible movement should be rated as slightly[25].

The present study observed significant differences in mandibular advancement and setback after BSSO and HSSO. The observations included all joint space measurements, the inner and outer intercondylar distances, the axial and coronal intercondylar angles, and the angulation of the condylar segment in all three planes.

Mandibular advancement led to an anterior compression and posterior extension, whilst mandibular setback resulted in the opposite results. Moreover, these effects increased with increasing movement. The coronal space was compressed in both directions. No statistically significant difference was found between the two surgical techniques. The present results differ from those of Kuehle et al., who reported a slight extension of all three joint spaces after surgical treatment of class II and class III patients[17]. Whilst the inner and outer intercondylar distances increased during mandibular advancement and decreased after setback, statistically significant differences between the osteotomy methods were not observed, even when the outer distance was descriptively larger for mandibular advancement based on BSSO and smaller for mandibular advancement based on HSSO. This finding suggests a proximal segment rotation especially in the axial plane, which seemed to lead to a significantly greater reduction in the intercondylar angle in the HSSO group. In general, both sagittal split osteotomies resulted in an increase in the intercondylar angle in the axial and coronal planes during backward movement and a decrease in this angle during forward

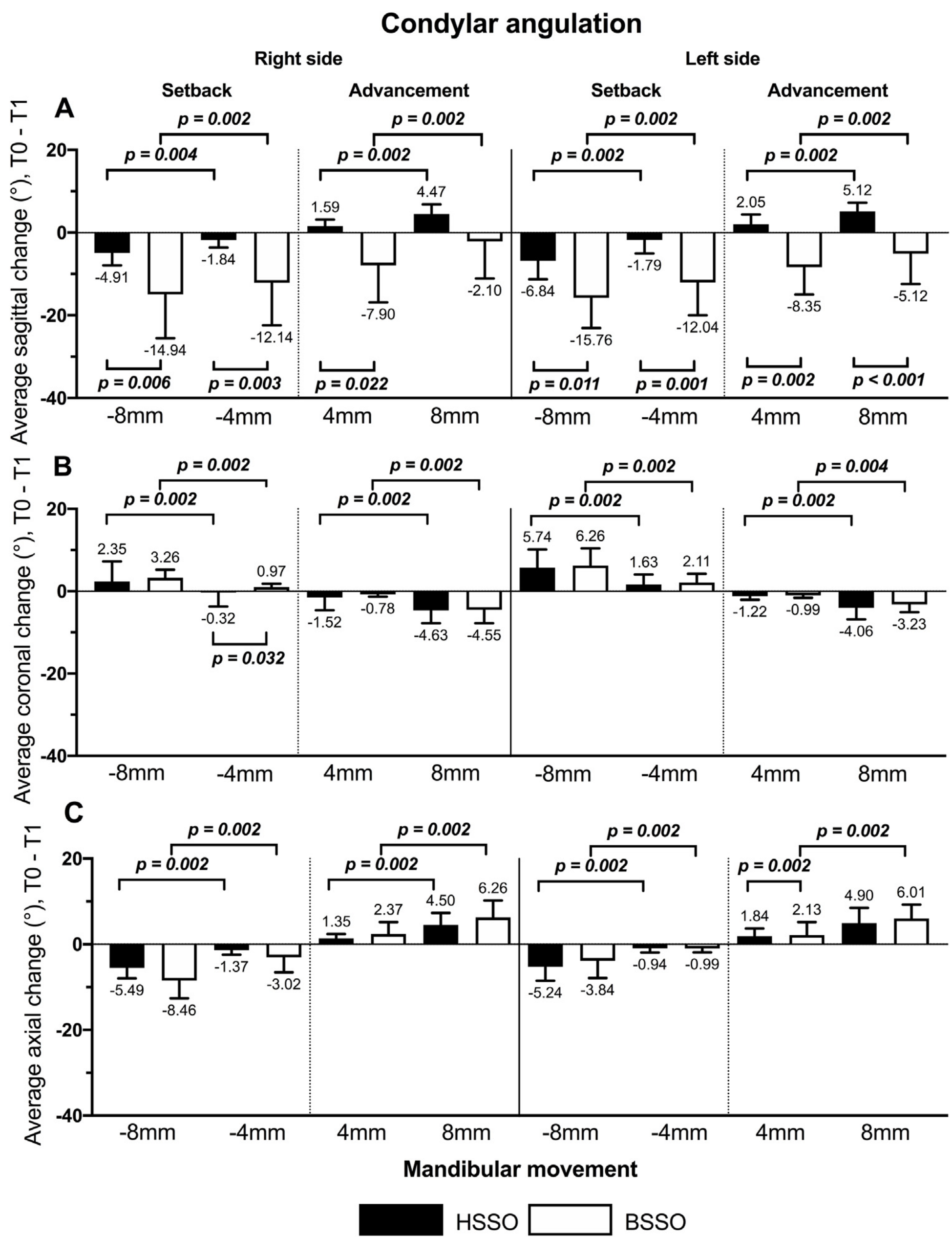

Fig. 10. Mean changes in the condylar joint angulation in the (A) sagittal, (B) coronal, and (C) axial plane of the left and right temporomandibular joint depending on the sagittal split osteotomy technique (high oblique sagittal split osteotomy (HSSO) vs bilateral sagittal split osteotomy (BSSO)) and movement distance of mandibular setback (−4 mm vs −8 mm) and advancement (4 mm vs 8 mm).

movement. The results for the intercondylar distance are similar to those of Möhlhenrich et al.[11] and different from those of Seeberger et al.[16], who reported increases in intercondylar distance from approximately 8.04 ± 0.11 mm to 8.42 ± 0.12 mm for mandibular advancement and from approximately 8.03 ± 0.11 mm to 8.31 ± 0.12 mm for mandibular setback.

Significant differences between the two surgical techniques were found when considering condylar angles, especially for sagittal angulation. Here, both forward and backward movement of the mandible led to significant reductions in angulation. These results are comparable to those of Kuehle et al., who reported slight differences in proximal segment angulation in the axial and coronal planes but not in the sagittal plane[17].

In conclusion, changes in TMJ position depending on the sagittal osteotomy technique are only minor and mainly involve the intercondylar angle in the axial plane and the condylar angle of the proximal segment in the sagittal plane. Changes in the TMJ are mostly opposite when moving the mandible forwards and backwards and increase with increasing movement distance. The results of this study differ in part from those reported in the current literature. Therefore, further clinical studies must be conducted to examine the extent of the movement distance between BSSO and HSSO.

Funding

The osteosynthesis plates were provided free of charge by Medartis GmbH, Umkirch, Germany.

Competing interests

The authors do not have any financial interests or commercial associations to disclose.

Ethical approval

The Ethics Committee of the Medical Faculty of the RWTH Aachen (EK 219/16) reviewed and approved the study design.

Patient consent

Not required.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.ijom.2020.06.009.

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