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Bilateral sagittal split ramus osteotomy using a conventional osteotome-hammer and a magnetic mallet device: an *in vitro* comparison

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Abstract. – OBJECTIVE: The conventional chisel osteotome technique (CCOT) and the magnetic mallet osteotome technique (MMOT) with a newly manufactured custom osteotome tip for the magnetic mallet device (MMD) were compared to determine whether magneto-dynamic osteotomies are as reliable for orthognathic surgery as the conventional method.

MATERIALS AND METHODS: A custom osteotome tip compatible with a magnetic mallet device was manufactured. Thirty-two fresh 1-year-old sheep hemi-mandibles were chosen for osteotomy procedures to achieve the most human-like results. Sagittal split ramus osteotomies were performed, and lingual fracture pattern (LFP), basis split pattern (BSS), duration of sagittal split osteotomy, and alveolar inferior nerve injury were investigated macroscopically.

RESULTS: Six of the defined fracture schemes were observed out of the 27 lingual split patterns. After LFP and BSS evaluation, the unfavorable fracture counts for MMOT and CCOT are 3 and 4, respectively. The macroscopic nerve damage assessment for both groups is 2 for MMOT and 1 for CCOT. Although the average durations are similar in both groups, the difference between MMOT samples is closer. None above showed a significant difference.

CONCLUSIONS: MMOT was evaluated as a reliable alternative to CCOT in bilateral sagittal split ramus osteotomy based on the lingual and basis split patterns, duration, and nerve damage findings.

Key Words:
Orthognathic surgery, Magnetic mallet, Bilateral sagittal split osteotomy, Unfavorable fracture, Lingual split scale.

Introduction

Sagittal split ramus osteotomy (SSRO) was introduced by Obwegeser[1-3] and updated since. SSRO is among the most common maxillofacial osteotomy procedures that involve producing a directed fracture along the alveolar inferior nerve canal to correct maxillofacial deformities[1,4,5]. A vertical cut from the linea obliqua at the second molar region's level to the jaw's lower border is defined as the buccal cortical plate osteotomy. Precise osteotomy lines for appropriate splitting and a stable fixation technique are two essential aspects of the efficacy of this treatment[1,3]. The most common SSRO complications are inferior alveolar nerve damage causing lower lip paresthesia, poor or undesirable segmental splitting causing bone malunion and unexpected condylar location causing an unwanted postoperative modification of the closure[6-8]. Unfavorable splits are defined as those that do not conform to the established scheme[9].

Current surgical procedures are designed to be less invasive for improved recovery[10]. Hand mallets may entail complications associated with manual hammering and cause distant stress, dizziness, and vertigo[11]. In addition, when the conventional chisel osteotome technique (CCOT) is used, especially by inexperienced surgeons, the force may not be transmitted in an orthogonal direction, causing inadvertent off-axis shifts that can damage vital structures and surrounding soft tissue. The magnetic mallet device (MMD) uses an electronically controlled electromagnetic collision between two masses to apply a high-intensity impact very quickly; this produces an elastic wave, followed by a certain amount of motion, which creates an inelastic shock wave on the bone, which promotes plastic deformation. MMD is used for dentoalveolar surgical procedures like alveolar ridge splitting, closed sinus lift, and horizontal bone expansion. It is designed to reduce craniofacial stress as much as possible by concen-

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trating pressure on the targeted area. This design is crucial because the bone comprises sections of different densities, and a conventional osteotome is prone to deflection when moving from one density to another. Since the magnetic mallet osteotomy technique (MMOT) generates axial and radial movements at the tip of the osteotome with less energy distribution, it is reported[12] that segmental ridge splitting with MMOT is a predictable surgical approach that does not result in osteotome deflection, unpredictable bone damage, or overheating. MMD operates on the principle of an electronically controlled electromagnetic collision between two masses, which enables an incredibly rapid application of a high-intensity impact; this produces an elastic wave, followed by a certain amount of motion, which generates an inelastic shock wave on the bone[13].

This study aims to investigate whether MMOT is a reliable alternative to CCOT in terms of lingual and basis fracture-split patterns, osteotomy duration, and inferior alveolar nerve damage.

Materials and Methods

Study Design

All SSRO procedures were performed on 32 fresh sheep hemi-mandibles aged one year with the Hunsuck[14] modification by a single applicant. As the medial surface of the sheep mandible and the area where the osteotomy was to be performed should not be in contact with the holding surface of the clamp, we fixed the clamps from the posterior region of the ascending ramus and the lateral part of the angulus region to expose the areas to be evaluated in this study. This design allowed access to the osteotomy site to facilitate the procedure. This setup also exposed the lingula area, allowing for the best *in vivo* fracture simulation and fracture pattern assessment. The clamps were fixed on a weighted table that withstands the applied forces and remains stable (Figure 1).

We used CCOT with a conventional osteotome to separate the distal and proximal segments in the control group (Figure 1). A pre-assigned force level of 260 daN was used in the MMOT group. In all samples after the initial split with MMOT or CCOT, the rest of the procedure was finished by the manual rotation of the osteotomes.

Evaluation Criteria

Osteotomy duration was measured from the start of the split to the point at which the distal and proximal segments were separated entirely. Alveolaris inferior nerve injury was evaluated macroscopically based on complete dehiscence, half dehiscence, and laceration; visible nerve sheath damage and lingual fracture pattern were analyzed according to the lingual fracture pattern (LFP) and basis split scale (BSS)[5].

The LFP was used to assess the lingual fracture line. Three distinct horizontal height levels (A, B, and C) and three separate anteroposterior regions constitute the pattern (1, 2, and 3) for LFP. Level A corresponds to the horizontal osteotomy, and level C to the inferior border of the ramus in the craniocaudal axis. In contrast, level B is the level that perfectly bisects the distance between A and C. The course of the mandibular canal in levels A and B and the intersection with the vertical osteotomy at level C are all part of fracture region 1. The area posterior to area 1, meaning the mandibular canal and the caudal junction of the vertical osteotomy extending to the mandibular angle and dorsal boundary of the ramus, is called fracture region 2. Fracture region 3 is the large rim bone at the mandibular angle and the ramus's dorsal border. This fractured system enables the classification of up to 27 different lingual fracture patterns[5]. The BSS is described in different lateral bone cuts, which are classified as having (A) a more buccal bone cut end, (B) a more central bone cut end, or (C) a more lingual bone cut end (Figure 2).

Modeling, Production, and Testing of Chisel

Since there is no chisel tip for the magnetic mallet device (MMD) (Sweden & Martina, Padua, Italy) to use in orthognathic surgery, a standard magnetic mallet tip and 4-mm wide conventional chisel osteotome were delivered to the computer numerical control (CNC) production center. The conventional and MMD-compatible osteotomes were split using a diamond cutting disc into two halves. In order to create a magnetic mallet-compatible osteotome for orthognathic surgery, the MMD-compatible osteotome's half piece adaptable to MMD was fused to the working tip of the conventional osteotome (Figure 3).

Statistical Analysis

GraphPad Prism Version 8 (GraphPad Software Inc., La Jolla, CA, USA) performed statistical analyses. A two-tailed *t*-test compared the two methods' durations. Mann-Whitney U tests analyzed non-parametric samples. The Chi-square

Figure 1. Photograph of the mandible held in place by clamps in lateral view.

and Fisher's exact tests examined fracture patterns and split methods. Data were mean ± SD. Significant p-values were < 0.05.

Results

As shown in Figure 4 and Table I, six fracture patterns were observed in our study out of the twenty-seven LFP fracture patterns. 222 fracture patterns were observed in 12 (37.5%), 221 patterns in five (15.63%), 211 patterns in nine (28.13%), 111 patterns in three (9.38%), 121 patterns in two (6.25%), and the 212 patterns in one (3.13%) hemi-mandible. There was no statistically significant difference between the two groups in the frequency distributions of LFP fracture patterns.

When the BSS patterns for the MMOT group were evaluated, the "A" pattern was found in 3 (18.75%) samples, the "B" pattern in 13 (81.25%), and the "C" pattern was not found in any samples. In the CCOT group, 3 (18.75%) samples showed an "A" pattern, 12 samples exhibited a "B" pat-

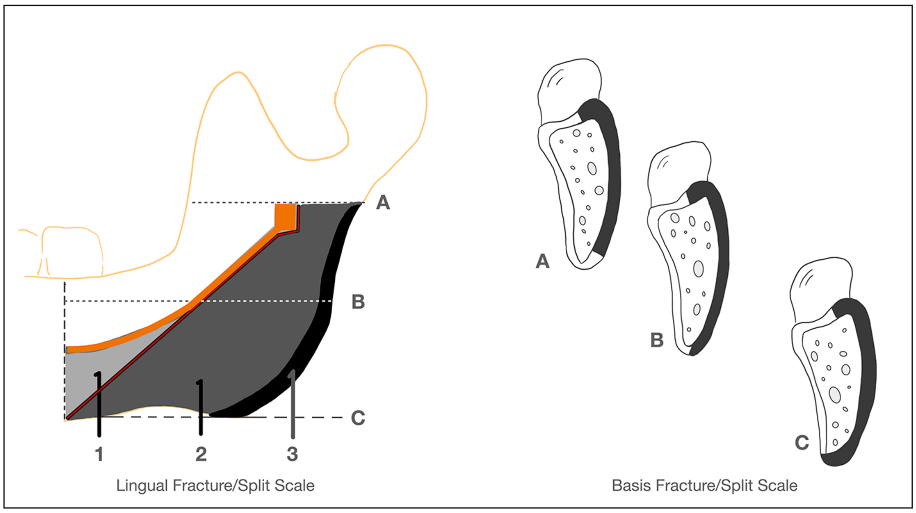

Figure 2. Split patterns are described for LFP and BSS.

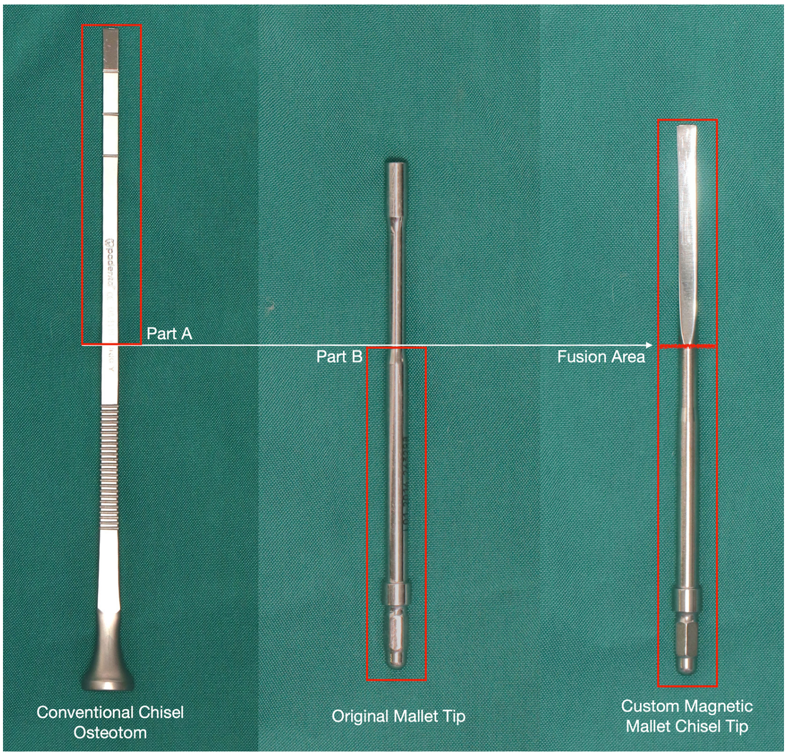

Figure 3. Photographs of the conventional chisel used for CCOT (Part A), the original mallet tip (Part B) used for copying the connection part to the custom MMD chisel tip, and the custom MMD chisel osteotome.

tern, and 1 (6.25%) sample showed a "C" pattern (Table II). There was no statistically significant difference between the two groups in the frequency distributions of BSS fracture patterns.

Unfavorable fracture patterns were observed in three (9.375%) of the MMOT hemi-mandibles and four (12.5%) of the CCOT hemi-mandibles. There was no significant difference between groups regarding unfavorable fracture ($p = 0.6809$).

The SSRO duration for the CCOT group ranged from 51 to 156 seconds, and for the MMOT group, from 63 to 143 seconds. The duration of the two methods was not significantly different ($p = 0.3631$) (Figure 5).

Three out of 32 hemi-mandibles, two (12.5%) in the study group and one (6.25%) in the control group had macroscopic nerve lacerations. No significant difference was found between groups regarding nerve laceration ($p = 0.5592$).

Discussion

There are various classifications for unfavorable fracture patterns in the literature[15,16]. In this study, of the seven (10.94%) unfavorable fracture patterns, three were observed in MMOT and four in CCOT. The findings indicate that MMOT

Table I. The distribution of fracture patterns and variations of the lingual split scale for both groups. Other possible variations did not occur.

LFP Variations	Total (n = 32)	Total (%)	MMOT (n = 16)	MMOT (%)	CCOT (n = 16)	CCOT (%)	Mean ± SD
222	12	37.5	4	25	8	50	6.00 ± 2.282
221	5	15.625	3	18.75	2	12.5	2.50 ± 0.707
211	9	28.125	7	43.75	2	12.5	4.50 ± 3.536
111	3	9.375	1	6.25	2	12.5	1.50 ± 0.707
121	2	6.25	1	6.25	1	6.25	1.00 ± 0.00
212	1	3.125	0	0	1	6.25	0.50 ± 0.707

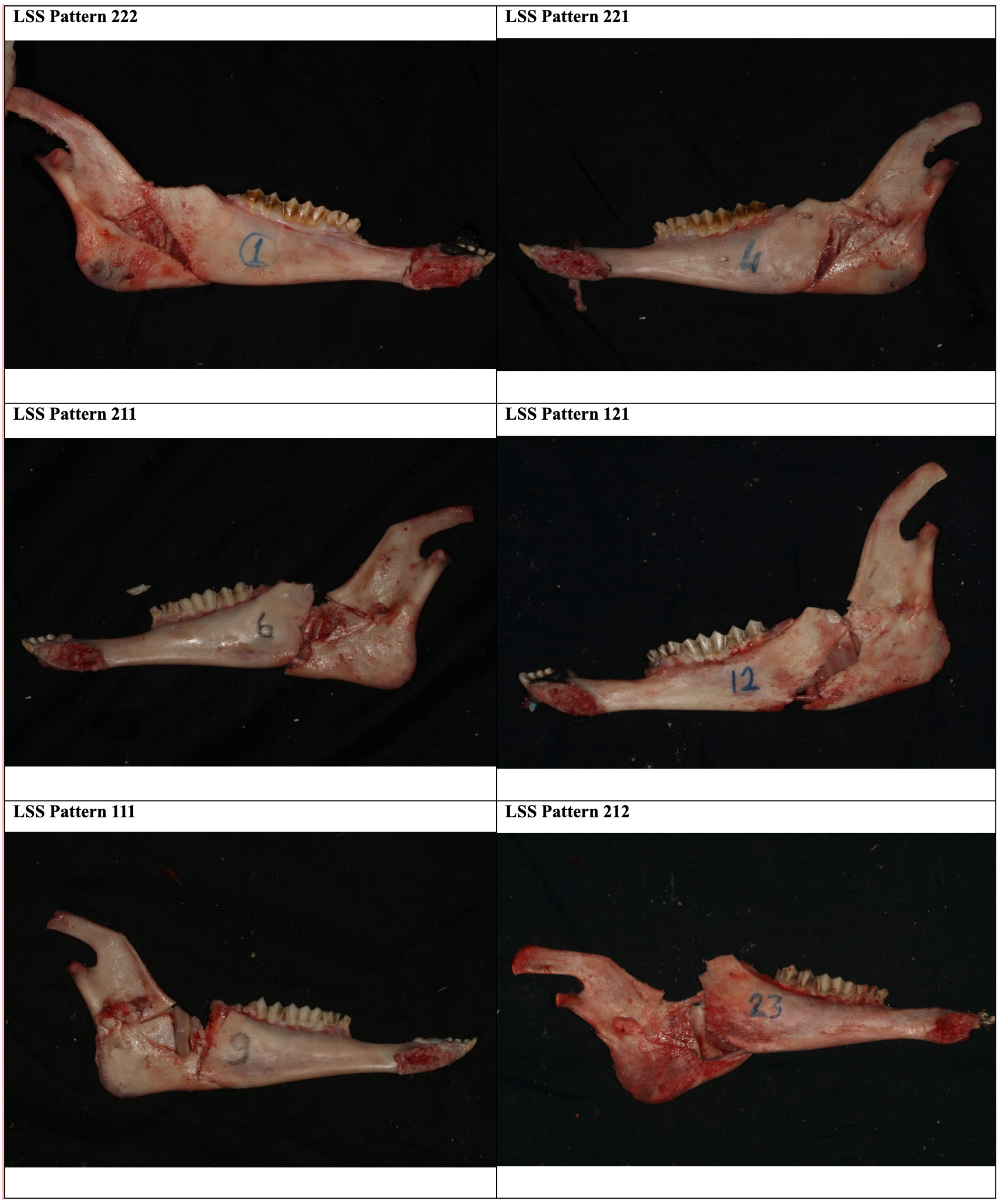

Figure 4. Photographs of LFP patterns observed with the associated scheme cited.

and CCOT presented statistically similar results. However, it may reduce the risk of inadequate or unfavorable splits by preventing the stress from being distributed to distant regions other than the intended region[17]. Because of this, MMOT can be regarded as a promising new technique in orthognathic surgery and a reliable substitute for CCOT because it does not increase the risk of unfavorable fractures. Wang et al[15] indicated that the third molar presence is another risk factor for

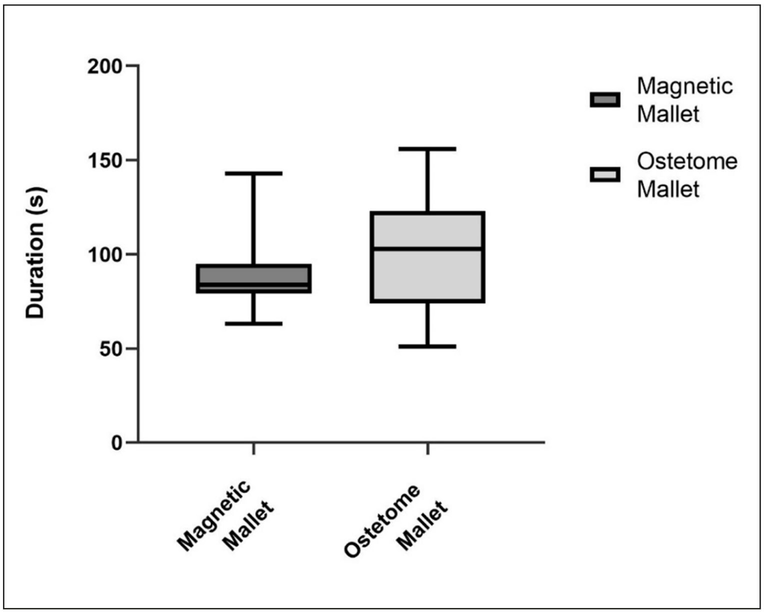

Figure 5. Comparison of CCOT and MMOT in terms of the SSRO duration.

unfavorable fractures. In our study, one-year-old sheep mandibles had impacted molars at the osteotomy region, which may have created some difficulties for a favorable split. A retrospective study[16] was conducted to determine the risk factors for bad splits. The results showed that operations performed by surgeons with less experience, such as residents, are more likely to result in bad splits. The learning curve of MMOT did not negatively affect the unfavorable fracture rates of MMOT in this study, despite the operator's lack of MMOT experience compared to the operator's CCOT experience.

The Hunsuck modification[14] encourages performing a medial horizontal cut close to the foramen by limiting the cut to the concavity of the mandibular foramen (rather than further toward the posterior border of the ramus), which was used for the osteotomies in this study. Our results show an increased tendency for unfavorable fractures when the lingual fracture line moves posteriorly or anteriorly from the mandibular canal. The patterns 211 (n = 7 for MMOT, n = 2 for CCOT), 221 (n = 3 for MMOT, n = 2 for CCOT), and 222 (n = 4 for MMOT, n = 8 for CCOT) had more favorable fracture patterns and typically were closer to the mandibular canal. The results of this study show that the CCOT group primarily formed the 222 (n = 8) pattern, whereas the MMOT group primarily formed the 211 (n = 7) pattern. According to these findings, the MMOT produced an anteriorly positioned fracture pattern from the mandibular canal, whereas the CCOT produced a posterior fracture pattern. Also, when the bad splits from the MMOT and the CCOT were analyzed, it was observed that the MMOT caused unfavorable splits anterior to the mandibular canal. In contrast, the CCOT caused unfavorable fractures posterior to the mandibular canal. The fact that the CCOT's stress distribution leads to a force distribution that is more dispersed than required helps explain why the fracture pattern of the CCOT tends to be posterior to the mandibular canal.

In order to perform SSRO with CCOT, the surgeon must hold the osteotome in one hand. The second hand should be placed along the basis corresponding to the vertical osteotomy line to avoid possible condyle displacement during CCOT. During surgery, a third hand from a second operator will be required to use the hammer to apply the necessary force to the osteotome. Similar technical challenges

Table II. The distribution of fracture patterns of the Basis Split Scale for both groups.

BSS Variation	MMOT (n = 16)	MMOT (%)	CCOT (n = 16)	CCOT (%)	Mean ± SD
A	3	18.75	3	18.75	3.00 ± 0.00
B	13	81.25	12	75	12.50 ± 0.707
C	0	0	1	6.25	12.50 ± 0.707

exist for maxillary pterygoid disjunction. MMOT, on the other hand, allows the splitting to be carried out by a single operator without hammering, thus simplifying the process. Performing surgery with just one hand gives the surgeon more control and visibility. It also allows the surgeon to position and align the instrument with greater precision, avoiding any deviations caused by working on the bone of varying densities. Crespi et al[17-19] compared MMOT with conventional osteotomes in oral surgical procedures and showed that MMOT provided several significant advantages during clinical use for dentoalveolar surgeries, such as precise control and minimal trauma to distant craniofacial bone structures. These critical and positive outcomes in oral surgery achieved with MMOT will also show comparable advantages in orthognathic surgery.

In this study, the mean SSRO durations for both groups showed similar results. The SSRO durations for the CCOT group were the fastest (51 s) and slowest (156 s), while MMOT findings were more evenly distributed. This may be caused by the standard nature of the MMOT technique, thanks to its adjustable force control of the device. The learning curve of MMOT may have a negative impact on the SSRO durations because the operator was experienced in CCOT but inexperienced in MMOT.

On a macroscopic level, there was no statistically significant difference between the groups in the inferior alveolar nerve damage. In this study, only three minor lacerations to the inferior alveolar nerve were found by macroscopic examination (two for MMOT and one for CCOT). The inferior alveolar nerve could be seen in all of the mandible samples used in this study, enabling the clinical assessment of nerve damage.

Compared to the human mandible, the anatomy of the sheep mandible mainly differs. To validate the findings of our study, it would be beneficial to conduct SSRO with MMOT *in vivo* or on a fresh human cadaver. Furthermore, our study performed a macroscopical evaluation of the nerve rather than clinical assessments or histopathological methods.

As a result, due to its promising clinical benefits, such as the need for fewer practitioners during the application, ease of manipulation for the direction of osteotome, application of controlled force, and avoidance of uncontrolled stress to distant areas, which can lead to uncontrolled soft tissue lacerations, optimized osteotomy duration and increased visibility in the surgical field, MMOT was regarded as a technique worthy of further clinical studies for orthognathic surgery including pterygoid osteotomies.

Conclusions

This study compared the CCOT used during BBS with a newer technique, the MMOT. Based on the evidence presented, the MMOT may be a reliable alternative to CCOT in oral maxillofacial surgery. Further studies are needed to obtain more evidence and improve it.

Conflict of Interest

The Authors declare that they have no conflict of interests.

Authors' Contributions

All authors contributed to the study's conception and design. All authors contributed to writing the first draft of the manuscript, and they commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Ethics Approval

Ethics Committee approval of this study was obtained from Istanbul Medipol University Clinical Research Ethics Committee (Protocol code: E-10840098-772.02-5951).

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Availability of Data and Materials

The datasets generated during and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Informed Consent

Informed consent was waived due to the *in vitro* nature of the study.

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