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**Title:** Bilateral sagittal split osteotomy: risk factors for complications and predictability of the splitter-separator technique  
**Date:** 2017-09-12
CHAPTER 10

Influence of the inferior border cut on lingual fracture pattern during bilateral sagittal split osteotomy with splitter and separators: a prospective observational study

This chapter is based on the manuscript:
(* both authors contributed equally)
Influence of the inferior border cut on lingual fracture pattern during bilateral sagittal split osteotomy with splitter and separators: a prospective observational study
ABSTRACT

Bilateral sagittal split osteotomy (BSSO) is a widely used orthognathic surgery technique. This prospective observational study investigated the correspondence between the planned inferior border cut and the actually executed inferior border cut during BSSO. The influence of the performance of the inferior border cut on lingual fracture patterns was also analysed.

Postoperative cone beam computed tomography (CBCT) scans of 41 patients, representing 82 sagittal split osteotomies were investigated. The inferior border cut was intended to penetrate completely through the caudal cortex. Descriptive statistics were used to analyse the planned and executed inferior border cuts. Mixed models were employed to investigate the influence of independent variables as the surgeon’s experience on the inferior border cut and secondarily the inferior border cut on lingual fracture patterns and the incidence of bad splits.

The inferior border cut reached the caudal cortex in all cases, but only reached the lingual cortex in 38% of the splits. There was no significant relationship between the inferior border cut and a specific lingual fracture line.

In this study, postoperative CBCT analysis revealed that the bone cuts during BSSO were often not placed exactly as planned. Despite this, no significant relationship between the inferior border cut and lingual fracture patterns or bad splits was detected. Further research is needed to identify factors that could make the sagittal split more predictable.

INTRODUCTION

Orthognathic procedures are widely used for the correction of maxillofacial deformities. One of the most popular techniques is the bilateral sagittal split osteotomy (BSSO). The technique originates from Schuchardt1 (1942), who introduced a modification of the horizontal subcondylar osteotomy previously described by Blair2 in 1907. This modification consisted of two horizontal cortex osteotomies in the mandibular ramus, with the aim of bilaterally splitting the mandibular ramus. The first horizontal cut was placed just above the mandibular foramen at the lingual side of the ramus, and the second cut was positioned approximately 10 mm caudally at the buccal side.1 This first version of the BSSO was subsequently popularised and further developed by Trauner and Obwegeser3 in 1957. They extended the horizontal cut at the buccal side more caudally, so the distance between the bone cuts was approximately 25 mm.

Since then, several modifications have been suggested to improve the technique. Dal Pont4 extended the buccal bone cut more ventrally towards the second molar, in order to increase bony contact and stability. Hunsuck5 proposed a shorter horizontal bone cut at the medial side in order to achieve a controlled fracture in the lingual cortex, and was the first to complete the sagittal split by performing a controlled lingual fracture. Epker6 later emphasised the importance of an inferior border cut that extended completely through the inferior cortex, for ease of splitting. Several authors subsequently advocated a cut through the inferior cortex of the mandible.7-9 With this technique the full thickness of the lower border of the mandible remains on the proximal segment. The aim of this is to strengthen the proximal segment and thereby increase control of the lingual fracture and prevent unfavorable splits.10

The influence of the osteotomy design and orientation of the bone cuts on the lingual fracture pattern during BSSO have been the subject of recent research.11-13 Modification of the osteotomy design can increase the predictability of the sagittal split.12 An altered orientation of the bone cuts or incomplete bone cuts can, on the other hand, increase the risk of a bad split.14, 15 Recent reports show that accomplishing the bone cuts completely as planned is a challenge, due to limited visibility during BSSO.11, 14, 15 The course of the lingual split results from the design and the extent of the
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cortical bone cuts, including the type of manipulation during the splitting technique. Evaluation of the position of the bone cut as a factor in the sagittal split procedure is therefore important. Visualisation of the lingual part and inferior border of the mandible is compromised during surgery, and is only possible using (postoperative) cone beam computed tomography (CBCT) scanning. The chance of an incomplete bone cut due to limited visibility could therefore be high when performing the inferior border cut that was proposed by Epker.6

In this study, the position of the inferior border cut was investigated and secondarily the influence of this inferior border cut on lingual fracture patterns and unfavorable fractures was analysed.

MATERIAL AND METHODS

Study group
This study prospectively observed a consecutive group of 43 patients who received a BSSO alone or bimaxillary procedures either with or without genioplasty. The procedures were performed between January 2013 and July 2014 at the Department of Oral and Maxillofacial Surgery of the Leiden University Medical Center. The procedure was always performed by one of four experienced surgeons, usually supervising a resident on the contralateral side. All procedures were performed according to the same treatment protocol that included the use of postoperative CBCT as part of standard clinical follow-up.

The patients’ medical files were screened for age at surgery, gender, malocclusion class, and simultaneous procedures (i.e. Le Fort I osteotomy or genioplasty). The postoperative CBCT scan was used to evaluate the position of the mandibular segments and the lingual fracture pattern within the first week after BSSO.

All consecutive patients that received BSSO in the aforementioned time period were included. Patients were excluded when alternative surgical techniques were used and in the case of incomplete data, for example when postoperative scans were not performed correctly and the bone cuts or fracture lines could not be visualised adequately.

The main outcome variable in this study was the position of the inferior bone cut, defined as either in the buccal cortex, in the inferior border or through the inferior border reaching into the lingual cortex. Secondary outcome variables were the lingual split pattern and the occurrence of a bad split possibly influenced by the inferior border cut.

Evaluation of the CBCT
A postoperative CBCT scan (Planmeca Promax®3D Max, 96 kV, 11 mA) was performed within the first week after BSSO. The patients’ CBCT images were uploaded into OsiriX v.5.7.1 32 in the form of DICOM files in order to generate a 3D reconstruction of the mandible. The view settings used were: WL/WW; CT bone, CLUT; 16 bit CLUT, opacity; linear table.

The mandible was separated from the scan and positioned in a symmetrical position by aligning the inferior borders, occlusal plane, and temporomandibular joints. A crop cube was generated and aligned with the inferior border of the mandible (Figure 1). The caudal position of the crop cube and the aligned mandible were not changed. The cube and mandible where subsequently rotated 90 degrees in order to get a perpendicular view of the caudal side of the mandible. This view was exported and subsequently used to derive measurements at the inferior border. The crop cube was then aligned with the buccal and lingual cortex of the distal segment and rotated to achieve a view perpendicular to the buccal and lingual side of the mandible. Once aligned, the region of interest was further explored by using the crop tool. Points of interest were specified in the CBCT and checked from the different views. Acquired projections were exported in standard format
and subsequently used to derive further measurements. Contrast corrections were only used when difficulties involving split pattern tracing were present.

Figure 1: Alignment of the inferior borders, occlusal plane, and temporomandibular joints of the mandible in the crop cube.

**Measurements**

The inferior border cut was categorised as either ending in the buccal cortex, in the caudal cortex, or in the lingual cortex. If the inferior border cut was performed completely through the caudal cortex and extended into the lingual cortex, the length of the inferior border cut in the lingual cortex was measured.

The postoperative CBCT was evaluated in the abovementioned standardised lingual view, caudal view, and buccal view. First, the lingual view (constructed perpendicular to the lingual cortex, with the inferior borders exactly aligned) was assessed. When the inferior border cut was visible from the lingual view, the lingual corticalis was thus affected and the inferior border cut was categorised as ending in the lingual cortex. Second, the caudal view (constructed perpendicular to the tangent to the caudal border) was assessed. When the inferior border cut was not visible from the lingual view, but was visible in the caudal view, the cut was categorised as ending in the caudal cortex. When the inferior border cut was not visible from the lingual and caudal view, and thus did not reach into the caudal cortex, it was categorised as a cut ending in the buccal cortex.

The measurement of the inferior border cuts that extended into the lingual cortex was performed in the standardised lingual view (Figure 2). This measurement was defined as the distance in the cranial dimension from the inferior border of the distal segment to the end of the cut. In cases where difficulties were encountered in differentiating between the end of the cut and the beginning of the split in the perpendicular views, the reconstructed mandible was rotated in different directions to get a clear view of the end of the cut and beginning of the split. In unclear cases, the axial, coronal, and transversal views of the plain CBCT scans could furthermore be consulted in order to define this transition. A point of interest was placed at the end of the inferior border cut of the reconstructed mandible. This point was automatically transferred to all standardised views of the reconstructed mandible and enabled exact positioning of the end of the inferior border cut.
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The lingual fracture line was evaluated using the lingual split scale (LSS).\textsuperscript{11} A LSS1 split was defined as a fracture line originating through the caudal cortex and progressing caudal and dorsal to the mandibular canal (‘true’ Hunsuck). A LSS2 split was defined as a fracture line through the caudal and posterior cortex of the ramus. A LSS3 split was defined as a fracture line originating from the inferior border and progressing through the mandibular canal. A LSS4 split was defined as any other (unfavorable) fracture pattern (Figures 3 and 4). The lingual fracture patterns were scored by two observers, who evaluated the lingual fractures of every scan separately. Differences were subsequently discussed and classified based on a consensus between both investigators. If a consensus could not be reached, a third observer could be consulted.

Figure 2: Measurement of the inferior border cut in the lingual cortex. (a) LSS1 fracture pattern that did not initiate from the (end of the) inferior border cut, but started from the caudal cortex, extending dorsally before reaching the lingual cortex. The red line represents the measured length of the inferior border cut. (b) LSS3 fracture pattern that initiated from the end of the inferior border cut. A clear transition from the inferior border cut into the lingual fracture is visible. The red line represents the measured length of the inferior border cut.

Figure 3: Different lingual fracture patterns according to the lingual split scale (LSS), as previously described by Plooij et al. (a) LSS1 fracture line originating from the caudal cortex and progressing through the caudal cortex, caudally and dorsally of the mandibular canal (‘true’ Hunsuck). (b) LSS2 fracture line through the caudal and posterior cortex of the ramus. (c) LSS3 fracture line originating from the inferior border (cut) and progressing through the mandibular canal.
Surgical procedure

All BSSOs were performed according to the same treatment protocol, using the same surgical technique that was previously described by van Merkesteyn et al.\textsuperscript{16} Splitting forceps and separators (Smith ramus separator, sagittal separators curved left and right, Walter Lorentz Surgical, Jacksonville, FL, USA) were used to perform all BSSO procedures without the use of chisels. The procedures were performed under general anesthesia, and local anesthetic was infiltrated (1:160000 Ultracaine D-S; Aventis Pharma, Hoevelaken, Netherlands).

The medial side of the ramus was exposed and a peristeal flap was elevated with a peristeal elevator to identify the mandibular foramen. The first bone cut was performed with a long Lindemann burr (2.3 mm x 22 mm), approximately 5 mm above the mandibular foramen and just dorsal of the mandibular foramen. The subsequent sagittal and vertical bone cuts were performed with a short Lindemann burr (1.4 mm x 5 mm). Based on surgical preference either a Lindemann burr or a Piezo

\textbf{Figure 4:} 3D reconstructed models of the mandible from a lingual view. (a) LSS1 fracture line. In this case the inferior border cut was not visible from this lingual view as it ended in the caudal cortex.

(b) LSS3 fracture line progressing through the mandibular canal. The inferior border cut is not visible as it ended in the caudal cortex.

(c) LSS4 fracture line, or unfavorable split. Although the inferior border cut reached in the caudal cortex, the initiation of the fracture line was in the buccal cortex.
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(Mectron, Piezosurgery 3) was used for the inferior border cut. The inferior border cut was aimed perpendicular to the caudal cortex of the mandible. In all cases, the surgeon attempted to perform the inferior border cut completely through the inferior cortex and reaching into the lingual cortex. A dental probe was used to check the extent of the inferior border cut.

To initiate the split, the splitting forceps and separator were placed in the vertical and sagittal cut respectively. First, the mobility of the fragments was checked vertically and horizontally by spreading the sagittal splitter and rotating the separator. Subsequently, the sagittal separator was replaced at the inferior border of the mandible and rotated again. The sagittal split was completed with the alternating use of the splitter and the separator.

When the inferior alveolar nerve was attached to the proximal segment, it was freed with blunt instruments or with the help of either a burr or Piezo. The nerve was always released before completing the sagittal split. Care was taken to prevent nerve damage by sharp bony spicules or instruments. Sharp bony spicules or edges of the mandibular canal were thoroughly removed via a round burr. Chisels were not used to perform BSSO, unless a small bridge of cortical bone at the inferior border between the proximal and distal segment was present.

After mobilisation of the mandibular segments, the mandible was placed into its new intermaxillary position using a wafer. Rigid fixation was performed with three bicortical screws in the upper border of the mandible (Martin GmBH, Tuttlingen, Germany: 9, 11, 13, or 15 mm long; diameter 2.0 mm). Champy plates (Martin GmBH, Tuttlingen Germany) where only used in the cases with a lingual fracture or fragile lingual bone due to removal of third molars.

Patients were discharged from our clinic within 2-4 days after surgery. Standard follow-up consisted of evaluations at 1 week, 3 weeks, and 6, and 12 months after BSSO.

**Ethical statement**

This study was performed in accordance with the guidelines of our institution and followed the Declaration of Helsinki on medical protocol and ethics. The study protocol was reviewed by the institutional review board (IRB) of the Leiden University Medical Center and because of the observational nature of this study, it was granted exemption in writing from IRB approval.

**Statistical methods**

Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS version 22.0 for Mac, SPSS inc., Chicago, IL, USA). Descriptive statistics were performed. Generalised linear mixed models (GLMM) were used to study the effect of the surgeon’s experience on the classification of the inferior border cut, lingual fracture pattern, and the occurrence of a bad split. The same models were employed to study the effect of the classification of the inferior border cut on the lingual fracture pattern and the occurrence of bad splits. As all factors were assessed per side, mixed models were required to account for the correlated nature of the left and right side measurements within each patient. Probabilities of less than 0.05 were considered statistically significant.
RESULTS

A total of 43 consecutive patients were prospectively included in this study. Two patients were excluded, because BSSO was performed by a (guest) surgeon using alternative techniques. The total study group was thus comprised of 41 patients.

The 82 sagittal split osteotomies were performed by a specialist on 40 sides (48.8%) and by a resident under close supervision of a specialist on 42 sides (52.2%). The inferior border cut was performed with Piezo in 36 (43.9%) sagittal splits and with Lindemann burr in 46 (56.1%) sagittal splits. Patient characteristics are shown in Table 1.

<table>
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<td>Age (years) 26.8 (10.6), 14.2-55.4</td>
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<td>Mean (SD), range</td>
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<td>Procedures</td>
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<td>BSSO 28 (68.3)</td>
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<td>BSSO + Le Fort I 12 (29.3)</td>
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<td>BSSO + Le Fort I + genioplasty 1 (2.4)</td>
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Table 1: Patient characteristics. The data represent the number of patients (%), unless otherwise specified.

CBCT revealed 51 inferior border cuts (62.2%) remaining in the caudal cortex and 31 inferior border cuts (37.8%) cutting completely through the caudal cortex and reaching into the lingual cortex. Of the 31 inferior border cuts in the lingual cortex, 19 (61.3%) were performed with Piezo and 12 (38.7%) were performed with a Lindemann burr. None of the bone cuts remained in the buccal cortex.

Of the cases where the inferior border cut reached into the lingual cortex, the mean length of the cut was 1.0 mm (SD 0.7, range 0.1–2.4). Of the 82 lingual fractures, 39 splits (47.6%) were classified as LSS1, 40 (48.8%) were classified as LSS3, and 3 (3.7%) were unfavorable fracture patterns classified as LSS4. No LSS2 fractures occurred (Table 2). In two sagittal splits, additional (partial) lingual fracture lines were recorded. The three LSS4 splits that were classified as bad splits all ran through the buccal cortex of the proximal mandibular segment. No bilateral bad splits occurred.

No additional measures (i.e. different fixation methods) were necessary in any of the cases of a bad split. All sagittal splits were completed successfully. All lingual fracture patterns were classified from the CBCT images based on a consensus between the two primary investigators. The third observer did not need to be consulted.
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<table>
<thead>
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<th>LSS1</th>
<th>LSS3</th>
<th>LSS4</th>
<th>Total</th>
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<tbody>
<tr>
<td>Inferior border cut in the lingual cortex</td>
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<td>13</td>
<td>2</td>
</tr>
<tr>
<td>Inferior border cut in the caudal cortex</td>
<td>23</td>
<td>27</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>39 (47.6%)</td>
<td>40 (48.8%)</td>
<td>3 (3.7%)</td>
</tr>
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</table>

Table 2: Lingual fracture patterns. The data represent the number of sagittal splits (%).

GLMMs were employed to investigate the influence of different factors while adjusting for the correlated nature of the data (left and right side within each patient). The experience of the surgeon was not statistically significantly associated with the classification of the inferior border cut ($p = 0.59$) or the lingual fracture pattern ($p = 0.28$). Bad splits occurred on the specialist’s side in one patient, and on the resident’s side in two patients. The surgeon’s experience was not significantly associated with the occurrence of bad splits ($p = 0.08$).

Inferior border cut classification was not statistically significantly associated with lingual fracture pattern ($p = 0.53$). Bad splits occurred with the inferior border cut ending in the caudal cortex in one patient, and with the inferior border cut extending lingually in two patients. There was no significant association between inferior border cut classification and bad splits ($p = 0.31$).

**DISCUSSION**

This study aimed to assess the location of the inferior border cut during BSSO.

Subsequently, the association between the end of the inferior border cut and the lingual split pattern after BSSO was investigated. A complete inferior border cut was attempted in all patients, but achieved in little over 40% of the sagittal splits. When the inferior border cut did reach the lingual cortex, this did not significantly influence the lingual fracture pattern or the occurrence of bad splits.

To date, the investigation of human fracture patterns associated with BSSO has been limited to cadaveric studies, because of the concealed nature of the lingual fracture. The use of CBCT now facilitates clinical evaluation of the different patterns of lingual fractures in living patients. Plooij et al. recently described a lingual split scale to differentiate between a ‘true Hunsuck’ fracture (LSS1), a posterior ‘Obwegeser’ fracture (LSS2), an anterior lingual fracture line (LSS3), and an unfavorable fracture line (LSS4).

Using this scale, we evaluated lingual fracture patterns and found no significant association between them and the inferior border cut. We believe this is mainly due to the fact that none of the inferior border cuts remained in the buccal cortex, and all cuts ended in either the caudal cortex or extended through the caudal cortex into the lingual cortex of the mandible. Thus, the buccal cortex was cut completely in all cases. In a previously published study by Muto et al., the occurrence rate of bad splits was 15%, and in all of those cases the vertical cut ended in the buccal cortex without extending into or through the caudal cortex. This is concordant with Song et al., who reported no bad splits if the inferior border cut ran through the caudal cortex and into the lingual cortex, and they also detected bad splits only when the inferior border cut was not thoroughly placed through the inferior cortex.

In a recently published report by Agbaje et al., the authors suggest performing an inferior border cut into the caudal cortex that does not extend into the lingual surface, to prevent possible inferior border defects. However, we believe that with alternative osteotomy designs, a complete inferior border cut is possible especially when the cut is placed more dorsally near the masseter, and soft.
tissue can camouflage possible inferior border defects. Further studies investigating inferior border defects are needed to clarify these findings.

In the current study, the inferior border cut was placed through the caudal cortex as planned in approximately 40% of the sagittal splits. In the other cases the completeness, orientation, or location of the inferior border cut was not precisely in accordance with the standard planning of this bone cut. Plooij et al. described a comparable outcome for the medial bone cut in their study. They placed this horizontal bone cut just dorsal of the mandibular foramen, but actually placed this cut more ventrally in 66% of the cases. This disparity between the planned and actual placement of the bone cuts in BSSO is probably due to limited visibility during surgery, and emphasises the importance of postoperative CBCT usage in the contexts of both research and education. In this study a dental probe was used to check the extent of the inferior border cut as a tool to overcome the limited visibility. In this current study a complete inferior border cut through the caudal cortex was only observed in approximately 40% of the sagittal splits, which makes the use of the dental probe at least questionable.

Plooij et al. also reported a significant association between the end of the medial bone cut and the split pattern. In that study, a horizontal bone cut ending just in front of the mandibular foramen resulted in LSS1 (‘true Hunsuck’) in 45% of cases, and LSS3 in 43%. A horizontal bone cut ending dorsal to the mandibular foramen resulted in LSS1 in 63% of cases, and LSS3 in 11%. In the current study, we attempted to place the horizontal bone cut just dorsal of the mandibular foramen, and observed 47.6% LSS1 fractures and 48.8% LSS3 fractures. Our technique using sagittal splitters and separators may account for the differences in fracture patterns.

An association between the split pattern and third molar presence has been reported by both Reynke et al. and Kriwalsky et al. Furthermore, Verweij et al. reported a significantly increased risk of bad splits when third molar removal was performed during BSSO. Zamiri et al. reported that a smaller buccolingual thickness of the ramus was a risk factor for an unfavorable fracture in the lingual surface. Hou et al. investigated cortical bone thickness dorsal to the mandibular canal, and reported that 75.38% of their splits proceeded as described by Hunsuck. They also classified the shapes of the mandibular ramus in the axial plane into three categories, half-crescent moon, sim-triangle, and a well distributed shape. In that study, they reported that the half-crescent moon and sim-triangle shapes were associated with more splits, as was reported by Hunsuck, and that the well distributed shape was associated with more LSS2 splits as was reported by Plooij et al.

Hou et al. showed that a split in mandibles with a high mandibular angle is more likely to progress as described by Hunsuck (i.e., LSS1), and mandibles with a low mandibular angle showed more LSS2 split patterns.

This study evaluated the position of the inferior border cut using postoperative CBCT scans. The development of the lingual fracture from the end of this bone cut can however cause a smooth transition impeding the exact definition of the end of the inferior border cut. When evaluating the sagittal views of the plain CBCT-scans, the differentiation between the end of the bone cut and the beginning of the fracture seemed difficult. In the reconstructed mandible, the transition from bone cut to lingual fracture was however clearly visible in almost all cases. The standardised views of the reconstructed mandible could be combined with the sagittal, coronal, and axial views of the plain CBCT-scans. If difficulties in the interpretation of the end of the bone cut were encountered in one view, the different views always clearly showed the exact position of the end of the inferior border cut and this point of interest could be indicated in the reconstructed mandible.

The visibility of the cuts on the lingual, caudal and buccal side of the reconstructed mandible is dictated by the orientation of the reconstructed mandible. To avoid measurement errors, the reconstructed mandible was symmetrically placed in a crop cube and the different views of the
mandible were standardised according to the crop cube. By rotating the crop cube, the mandible was rotated simultaneously and could easily be placed in a perpendicular lingual, caudal and buccal view. A simple reproducible view was obtained by using this method.

This study revealed slightly more inferior border cuts extending through the lingual cortex by using Piezo compared with a Lindemann burr, (61.3% and 38.7% respectively). This could suggest that Piezo predisposes a complete inferior border cut into the lingual cortex. Although this relevant topic exceeds the scope of this study, future research should include the investigation of the influence of surgical instruments (e.g. Piezo versus burr) on the inferior border cut and subsequent lingual fracture patterns.

Based on the results of the current study, it is questionable whether or not an inferior border cut extending into the lingual cortex increases the predictability of a sagittal split. A potential explanation for these findings is that the bone cuts are often not performed as planned and an inferior border cut extending into the lingual cortex does not necessarily extend completely through the full thickness of the caudal cortex.

In conclusion, this study shows that postoperative CBCT imaging can facilitate the visualisation of concealed parts (e.g. the inferior border and lingual split patterns), and reveals discrepancies between planned bone cuts and actual bone cuts. The study also suggests that an inferior border cut extending through the lingual cortex does not necessarily lead to higher predictability of a split in BSSO.
REFERENCES
