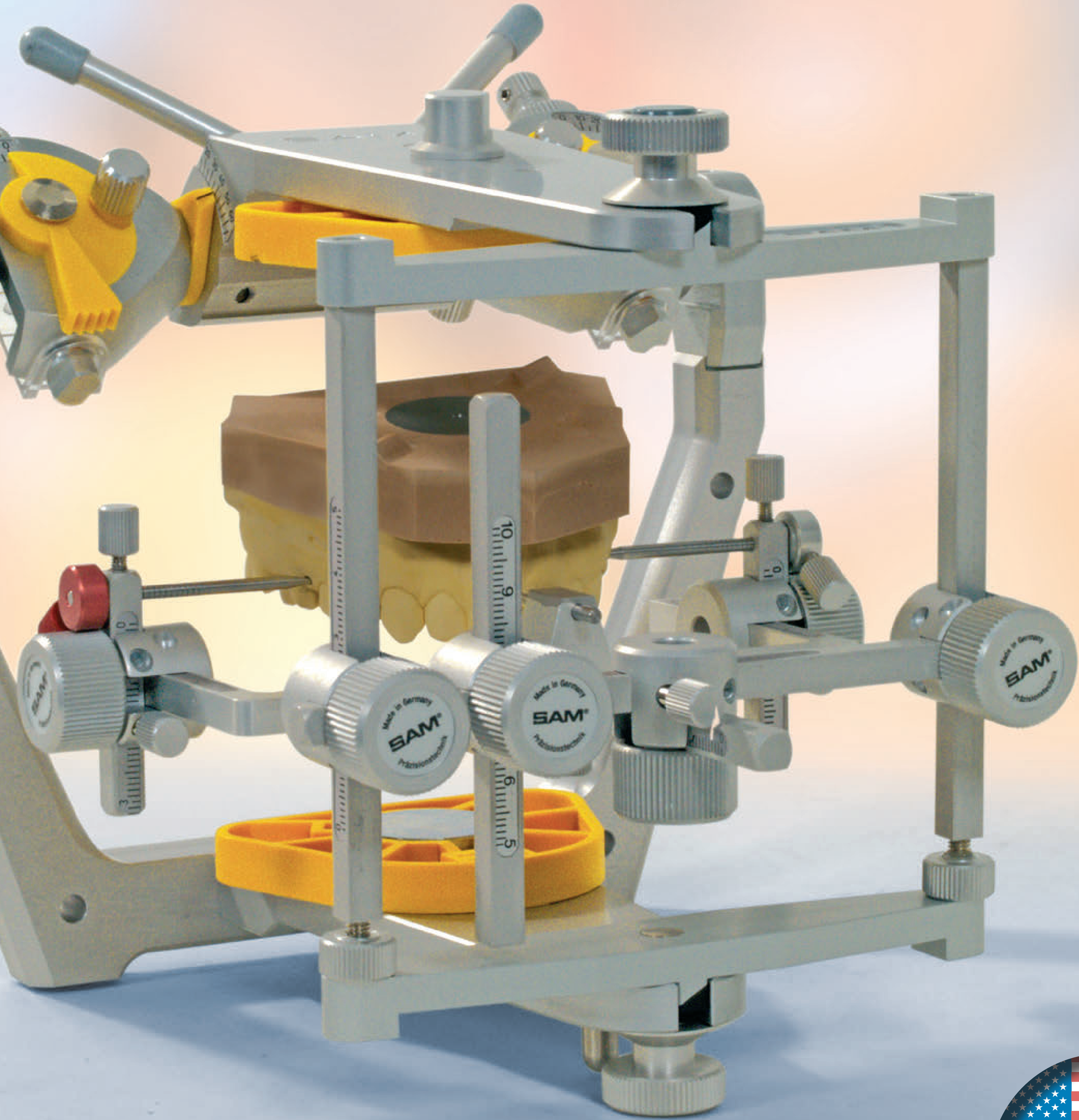
MRI

MODELL REPOSITIONING INSTRUMENT

This device is used in orthognathic analysis and treatment planning. Three dimensional repositioning of either upper or lower mounted casts is possible with accurate measurements.



MRI 220K

MRI Dübelkit
beinhaltet Dübelsetzer (MRI 212), Dübelbohrer (MRI 211) und 200 Dübel (MRI 210)

MRI plastic sleeve insert kit
includes sleeve insert tool (MRI 212), drill bit (MRI 211), and 200 plastic sleeve inserts (MRI 210)

MRI 300

Modell-Repositionierungs-Instrument
nach Prof. Dr. Rainer Schwestka-Polly - für die Operationsplanung in der Kiefer- und Gesichtschirurgie, zur dreidimensionalen Verlagerung des Ober- oder Unterkiefermodells, mit MRI Hülsen-Kit II (MRI 220K)

model repositioning instrument
according to Prof. Dr. Rainer Schwestka-Polly - used with SAM® 3 articulator mounted casts for diagnosis, analysis and treatment planning in maxillofacial orthopedics, articulator mounted casts can be moved 3D without sectioning, includes MRI sleeves kit II (MRI 220K)

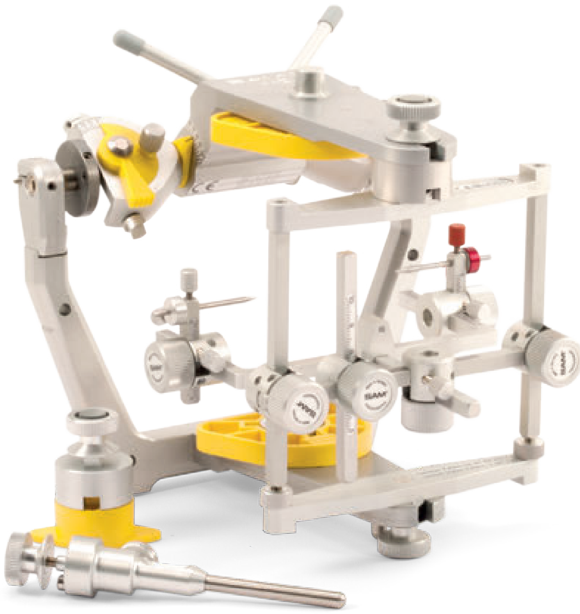
MRI II Articulator H Kit

nach Prof. Dr. Rainer Schwestka-Polly -
für noch mehr Platz bei der Modellmontage - beinhaltet
SAM® 3 H (ART 560 / ART 575M) und
Modell-Repositionierungs-Instrument (MRI 300)

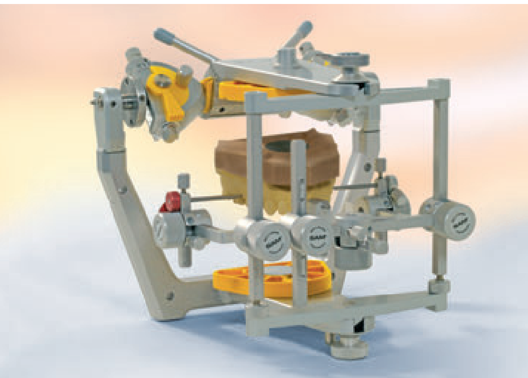
according to Prof. Dr. Rainer Schwestka-Polly -
for even morespace when mounting includes
SAM® 3 H (ART 560 / ART 575M) and
model repositioning instrument (MRI 300)

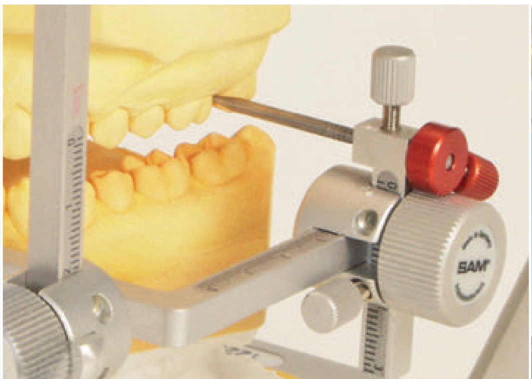
MRI 351K
für Schraubmontageplatten-Systeme /
for systems with screw type mounting plates

MRI 366 MK
für MPS-System / *for MPS-system*



MRI 366 MK





beinhaltet / *includes*

01 SAM® 3 Artikulator
SAM® 3 articulator

02 Modell-Repositionierungs- Instrument (MRI 300)
model repositioning instrument (MRI 300)

03 AXIOQUICK® Transferbogenkit - AX (ATB 390K)
AXIOQUICK® transferbow kit - AX (ATB 390K)

04 Teleskop-Bissgabelstütze (ATB 336)
telescopic transfer fork support (ATB 336)

05 Magnetsockel für Bissgabelstütze (ATB 338 / ATB339)
magnetic block for transfer fork support (ATB 338 / ATB 339)

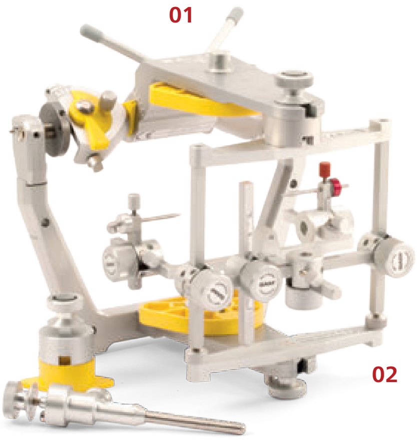
06 Transferstand AX (ATB 398)
transfer stand AX (ATB 398)

07 Montagestand (MOH 560) mit 30 Elastikstäben
red mounting stand (MOH 560) with 30 flexible plastic rods

08 20 gelbe Montageplatten (Schraub- oder Magnetsystem) /
20 yellow mounting plates (screw or magnetic type)

09 gelber Stapelbox (ART 599)
yellow carrying case (ART 599)

01



02

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MRI 330K
für Schraubmontageplatten-Systeme / *for systems with screw type mounting plates*

MRI 345MK
für MPS-System / *for MPS-system*

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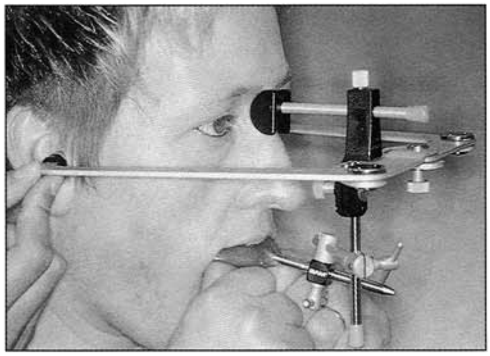
Techniques for achieving three-dimensional positioning of the maxilla applied in conjunction with the Göttingen concept

Three-dimensional repositioning of the maxilla is possible after Le Fort I osteotomy. However, the preoperatively planned and desired position of the maxillary dental arch often cannot be sufficiently achieved during actual surgery, and deviations in the sagittal and vertical dimensions are common. To reduce these errors, the model-repositioning instrument was developed for model surgery in conjunction with the Göttingen concept for orthodontic-surgical treatment with condylar position control. This instrument allows a controlled three-dimensional positioning of jaw segments with three reference points directly on the teeth. The three-dimensional double-splint method combined with a surgical facebow was developed for a controlled three-dimensional positioning of the maxilla during surgery. This instrument and method were applied during treatment of 20 adult patients, and the position of the maxilla before and after surgery was analyzed. It was found that the planned position of the maxillary dental arch could be transferred from model surgery to actual surgery with an accuracy of ± 1 mm sagittally and vertically. Thus, the application of the Göttingen concept for three-dimensional positioning of the maxilla results in an improvement of accuracy compared with other methods. Furthermore, use of these procedures is easier and less time-consuming during model and actual surgery than are other procedures.
(Int J Adult Orthod Orthognath Surg 1998;13:248–258)

Treatment of patients with severe dentofacial deformities has become routine in modern orthodontics and maxillofacial surgery.[1–4] During treatment the dental arches of the maxilla and mandible are aligned by fixed orthodontic appliances, and the whole dental arch of the maxilla or the mandible can be mobilized and repositioned in the new, preplanned position after Le Fort I osteotomy of the maxilla[5–8] or sagittal split osteotomy of the mandible.[9–12] An increase of bimaxillary surgery has been noted.[13] If the dentofacial deformity is caused primarily by skeletal malposition of the maxilla to the rest of the skull, such as a maxillary retrognathism or a skeletal open bite, Le Fort I osteotomy is indicated. To bring the condyle into centric relation to the os temporale on each side and to reproduce this position before, during, and after surgery, the Göttingen concept for orthodontic-surgical treatment with condyle position control was introduced about 10 years ago and has since been applied routinely.[14–18]



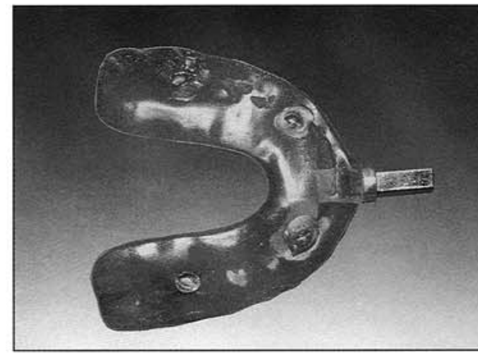


Fig 1 *(left)* Transfer of the maxillary position with an anatomic transfer bow.

Fig 2 *(right)* Centric bite registration for mounting the mandibular cast in the articulator.

The model-repositioning instrument and the three-dimensional double-splint method were developed recently for three-dimensional positioning of the dental arches in model surgery and for a three-dimensionally controlled transfer of the position of the maxilla from model surgery to actual surgery, respectively. In this study, the results of the application of these new developments in conjunction with the Göttingen concept are presented.

Method and materials

Cast mounting

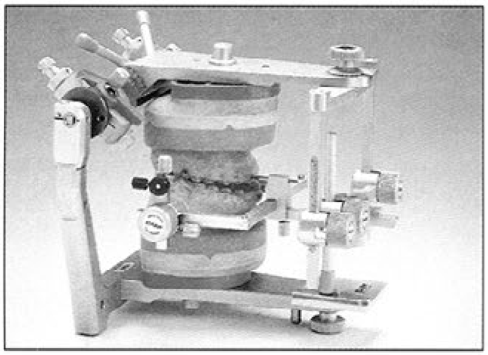
The casts of the maxilla and mandible are mounted in centric relation in the articulator according to the Göttingen concept. This ensures that the surgical splints can be fabricated with the condyle in centric relation to the os temporale on each side. With use of these splints centric relation can be transferred from the patient before surgery to the patient during surgery. Repositioning of the condyles in centric relation is reproduced during surgery using condylar positioning appliances. This is a necessary condition for a controlled three-dimensional repositioning of jaw segments.

The maxillary cast is mounted by a facebow transfer (Anatomic transfer bow, SAM) in a semiadjustable or fully adjustable articulator (Fig 1). The cast of the mandible is mounted using centric registration (Fig 2). To make the registration as exact as possible and to avoid deformation of the bite registration plate during cast mounting due to discrepancies of the position of the maxillary and mandibular arches, an acrylic resin base is prepared, and registration is taken using four points of Aluwax (Aluwax Dental Products). Using this base for the bite registration, the position of the mandible and both temporomandibular joints can be accurately transferred in centric relation from the patient to the articulator.[19,20]

For model surgery two sets of casts are mounted in two different articulators: According to the Göttingen concept, the presurgical position remains unchanged in the first articulator, and model surgery is performed in the second articulator.[21–28]

Model surgery with the model-repositioning instrument

Ruler measurements at the base of the articulator above the dental arch and saw cuts along a planned osteotomy line appear to be too inaccurate for repositioning the maxilla during model surgery. Deviations of up to 3.8 mm sagittally and 5.5 mm vertically from the planned position have been observed at the dental arches.[29] These errors occur especially when the maxilla is moved in several dimensions simultaneously. If, for instance, the maxillary dental arch is moved anteriorly and its dorsal part is rotated upward, the incisal edge of a maxillary incisor moves posteriorly away from the planned position. To solve this problem, an appliance for controlled three-dimensional positioning during model surgery was developed.[30] After testing and modification, this appliance,



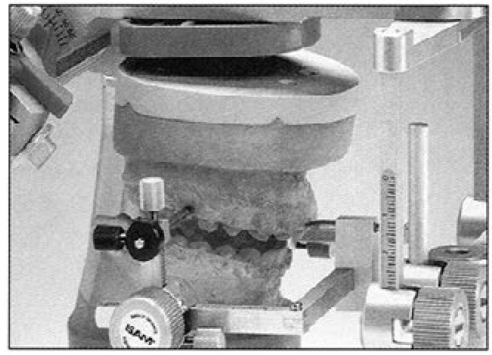


Fig 3 *(left)* Model-repositioning instrument with the maxilla in the preoperative position.

Fig 4 *(right)* The maxillary cast is loosened from its base. The tips of the measuring pins are adjusted to the postoperative position and hold the cast.

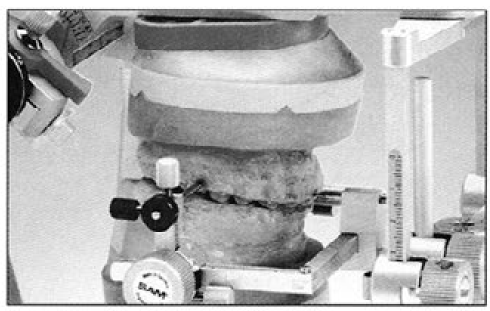


Fig 5 The maxillary cast is attached in the desired postoperative position.

called the *model-repositioning instrument,* is now in use for routine treatment.

The model-repositioning instrument (SAM) permits simultaneous measurement of the position of three reference points at the dental arch of the cast mounted in the articulator. These reference points are marked on the edge of a maxillary incisor and at the mesiobuccal cusps of the first or second molars bilaterally, and their positions are registered with measuring pins (Fig 3). The measuring pins can be moved in a three-dimensional orthogonal coordinate system. The hinge axis–orbital plane was chosen as the reference plane for this study. This plane is represented by a parallel to the upper surface of the upper part of the articulator. Using these coordinates, the repositioning is exactly defined by the relative sagittal, vertical, and transverse movements of the reference points. Thus, metric repositionings that have been planned clinically or radiographically can be transferred precisely to the cast. For geometric reasons the use of reference points on the teeth leads to a much higher accuracy than reference points on the base of the maxillary cast. Furthermore, the appliance allows an exact transfer of the position of the dental arch from one position to the next. During repositioning the cast is fixed by the tips of the three measuring pins. No osteotomy lines have to be drawn on the base of the cast. In addition, the application of the model-repositioning instrument permits control and adjustment of the position of the maxilla in relation to the mandible.

After two pairs of casts have been mounted in two different articulators, the second pair of casts is first mounted in the preoperative situation, and the incisal pin and incisal table of the second articulator are removed. Then, the model-repositioning instrument is attached to the upper part of this articulator. The tips of the measuring pins are adjusted to the three reference points directly on the teeth. Thus the coordinates for the reference points in the preoperative position are defined, and they are obtained from measuring scales on the appliance. The maxillary cast is now loosened from its base irrespective of any osteotomy line, and the tips of the measuring pins are subsequently shifted to the coordinates of the desired postoperative situation (Fig 4). The position of the maxillary dental arch in relation to the mandibular dental arch can be controlled and, if necessary, corrected. Subsequently the maxillary cast is attached in the desired new position on the upper part of the articulator (Fig 5). The model-repositioning instrument is removed from the articulator, and the incisal pin and incisal table are reinserted.

Now the maxillary cast is three-dimensionally positioned with respect to the upper part of the articulator, ie, with respect to the chosen reference plane. As a result, the maxillary cast in the second articulator has been moved from the preoperative situation with the condyles in centric relation into the desired postoperative situation while keeping its centric relation.

Splint fabrication according to the three-dimensional double-splint method

In both articulators self-curing acrylic resin surgical splints are fabricated. According to the Göttingen concept, the first surgical splint is used to transfer and reposition the condyles in the preoperatively obtained centric relation to the patient during surgery. This is important because the preoperative centric relation can differ from the intraoperative centric relation.[31] Without the application of this first splint and condylar position control, centric relation would be incorrect during surgery. The second surgical splint is used to achieve the correct relation of the jaw segments and the occlusion in the planned position.[32–37] In addition, a so-called postoperative splint is fabricated. This splint is constructed like a miniactivator without wires and represents the postoperative dental relation with centric relation of the condyles.

Until now, it has been difficult to transfer the postoperative position of the maxillary dental arch from model surgery to the intraoperative situation with sufficient accuracy. Deviations of the dental arches up to 6.0 mm sagittally and up to 15.0 mm vertically have been observed.[38] These deviations can be explained as follows: After the maxilla is mobilized, the planned dental relationship is obtained using the second surgical splint. However, this dental relationship is only controlled in the sagittal and transverse dimensions. Since the maxillomandibular complex is rotated upward anteriorly and cranially, maintaining centric relation, additional control of the vertical position is necessary. This is usually performed by using one reference point on the maxilla below the osteotomy line, ie, in the area that is moved during surgery, and a second reference point located either intraorally on the maxilla above the osteotomy line or extraorally on the nose bone.[39–43] Both approaches lead to a displacement of the lower reference point, especially in cases of large anterior advancements or transverse rotations of the maxilla after osteotomy, which makes the vertical placement difficult to control. Deviations for the intraoral approach are higher because the relative error is greater with short measurement distances than with larger extraoral distances.[44,45] For these reasons the exact three-dimensional placement of the maxillary complex in relation to other skeletal structures during surgery was impossible.

To solve this problem, the three-dimensional double-splint method was developed.[46,47] First, the sagittal and transverse placement of the maxillary arch is directed by the surgical splint. Second, the vertical placement is based on the fact that the vertical position of the mandible in relation to a reference plane above the osteotomy line can be exactly reproduced during model surgery and actual surgery. By reproducing a defined mandibular position, the maxilla can therefore be placed three-dimensionally with the aid of surgical splints. Thus, a reference system, which is especially reproducible in the vertical dimension, is chosen for fabrication of these splints in the articulator. This reference system consists of the upper part of the articulator, the condylar boxes, the lower part of the articulator, and the incisal pin.

For preparation of the splints, the bite is opened to the same extent in the preoperative and postoperative articulators, in both cases about 2 or 3 mm. The length of the incisal pin remains constant for the preoperative and postoperative situation (Fig 6). This way it is possible to fabricate a surgical splint for the postoperative situation that represents the planned movements of the maxilla in all three dimensions. The first splint (in the preoperative articulator) is prepared in the articulator representing the preoperative situation. It is applied for positioning the maxilla and the condyles in centric relation before osteotomy. The second splint (in the postoperative articulator) is fabricated for the controlled three-dimensional movement of the maxilla during actual surgery. For instance, if an upward movement of the maxilla is desired, the second splint will be vertically enlarged in the corresponding way.

According to the Göttingen concept for Le Fort I osteotomies, the two surgical splints are armed with a connection bar for mounting the surgical facebow in the preoperative and postoperative situations on identical positions with respect to the mandibular arch. Before surgery the connection device of the splint in the first articulator, ie, the centric splint, is adapted to the surgical facebow, which is a modification of the system as described by the manufacturer (SAM). The axial pins are then adjusted to centric condylar position of the hinge axis of the articulator (Fig 7).

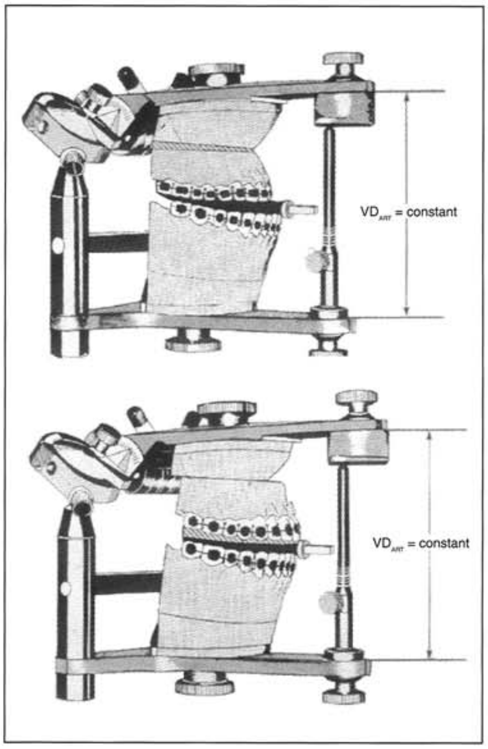


Fig 6 Principle of fabrication of the surgical splints in the articulators according to the three-dimensional double-splint method. The vertical dimension, eg, the length of the incisal pin, is the same in the preoperative and postoperative situations. (Black splint = first splint; striped splint = second splint.)

Surgical procedure

During actual surgery the first splint is inserted, representing the centric condylar position, and temporary intraoperative maxillomandibular fixation is applied. The centric position of each condyle, which is represented by the tips of the axial pins of the surgical facebow, is transferred to the preauricular skin of the patient by a needle puncture with methylene blue (Fig 8). This guarantees that the centric condylar position, which is preoperatively obtained from the patient, will be effectively transferred to the patient during surgery. After the maxilla is mobilized, the second surgical splint is inserted, bearing the connection device for the surgical facebow in an identical position as the first splint. Thus, centric condylar position can be adjusted and controlled. While centric condylar position is maintained, the maxilla is repositioned three-dimensionally, and an osteosynthesis is performed with four minifixation plates and screws (Mini-fixation plate system or Panfix-fixation plate system from LUHR osteosynthesis system, Leibinger). In the case of bimaxillary

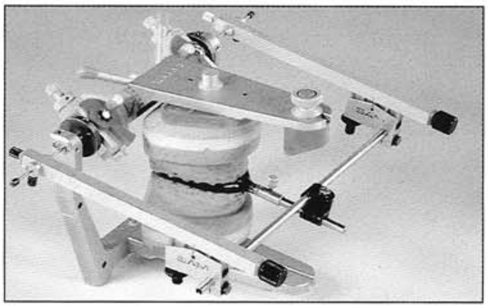


Fig 7 Adjustment of the surgical facebow with the preoperative splint in the articulator.

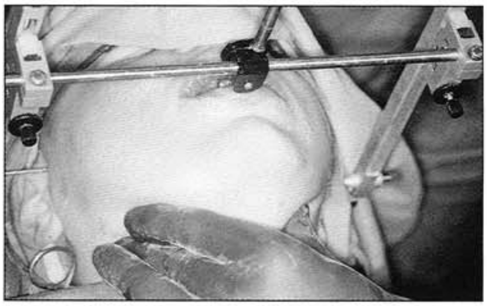


Fig 8 Application of the surgical facebow during surgery.

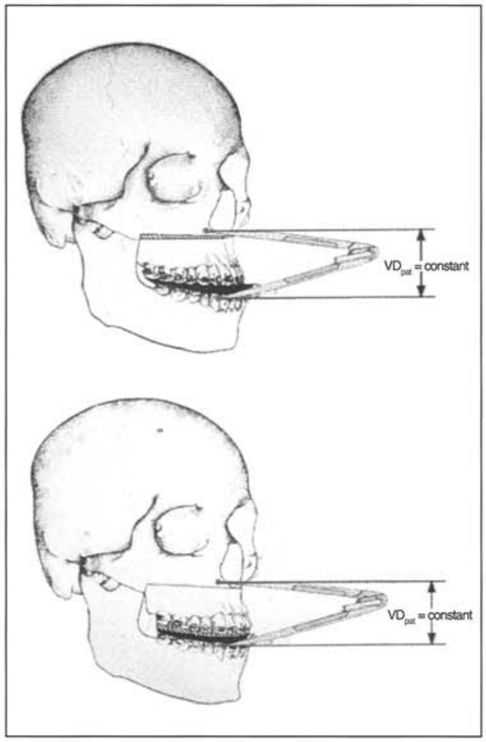


Fig 9 Principle of repositioning the maxilla during surgery according to the three-dimensional double-splint method. The reference length in the calipers is the same in the preoperative and postoperative situation. (Black splint = first splint; striped splint = second splint.)

surgery, the centric position of the condyles during maxillary osteotomy is controlled using a facebow, and the positioning of the condyles during sagittal split osteotomy of the mandible is performed by use of special positioning plates (Mini-fixation plate system from LUHR osteosynthesis system), which are applied bilaterally between the lateral cortex of the mandibular ramus and the anterolateral area of the zygoma.

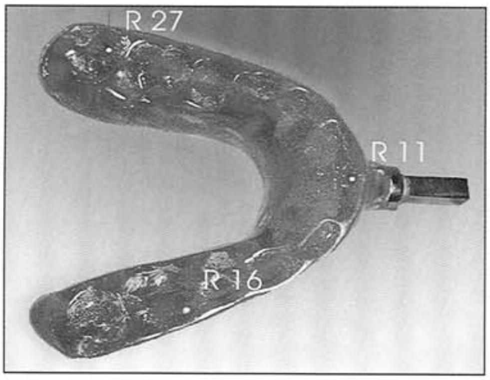
The three-dimensional placement of the maxilla during surgery is especially based on the fact that the vertical position of the mandible in relation to the skull above the osteotomy line can be exactly reproduced in the preoperative situation as well as in the postoperative situation (Fig 9). The centric condylar position is transferred from the articulator to the patient with the first surgical splint and the facebow. Subsequently a reference point, eg, a drill hole, on the bony structure of the maxilla above the osteotomy line is defined, and its vertical distance to a reference point on the mandible, eg, a premolar bracket, is measured with calipers. The initially defined distance is arbitrary and depends only on anatomic structures. After the maxillary complex is mobilized, the second surgical splint is inserted, representing the new maxillary position. Temporary maxillomandibular fixation is performed again, and the maxillomandibular complex is rotated upward anteriorly and cranially.

During rotation of the maxillomandibular complex, the desired centric condylar position is controlled and maintained by the facebow, and the vertical dimension is controlled by the calipers, which measure the distance of the two reference points. Since the second splint represents the three-dimensionally controlled position of the maxilla, the distance between the two reference points must be equal to the preoperative distance. This again is controlled with calipers. At this stage, the following points are of main importance: *(1)* the condyles are in centric relation due to the application of the facebow for positioning control; *(2)* the position of the mandible in relation to the skull above the osteotomy line is identical to the situation fixed in the first articulator; and *(3)* the maxilla is three-dimensionally positioned by the second surgical splint.

After osteosynthesis the second surgical splint is removed, and the mandible rotates into the new centric occlusion without any postoperative maxillomandibular fixation. The postoperative splint in combination with light maxillomandibular guiding elastics are inserted.

Cephalometric analysis

The results of the application of the new developments in the Göttingen concept were analyzed in 20 adult patients. Each patient had received orthodontic-surgical treatment by means of Le Fort I osteotomy alone or in combination with a sagittal split osteotomy. The position of the maxilla for each patient was obtained from lateral radiographs, which were taken preoperatively and postoperatively for routine diagnostic purposes. The sagittal and vertical dimensions of the maxilla were investigated, since



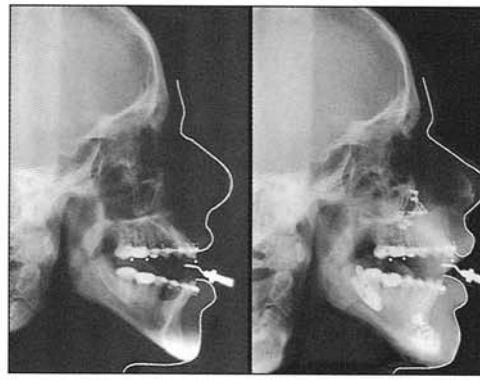


Fig 10 *(left)* First surgical splint with three metal balls as reference points (R 11, R 16, and R 27) on the upper surface.

Fig 11 *(right)* Lateral radiographs before and after surgery with the first surgical splint in place.

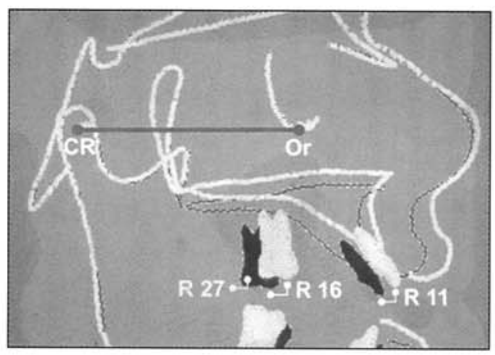


Fig 12 Superimposition of the lateral radiograph tracings and measurement of the movements of reference points R 11, R 16, and R 27. Light lines and teeth = preoperative position; dark lines and teeth = postoperative position. CR = center of rotation; Or = orbitale.

marked deviations from the planned position have been observed in these dimensions. Three reference points in the maxillary dental arch were selected for measurements: the mesial edge of the right central incisor (R 11), and the mesiobuccal cusp of the right first molar (R 16) and the left second molar (R 27). Each was marked with a metal ball (2-mm diameter) inserted in the upper surface of the first surgical splint (Fig 10). Both preoperative and postoperative lateral radiographs were taken with the splint in position in the patient's mouth (Fig 11). In the postoperative situation the splint was lined with wax on the mandibular side.

The computer program WinCeph 4.0 (Compudent) was used to analyze the radiographs. After the tracings of the preoperative and postoperative radiographs were superimposed anatomically with respect to the anterior base of the skull, the achieved displacements of the reference points were measured in the vertical and sagittal dimensions with respect to the hinge axis–infraorbital plane as the reference plane (Fig 12).

The real movement measured on the tracings of the lateral radiograph and the planned movements from model surgery were compared and analyzed using the statistical package STATISTICA (StatSoft). The following values were calculated as essential parameters for the patient groups: *(1)* the emperical median as an estimate for the true median, describing the values for the average patient, and *(2)* the interquartile difference as a measure for the deviation from the median. Furthermore, the data were presented as Box-Whisker plots. The central value of the box plot represents the median, below which and above which 50% of all values can be observed. The upper and lower boundaries of the box represent the 25% and the 75% quartiles. Finally, the minimal and maximal values are presented.

Results

The vertical deviation from the planned position of the maxillary complex with reference points R 11, R 16, and R 27 did not exceed 1.5 mm. In the box plot, negative values correspond to

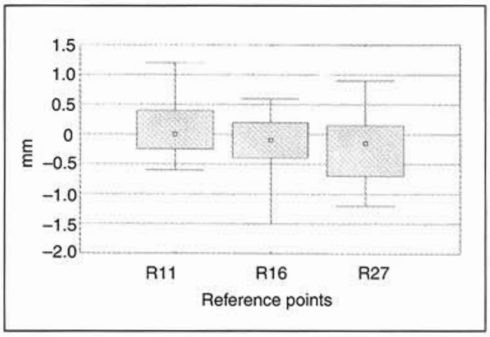


Fig 13 Deviations of the achieved position of reference points R 11, R 16, and R 27 from the planned position in the vertical dimension. Negative value indicates deviation in cranial direction; positive value indicates deviation in caudal direction.

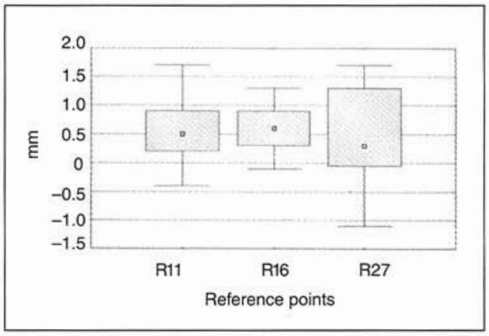


Fig 14 Deviations of the achieved position of reference points R 11, R 16, and R 27 from the planned position in the sagittal dimension. Posterior value indicates deviation in cranial direction; anterior value indicates deviation in caudal direction.

a cranial deviation, positive values to a caudal deviation. The median value is zero; hence the errors encountered are due to random effects (Fig 13). In addition to the cranial and caudal deviations, the absolute values of the deviations were calculated as a measure for the absolute error that had occurred. In the vertical dimension, the median for reference point R 11 was 0.3 mm (75% quartile: 0.55 mm; maximum: 1.2 mm); the median for reference point R 16 was 0.25 mm (75% quartile: 0.55 mm; maximum: 1.5 mm); and the median for reference point R 27 was 0.4 mm (75% quartile: 0.8 mm; maximum: 1.2 mm).

For the sagittal dimension, the values for reference points R 11, R 16, and R 27 differed by, at most, 1.7 mm between the achieved position and the planned position. In the box plots, positive values correspond to deviations to the anterior, negative values to posterior deviations. A small systematic tendency of 0.5 mm for the median toward the anterior could be observed (Fig 14), but this tendency is in the range of the accuracy for surgery and for the measurement method. The median of the absolute value of the deviations in the sagittal dimension at R 11 was 0.5 mm (75% quartile: 0.9 mm; maximum: 1.7 mm); the median for R 16 was 0.6 mm; (75% quartile: 0.9 mm; maximum: 1.7 mm); and the median for R 27 was 0.35 mm (75% quartile: 1.3 mm; maximum: 1.2 mm).

Altogether the results show that an orthodontic-surgical treatment of the maxillary complex using the model-repositioning instrument and the three-dimensional double-splint method permits an accuracy of ± 1 mm in the vertical and sagittal dimensions for the achieved position of the maxilla.

Discussion

The present study describes the principles and practical application of the model-repositioning instrument and three-dimensional double-splint method for orthodontic-surgical treatment with condylar position control according to the Göttingen concept. As a precondition for the application, the models must be mounted in exact centric relation in the articulator for model surgery, and the centric relation of the condyles must be preserved throughout actual surgery.

The problems with the inaccuracy in measurements at the base of a model during model surgery have been well-known for a long time. Various devices have been developed for a controlled adjustment of single reference points at the maxillary teeth. One method used to precisely position the edges of the maxillary incisors in the sagittal-vertical plane during model surgery is to wind a piece of wire around the incisal pin of the articulator before model surgery. The tip of the wire touches the incisal edge of a maxillary incisor. The wire can be removed during model surgery and later replaced in its original position. The displacement of the tip of the wire in relation to the position of the maxillary incisal edge demonstrates the movement of the maxillary incisor.[48] Another method is the three-dimensional positioning of the incisal edge of a maxillary incisor by using the model positioning device.[49] Other authors describe methods for successive measurements of different reference points at the teeth by using the modified boley gauge in the articulator[50] or the model surgery platform outside the articulator.[51]

Application of the model-repositioning instrument makes it possible to simultaneously determine the position of three reference points in relation to a reference plane in the articulator and to perform controlled relative movements. In maxillary surgery the dental arch of the mandible defines the position of the maxilla in the sagittal and transverse dimensions. In this case only the vertical dimension needs to be controlled and adjusted by the model-repositioning instrument. In bimaxillary surgery the maxilla is the first mobilized. Since the mandible is mobilized after the maxilla and since its position is also changed, it cannot be used for reference purposes. This increases the difficulties in controlling the position of the maxilla, which now must be positioned with control in all three dimensions. Here, the model-repositioning instrument enables three-dimensional positioning of the maxilla.

The model-repositioning instrument can also be used in surgery with a segmented maxilla. The procedural principles are the same. After the coordinates of the preoperative position are registered, the maxillary cast is loosened from its base and cut in segments. The segments are positioned in the planned postoperative situation corresponding to the dental arch of the mandibular cast, and subsequently the segments are stabilized with plaster. This newly configurated maxillary cast is adjusted in the model-repositioning instrument and moved to the postoperative situation. The coordinates for the new position can be read from measuring scales. The application of this new appliance not only increases accuracy, it is also less time-consuming because the marking of reference lines and cutting along them can be omitted. Furthermore, the maxillary cast can be easily separated from the articulator using a splitcast and moved into the new position.

In actual surgery the precise positioning of the maxilla has often been difficult, especially in regard to its complex three-dimensional repositioning. Problems arose, for instance, when large advancements in the sagittal dimension were planned, when the anterior and posterior regions were moved cranially by different distances, when the midline was rotated, or when the maxillary arch was extended in the transverse direction by an additional paramedian sagittal split in the palatal region. The difficulties of repositioning can be explained by the fact that the positions of the reference points could not be reproduced for the vertical positioning of the maxilla. With use of the three-dimensional double-splint method, a vertical reference line can now be exactly reproduced, since the reference points are above the osteotomy line and at the mandible. This establishes the three-dimensional double-splint method as a new method. The combination of a reproducible reference line, surgical splints, and maintenance of centric condylar position can be seen as the key to successful three-dimensional positioning of the maxilla: In the condylar region, centric relation is obtained with a facebow, while in the anterior region, the defined reference line is reproduced by calipers. If the vertical relation cannot be achieved immediately, it is possible to carefully remove some bone to enable an exact vertical positioning and to create as much bony surface as possible between the osteotomy segments and the rest of the skull. The application of the three-dimensional double-splint method represents a major improvement for the surgeon and introduces additional control when moving the maxilla into the desired position, which in turn means a reduction of the duration of surgery.

The results of the present study show that the model-repositioning instrument and the three-dimensional double-splint method can be used in combination with standard methods for orthognathic surgery with condylar position control to achieve a controlled and exact positioning of the maxillary complex. This approach is also less time-consuming than other methods. In addition, the stability of the achieved results was found to be high.[52] A necessary precondition for successful application is that the casts, which are mounted by routine for preparation of the osteotomy, must be in centric condylar position. This guarantees that the maxillary segments can be repositioned as planned. The intraoperative positioning of the maxilla with an accuracy of ± 1 mm in the sagittal and vertical dimensions denotes a major improvement for orthodontic-surgical treatments.

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Significance of the contour of the lateral surface of the maxilla for planning osteotomy lines in orthognathic surgery

The Le Fort I osteotomy is one of the most frequently used procedures in orthognathic surgery. The preoperative planning of a Le Fort I osteotomy usually involves a two-dimensional lateral radiograph. On the lateral radiograph, the movement of the maxilla in the sagittal and vertical planes can be simulated, and the position of the osteotomy line in relation to the occlusion can be determined. However, the lateral radiograph consists of two dimensions, whereas, during surgery, three dimensions have to be considered. The contour of the lateral surface of the maxilla and its individual regional variations are not reflected on the lateral radiograph. Therefore, this third dimension's influence on treatment planning is investigated. Discrepancies of the position of planned osteotomy cuts are described after the transfer from two to three dimensions. Discrepancies of the positions of reference points and lines are up to 3.3 mm. Therefore, it is not possible to transfer reference points and reference lines from the lateral radiograph to the maxilla nor to move the mobilized maxilla along the planned osteotomy lines in a precise manner. It is possible to indicate the general direction of the osteotomy lines. Results of this study show the necessity for the precise control of three-dimensional positioning of the maxilla during treatment planning, cast surgery, and actual surgery. (Int J Adult Orthod Orthognath Surg 1993;8:191–201.)

Introduction

Modern orthodontics and oral and maxillofacial surgery enable a combined approach for correction of dentofacial deformity. The dental arches of the maxilla and mandible are aligned by fixed orthodontic appliances. The maxilla and/or mandible can be mobilized with surgery, adjusted (three-dimensionally) in a new position, and fixed with miniplates and screws. Following surgery, a fine adjustment of occlusion and muscular rehabilitation are completed by orthodontics.

In orthognathic surgery the Le Fort I osteotomy and subsequent three-dimensional positioning of the maxilla is frequently performed.[1-4] This method might be isolated or combined with mandibular osteotomy. Surgery is planned after clinical evaluation and record analysis. On the lateral radiograph, the surgical movement of the maxilla in the sagittal and vertical planes and the position of the osteotomy cuts in relation to occlusion can be planned.

Reference lines are drawn perpendicular to the occlusal plane from the

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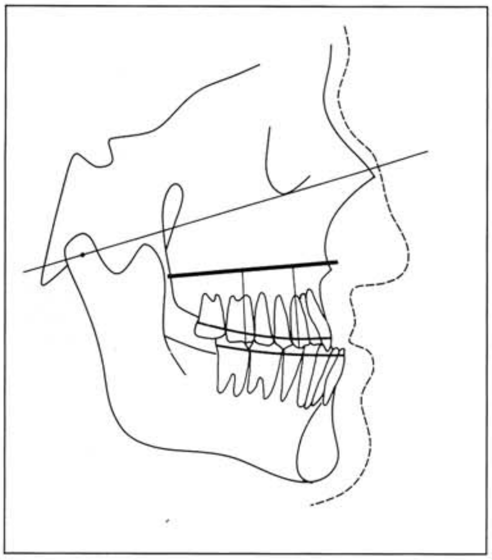


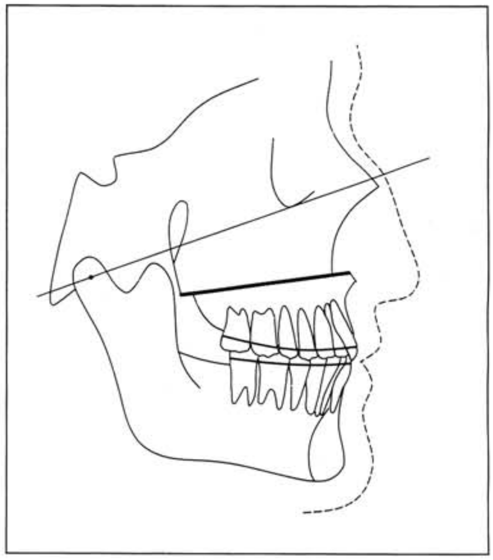


Fig 1 (left) Determination of the vertical reference lines and the position of the osteotomy cuts on the tracing from the lateral radiograph.

Fig 2 (right) Simulation of the maxillary movement along the osteotomy cuts.

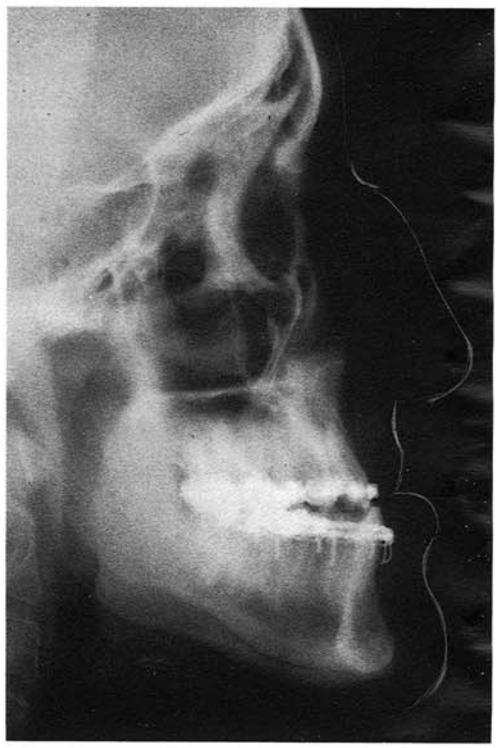


Fig 3 (left) Two-dimensional planning on the lateral radiograph.

Fig 4 (right) Three-dimensional transfer on a skull.

tips of the canine and the mesiobuccal cusp of the first molar to the maxilla. By linking the most cranial points of these reference lines at the level of the nasal floor, the position of the osteotomy cuts can be determined (Fig 1). According to these reference lines, the movement of the maxilla can be simulated in the sagittal and vertical dimensions (Fig 2).

During surgery the reference lines from the lateral radiograph are transferred to the lateral surface of the maxilla using a caliper. Treatment planning usually consists of two dimensions (Fig 3), whereas, during actual surgery, three dimensions must be considered. The contour of the lateral surface of the maxilla and its individual variations are

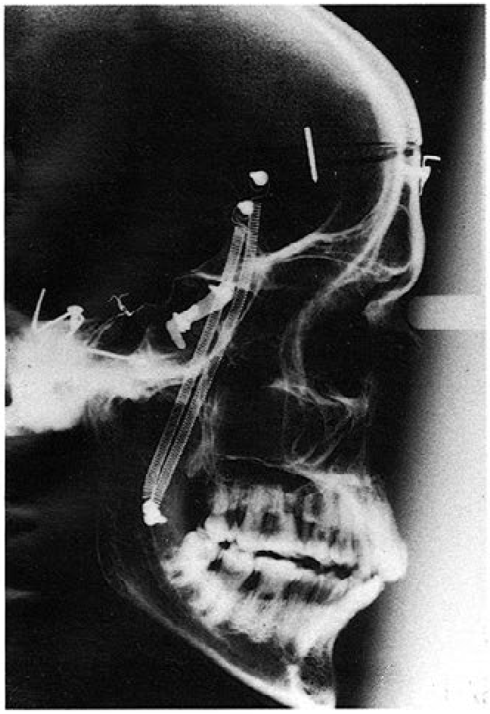


Fig 5 (left) Lateral radiograph of a studied skull.

Fig 6 (right, above) Individual impression tray for the maxilla.

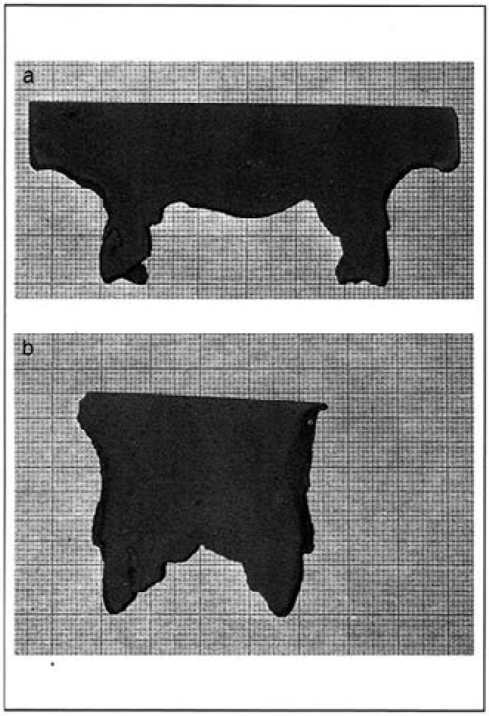
Fig 7 (right, below) Cast of a maxilla from a studied skull.

not considered on the lateral radiograph, but this contour is important during surgery (Fig 4). This problem is well known.[5,6] However, no study examines the extent of discrepancies when a planned osteotomy line is transferred from two into three dimensions. The aim of this study is to evaluate the discrepancies that arise when an osteotomy line is transferred from a lateral radiograph onto the maxilla using a caliper.

Method and materials

For this study, lateral radiographs were taken of 20 skulls (Fig 5). An individual impression tray was fabricated from self-curing resin (Fig 6). Impressions were taken of the maxilla and maxillary teeth with this tray. Casts were fabricated (Fig 7), and cuts were made in the transverse vertical plane at the level of the tips of the canines and the mesiobuccal cusps of the first molars bilaterally (Fig 8). Contour lines of the lateral surfaces of the cuts in the areas of the molars (Fig 9) and canines (Fig 10) were drawn with a pencil on graph paper. The cuts were so orientated that a line linking the tips of the left and right tooth was parallel to a horizontal line on the graph paper. Reference lines were drawn perpendicular to the occlusal plane from the tips of the canine and mesiobuccal cusp of the first molar to the maxilla. A desired height represented the length of reference line S_1 with end point P_1. The lengths of S_1 were chosen as tooth length (from the lateral radiograph) plus 2 mm and tooth length plus 4 mm. Therefore, an adequate distance from the tooth's roots was guaranteed during osteotomy, and different positions of osteotomy cuts could be examined (Fig 11).

The reference line S_1 was transferred from the lateral radiograph to the contour lines using a caliper. On the contour lines the base point of S_1 was the tip of the reference tooth; the vertical direction of S_1 ended cranially at point P_1. S_1 was drawn a second time so that



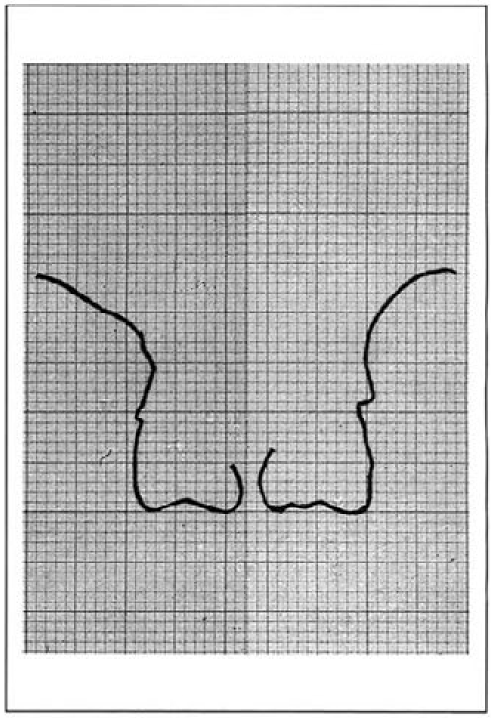
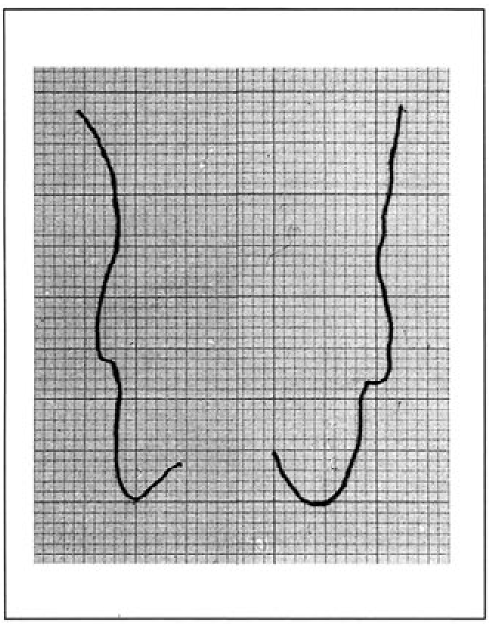


Fig 8 (left) Cuts on the casts in the transverse vertical plane at the level of the *(a)* mesiobuccal cusps of the first molars and the *(b)* tips of the canines bilaterally.

Fig 9 (right) Contour curves of the lateral surfaces of the cuts in the area of the molars.



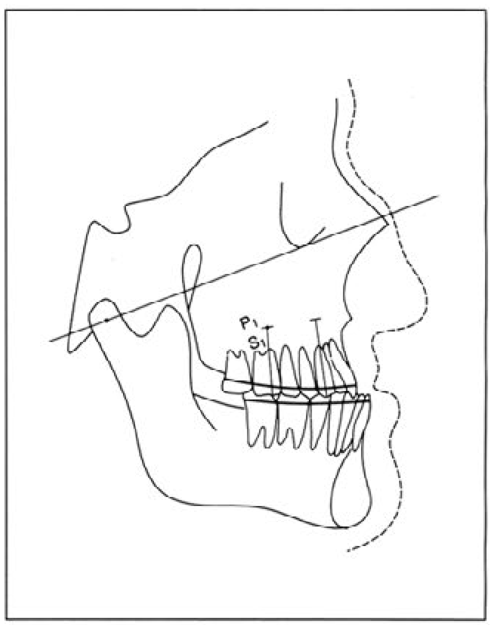


Fig 10 (left) Contour curves of the lateral surfaces of the cuts in the area of the canines.

Fig 11 (right) Reference line S_1 and end point P_1 on a tracing of the lateral radiograph.

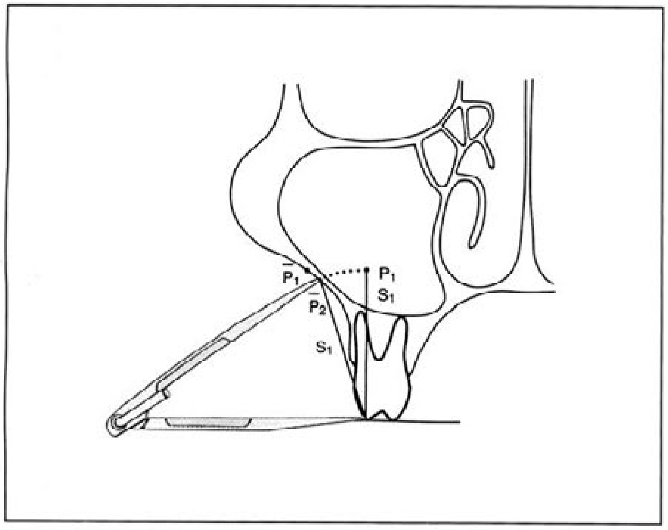


Fig 12 Transfer of the planned reference lines and end points from the lateral radiograph to the contour lines.

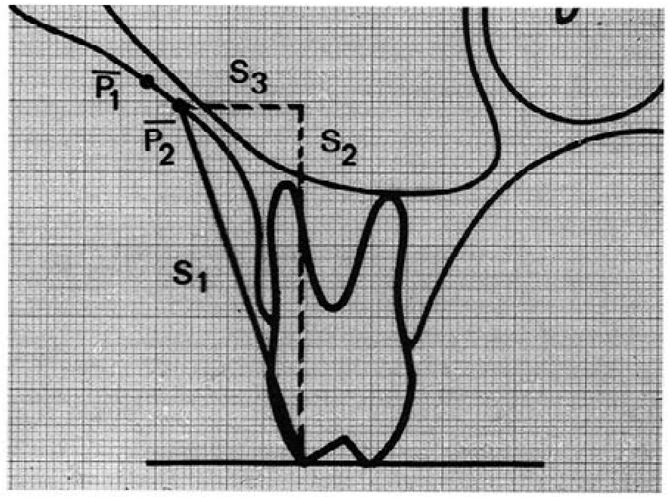


Fig 13 Transfer of the planned reference lines and end points for measurement and calculation of the discrepancy S_2 minus S_1, corresponding the lateral radiograph on the contour lines.

its base point ran through the tip of the tooth again, but the end point $\overline{P}_2$ overlapped the contour line, which represented the lateral contour of the maxilla.

After S_1 was drawn on the contour line, S_1 and $\overline{P}_2$ were projected onto the sagittal vertical plane. The desired heights of S_1 $\overline{P}_1$, and P_1 could not be obtained (for geometric reasons) using a caliper due to the inclination of the lateral contour of the maxilla; only the height of point $\overline{P}_2$, which lies more caudal than $\overline{P}_1$ and P_1, could be determined. (Fig 12). From the base point of S_1 (the tip of the examined tooth) and $\overline{P}_2$, a triangle was constructed with the base of S_1 and the sides of S_2 and S_3 (Fig 13). The length of S_3 was measured, and the length of S_2 was calculated using the Pythagorean theorem ($S_2^2 + S_3^2 = S_1^2$). The difference of the lengths of the lines S_2 minus S_1 characterizes the discrepancy between the height of the points $\overline{P}_1$ or P_1 on the lateral radiograph and the height of point $\overline{P}_2$ on the contour line, in projection onto the sagittal vertical plane. The difference of S_2 minus S_1 is negative because $\overline{P}_2$ is more caudal than $\overline{P}_1$ or P_1. The discrepancies are noted in statistical evaluations (mean, standard deviation, minimum, maximum).

When S_1 is drawn on the lateral contour of the maxilla, the desired height of point P_1 (with a distance S_1 from the base point) cannot be achieved. Only the height of point $\overline{P}_2$ can be determined (with a distance S_2 from the base point) when projected onto the sagittal vertical plane. Therefore, the length of $\overline{S}_2$ was calculated to obtain the desired height of point P_1 (with a distance S_1 from the base point) when projected onto the sagittal vertical plane—to obtain the exact height from the lateral radiograph. From the base point on the tip of the examined tooth and from the points $\overline{P}_1$ and P_1, a triangle was constructed with the base $\overline{S}_2$ and the sides S_1 and $\overline{S}_3$ (Fig 14). The length of $\overline{S}_3$ was measured, and the length of $\overline{S}_2$ was calculated using the Pythagorean theorem

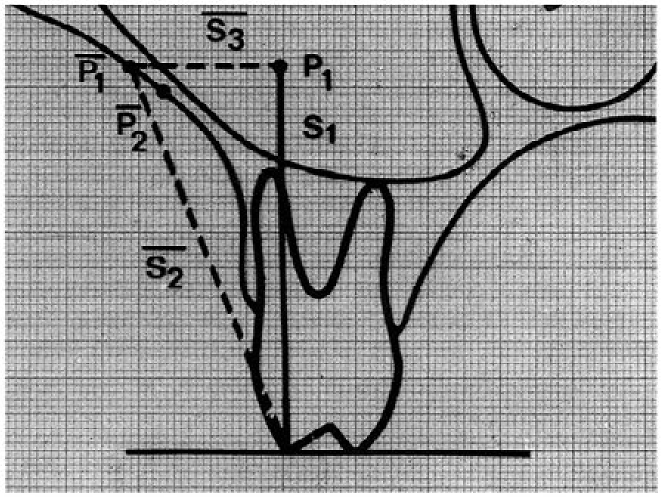


Fig 14 Transfer of the planned reference lines and end points for measurement and calculation of the discrepancy $\overline{S}_2$ minus S_1, corresponding the lateral radiograph on the contour lines.

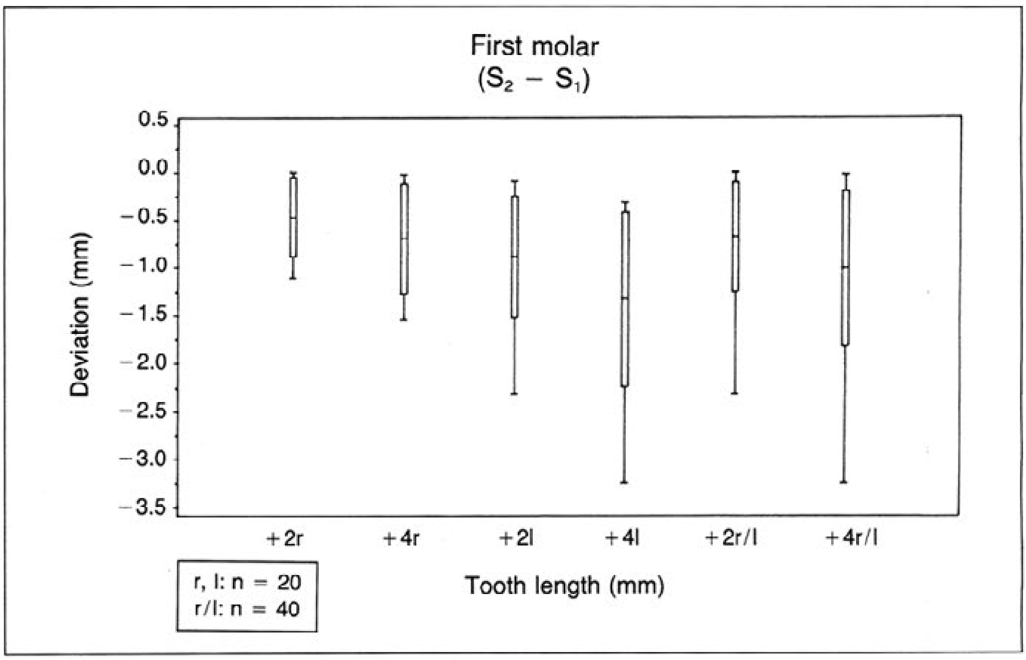


Fig 15 Statistical evaluations of the discrepancy S_2 minus S_1 for the first molar.

($S_1^2 + \overline{S}_3^2 = \overline{S}_2^2$). The difference of $\overline{S}_2$ minus S_1 characterizes the value of the length, which must be added to obtain the desired height of S_1 on the skull. The difference of $\overline{S}_2$ minus S_1 is positive. The discrepancies are noted in statistical evaluations (mean, standard deviation, minimum, maximum).

Results

The discrepancy of S_2 minus S_1 for the first molar averaged 0.3 to 1.3 mm, with a minimum of 0 mm and a maximum of 3.3 mm. The statistical evaluation shows severe discrepancies, which depend on the contour of the maxilla and the length of the examined reference lines—the longer the reference lines, the larger the differences. Differences were also noted between the right and left skull halves. The distribution of the varying values on the right and left sides is random (Fig 15).

The discrepancy of S_2 minus S_1 for the canine averaged 0.2 to 0.3 mm with a minimum of 0 mm and a maximum of

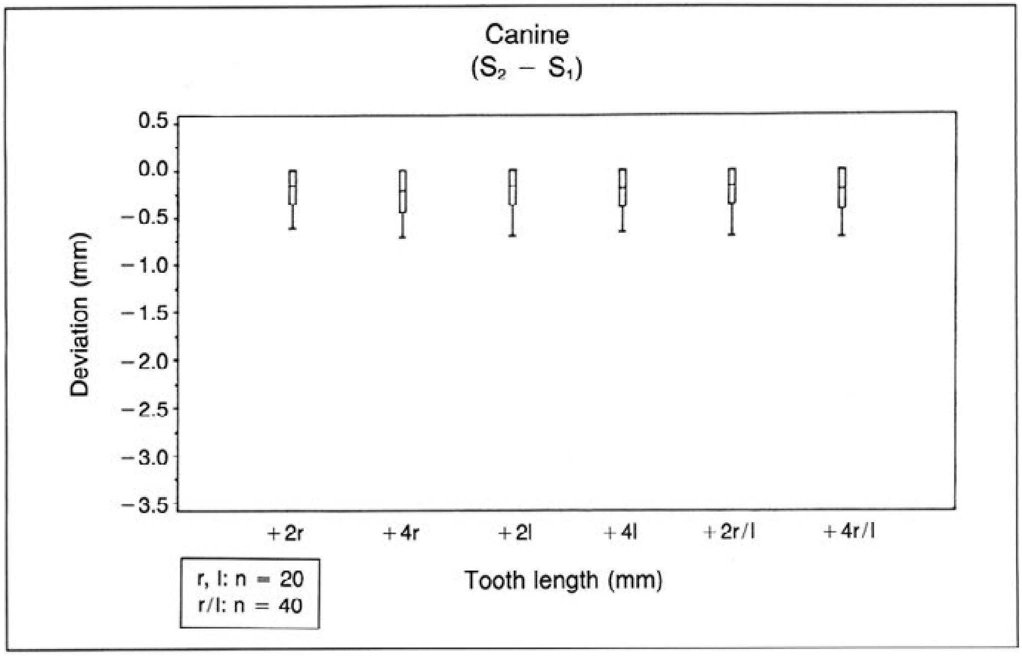


Fig 16 Statistical evaluations of the discrepancy S_2 minus S_1 for the canine.

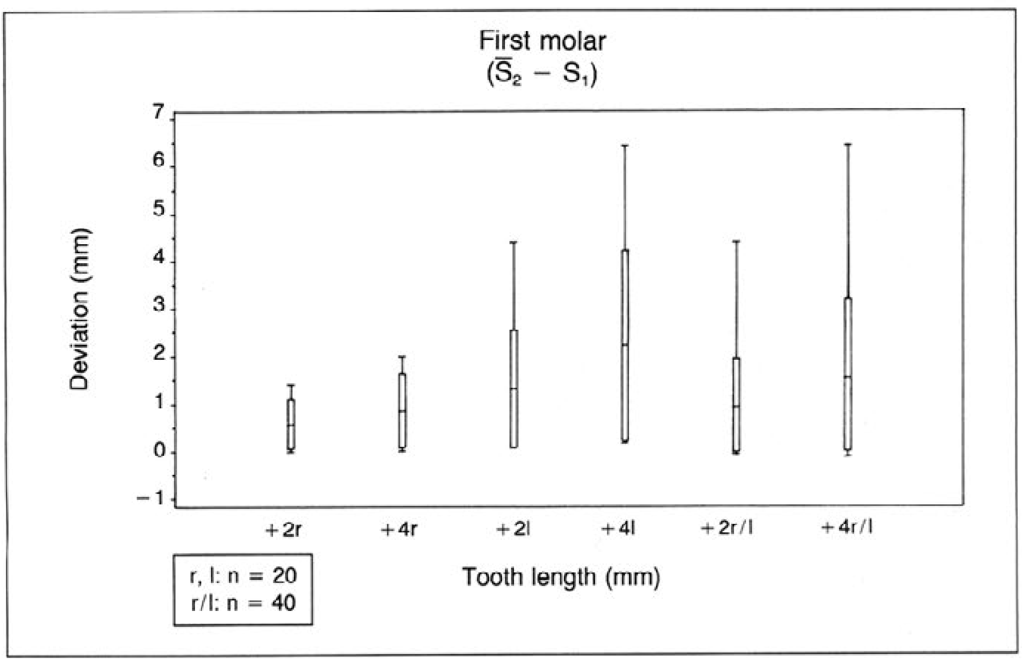


Fig 17 Statistical evaluations of the discrepancy $\overline{S}_2$ minus S_1 for the first molar.

0.7 mm. Therefore, discrepancies are distinctly less than those for the first molar area (Fig 16).

The discrepancy of $\overline{S}_2$ minus S_1 for the first molar, depending on the tooth's length, averaged 0.6 to 2.1 mm with a minimum of 0 mm and a maximum of 6.5 mm. The statistical values show that there are severe discrepancies (Fig 17).

The discrepancy of $\overline{S}_2$ minus S_1 for the canine averaged 0.2 to 0.3 mm with a minimum of 0 mm and a maximum of 0.7 mm (Fig 18).

Discussion

Because of the anatomy of the lateral contour of the maxilla, reference lines

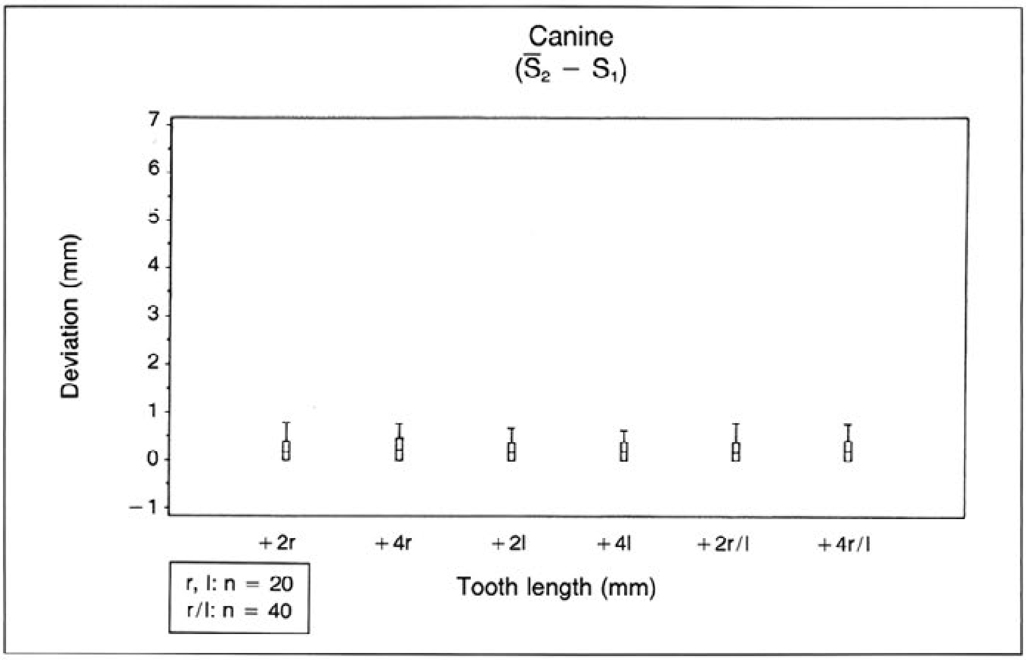


Fig 18 Statistical evaluations of the discrepancy $\overline{S}_2$ minus S_1 for the canine.

for osteotomy cuts determined by the lateral radiograph could not be transferred onto the maxilla in a precise manner. It is not possible to exactly move the mobilized maxilla along the planned osteotomy cuts. In the region of the first molar, the discrepancies may be several millimeters and cannot be estimated when the exact anatomy of the patient is unknown. The longer the reference lines are, the bigger the deviations—due to the inclination of the maxilla in the region of the zygomatic buttress. The discrepancies for the first molar and the canine are different. In the region of the canines, the discrepancy is relatively small and can be ignored for clinical purposes. The discrepancies that may exist can change the location of the planned osteotomy cuts, particularly when longer reference lines have to be transferred in the region of the molars. Distinct differences may also exist between the right and left sides. The distribution of the right and left sides may be random, but this only raises inaccuracy on the whole.

In this study discrepancies between reference positions for osteotomy cuts on the lateral radiograph and the maxilla are described quantitatively for the first time. These discrepancies must be accommodated during treatment planning, cast surgery, and actual surgery. Different approaches have been introduced.

One approach is to transfer reference lines more exactly from the lateral radiograph to the maxilla during cast surgery and actual surgery with the maxillary measuring appliance.[7] This device consists of a flat horizontal measuring table (30 × 10 mm) and a pillar (35 mm) made of metal—the pillar being vertical to the measuring table. The pillar is fastened to the longer side of the measuring table and can be moved along this side. During cast surgery the measuring table is fastened to the occlusal surface of the mounted maxillary cast extending from the canine to the first molar with self-curing resin. The vertical pillar enables the transfer (with a pencil) of vertical and horizontal reference lines from the lateral radiograph to the maxillary cast. The geometric error from a caliper is avoided. During actual surgery the measuring table is positioned on the dental arch of the patient. With the vertical pillar, vertical and horizontal reference lines can be transferred (with a bur) to the lateral walls of the maxilla. The application of the device appears relatively complicated, because two devices are necessary for the right and the left sides.

The second approach is to make the treatment planning not two dimensional, but three dimensional.[8–13] One procedure utilizes a radiograph in a posteroanterior direction, providing a second plane for treatment planning to obtain information about the anatomy of the lateral contour of the maxilla.

Another procedure utilizes computer tomography. From tomographic scans the anatomy of the skull can be visualized three dimensionally. This data can be integrated to produce plastic models in a milling machine. Using these models, orthognathic surgery can be simulated. This method requires equipment and time. This procedure may be indicated for special treatment planning of severe dentofacial deformities.

In addition to the described discrepancies due to the maxillary contour, the width of the saw cut for the osteotomy and three-dimensional movement of the mobilized maxilla must be considered. This is especially relevant with problems of asymmetry when complex three-dimensional movements are performed, and telescoping appears between the mobilized maxilla and the rest of the skull.[14] The goal is to make a controlled three-dimensional repositioning of the maxillary teeth and the entire maxilla during treatment planning, cast surgery, and actual surgery.[14–28] It is also important to consider and to position the cant of the occlusal plane with special surgical techniques.[29–31] Additional procedures are described in previous literature.[32–60]

The third approach assumes that only the general direction of an osteotomy line is important, but not its exact position. The position of the osteotomy line can run parallel to the occlusal plane or at an angle to it.

Through advanced technologies, the planned position of the maxilla can be exactly transferred from cast surgery to actual surgery. The application of advanced positioning techniques during cast surgery, such as with the model positioning appliance, and the application of advanced surgical splint technologies, such as the sandwich splint or the three-dimensional double splint in combination with the condylar positioning appliance, represent a closed concept and allow three-dimensional controlled positioning of the maxilla after Le Fort I osteotomies. This concept is independent of an exact positioning of osteotomy cuts, but it requires an exact control in the vertical dimension. This third approach is relatively easy to handle in daily routine.

The anatomy is the basis for the development and critical discussion of clinical procedures. Knowing the exact anatomy of the maxilla will help to avoid errors during planning and treatment of dentofacial deformities. Measurements obtained at the planning stage must be clinically modified if accurate repositioning of the maxilla is critical to a successful outcome.

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