The reproducibility of reference points in orthognathic surgery: a critical review

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Abstract

Introduction
Orthognathic surgery is a common surgical procedure being practiced in maxillofacial surgery. The most important part of the procedure is to achieve the planned prediction tracing and model surgery during the operation and to maintain the results postoperatively.

Controlling the maxillary movements constitutes a crucial phase of the surgery and the errors resulting from faulty or inaccurate methods usually leads to unstable and faulty results.

Many techniques for the controlling of vertical and horizontal repositioning of the osteotomized maxilla were described in the literature; some of them are based on internal reference points and the others on external reference points. The aim of this review was to evaluate the reproducibility of different reference points described in the literature in relocating the maxillary position during orthognathic surgery, addressing in details the types, location, advantages and limitations of these techniques.

Conclusion
Since the early years of practicing orthognathic surgery, it is obvious that no single method is absolutely reproducible in relocating the maxillary position in all directions. This fact emphasises the need of developing a new non-invasive three-dimensional technique to intraoperatively control the maxillary movements and thus to reduce the overall error rate and achieve better results.

Introduction
The most important purpose of orthognathic surgery is to achieve the planned prediction tracing and model surgery of the patient during the operation and to maintain stable results postoperatively. This target can be achieved by precise transfer of the model surgery, which is done beforehand, to the operating theatre minimizing the errors in different stages of the surgical procedure. The golden key of success in orthognathic surgery is the incisor—lip relationship, since the main concern of the patients is the aesthetic one.1,2

The control of maxillary position during Le Fort I surgery is the most important part of the procedure in terms of accuracy and stability.3-5

Since the early years of orthognathic surgery, many surgeons proposed different techniques to control the movements of osteotomized maxilla and therefore to achieve the optimum results, minimize the errors and avoid the relapse postoperatively.

In the literature there are many reports that describe different techniques for the control of maxillary repositioning in orthognathic surgery. They can be divided according to their location or placement into two groups:

(1) Internal reference points, placed usually on the maxilla, above and below the osteotomy line.
(2) External reference points, which usually use a point on the skull or face as a fixed reference point.

The aim of this review was to evaluate the reproducibility of different reference points described in the literature in relocating the maxillary position during orthognathic surgery, addressing in details the types, location, advantages and limitations.

Discussion
The precise repositioning of the osteotomized maxilla after Le Fort I osteotomy in all dimensions is of great importance; this is to facilitate the exact transfer of the model surgery to the patient intraoperatively, thus to minimize the errors, avoid the relapse and to achieve the planned image for the patient. The maxilla is usually moved in three directions; transverse, vertical and horizontal and the planned movements (in mm) are measured from a fixed reference point, some of these points proved to be inaccurate whereas others can provide more accurate results. Johnson described a technique for measuring maxillary movements during Le Fort I osteotomy; it was based on the measurement of the distance between two reference points: a fixed superior point in the soft tissue nasion (a horizontally placed suture) and a point on the maxillary central incisor tooth by using a large calliper or a Draftsman’s compass. He concluded that with appropriate operative sequencing, three-dimensional movement of the upper jaw position could be gauged to within 1 mm by means of simple two-point measurement system. The technique could be used to corporate direct bone measurements and permit assessment of maxillary repositioning at virtually any time during the surgical procedure.

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Van Sickels et al.\textsuperscript{7} discussed the predictability of postoperative maxillary central incisor position in two groups of patients undergoing maxillary osteotomies in which either internal reference lines or external reference points were used. The internal reference lines (in the lateral aspect of the piriform aperture and at the zygomatic eminence) were used in the first group and the external reference points (mark in the bridge of the nose and a bracket on the maxillary central incisor) were used in the second one. They found that in the internal reference group, the incisal tip was off an average of 3.6 mm in the horizontal measurements (x axis) and 2.5 mm in the vertical measurements (y axis). In the external reference group, x was off by an average of 1.1 mm and y was off by an average of 0.7 mm. They concluded that when accurate cephalometric tracings were done in combination with precise model surgery and the use of bone plates for stabilization, an external reference point could more accurately achieve maxillary central incisor position.

Heggie\textsuperscript{8} developed an external three-point calibrator to measure the horizontal and vertical maxillary incisor movement during the surgery. This method has improved the accuracy of incisor positioning, but could not improve the accuracy of the maxillary repositioning, as there is an arc of alternative positions along which a single measurement remains constant.

Pospislil\textsuperscript{9} compared the prediction tracing with the postoperative cephalometric radiographs taken six months after surgery in 40 patients. Forty percent of the unimaxillary and 40% of the bimaxillary cases could not achieve the predicted results.

In a study on Le Fort I osteotomies, Stanchina et al.\textsuperscript{10} compared between external and internal reference points. Their results showed the external reference point to be a more reliable method of positioning the maxilla in the vertical dimension than the internal reference point. However, there was no significant difference between the results obtained using an internal vs external reference point when the horizontal position of the maxillary incisor was evaluated and compared to the predicted change. This study indicates that the use of an external reference point can improve the predictability of vertical maxillary surgical repositioning.

Wylie et al.\textsuperscript{11} introduced the maxillary measuring appliance, this device enabled transfer of measurements from presurgical cephalometric and model surgery to the maxilla intraoperatively and the reference lines to be drawn on the maxilla during surgery in a similar position to those drawn on the model. Results showed that this device was useful in achieving predictable results during maxillary surgery by allowing accurate transfer of carefully determined treatment plan information to the patient at the time of surgery.

Neubert et al.\textsuperscript{12} mentioned that anterior and posterior vertical bony reference lines marked with fissure bur, as described previously, proved to be insufficient especially in cases where large sagittal maxillary shift and rotation are necessary. Therefore, they introduced a modified type of face bow provided with an interocclusal splint that has been adjusted beforehand on an articulator, in a model operation taking into account the skull and TMJ relationship. Despite the small number of patients they included in their study and the different types of patients operated, they argued that by using this type of face bow they achieved good accuracy of maxillary repositioning.

Kahnsberg et al.\textsuperscript{13} introduced a modified method of measurement of the vertical dimension during maxillary osteotomy, they aimed to compare the accuracy of orthognathic surgery when measuring the vertical dimensional changes of the maxilla using the conventional internal reference lines in the lateral walls of the maxilla or from a bone mark in the region of glabella to the incisal edge. In this study, patients were divided into two groups; one is an internal reference group and the other an external reference. Results from this study showed a fairly good agreement in both groups, however discrepancies of different sizes were found. In the conventional method group the mean difference was 2.1 mm whereas in the external reference point group, the mean difference was 1.3 mm. The main difference was noted in the measurement of vertical dimension and the mean difference in the horizontal plane was of no significant statistical importance. They concluded that more accuracy in the intraoperative control of maxillary repositioning is needed.

Polido et al.\textsuperscript{14} did a more detailed and comprehensive study. The purpose was to determine the ability to perform the orthognathic surgery that is planned based on the prediction tracing and model surgery when using the mandible as a guide for the horizontal repositioning of the maxilla and the internal reference points on the sides of the bone cut and external reference points (Kirschner pin driven into the bridge of the nose) to achieve the vertical repositioning at the time of surgery. They included 146 patients in their study, cleft and craniofacial syndrome patients were excluded, and the only measurement at surgery was the vertical dimension by the use of either internal reference points or external reference points. The results of this study indicated that the use of an arbitrary internal reference point is not an accurate method for the maxillary repositioning. One of the most important findings in their study was that less inaccuracy was seen in the horizontal rather than the vertical repositioning. Both rigid and non-rigid fixations were included in their study and it was shown that there...
was significant difference between them with a tendency of superior repositioning in the non-rigid fixation group. The explanation given for that was that the superior movement of the maxilla occurred while the wires were tightened until bone contact between segments was achieved. On the other hand, using plates and screws caused the maxilla to be positioned inferiorly at an average of 1 mm beyond that predicted showing that bone plates must be applied only after accurate vertical maxillary repositioning.

Schwestka et al.\textsuperscript{15} introduced a new method of three-dimensional repositioning of the maxilla. They stated that the model positioning device which is described in their study allows three-dimensional positioning of the upper incisors in one or two jaw surgery, the reference plane was the upper surface of the upper part of a semi-individually adjustable articulator, the application of the sandwich splint enables the three-dimensional repositioning of the maxilla in relation to the rest of the skull. The sandwich splint ensures that the vertical position of the maxilla in relation to the rest of the skull above the osteotomy plane is exactly reproducible in the pre- and postoperative situation in both model surgery and at the time of surgery.

Ferguson and Luyk\textsuperscript{16} investigated the accuracy of vertical repositioning of the maxilla in 45 patients, they did a comparison study to assess the reproducibility of the traditional internal reference lines and the external reference points consisting of bone screws placed at the nasion. The results of their study confirmed that a fixed reference point at nasion combined with a careful and accurate surgical technique would allow accurate control of vertical position during maxillary surgery.

Nattestad and Vedtofte published an extensive study to quantify the errors resulting from using different reference lines and points in model surgery and surgical operation. The results indicate that clinically significant differences between the planned and achieved position can result from the erroneous transfer of the reference lines and points from the model to the patient during surgery, this study illustrates that the possible inaccuracy from the erroneous use of references has a magnitude similar to that of the previously reported lack of precision in clinical studies of orthognathic surgery.\textsuperscript{6,12,13} The inaccuracy was measured as a variation in the vertical position of the maxillary molars and was found to depend on the type of error in the measurement method. The conclusions of this study gave emphasis to the importance of correct transfer of references from the articulator to the operation, it is also suggested that the use of internal reference lines gives rise to errors, since there is no predictable method of transferring the reference lines from model surgery to the operation, they believed that the instrument described by Wylie et al.\textsuperscript{11} could transfer the references from the models to the operation. The application of current and future computer graphics systems to the planning procedure could be a major advancement, but it presupposes the ability to achieve a strict coherence between the planning and the immediate surgical results.

In 1996, Manna and Berger\textsuperscript{17} described a new method of applying internal reference points to control the maxillary repositioning, this technique was based on the placement of 1.7 mm miniscrew in stable points in each lateral piriform rim area, superior to the osteotomy line. The distance is recorded to a convenient reference such as incisal edge, an orthodontic bracket or arch wire. The measurement is compared with the planned surgical movement before and after down fracture to determine the correct position for plating.

Masui et al.\textsuperscript{18} described a modification of the face bow system that was first introduced by Neubert et al.\textsuperscript{12} The new system comprised a modified face bow transfer and the use of occlusal plane indicator. They stated that when the vertical dimension requires a significant alteration, a high incidence of error occurs due to possible error in the centric relation guidance. They believe that the face bow has an advantage of reproducibility, not relying on mandibular position. Their face bow transfer method excluded an intermediate occlusal splint and is, therefore, free from error due to the mandibular position.

Scarborough et al.\textsuperscript{19} investigated the reproducibility of the external reference points, particularly Kirschner pins (K-wire), placed in the region of the nasion. The purpose of their study was to measure the shortest distance from the nasion to the anterior cranial fossa and from the nasion to the frontal sinus. These measurements were used to establish anatomic guidelines governing safe placement of external reference point pins. In their study, 27 cadaver heads were sectioned in the midsagittal plane for gross study. Using a Boley gauge (a calliper-type gauge graduated in millimetres used to measure the thickness of various dental materials), two specific measures were obtained: firstly the distance from deepest depression of nasion to the most anterior and inferior projection of the anterior cranial fossa, and secondly the distance from nasion to the most inferior aspect of the frontal sinus. All measurements were made in the midsagittal plane. They concluded that the use of such reference points is useful for the improvement of the accuracy of maxillary vertical repositioning. Although no complications associated with this technique have been reported, there is a potential for injury to the anterior cranial fossa or frontal sinus. The average distance from nasion to anterior cranial fossa was 16.9 mm (range 13.0–20.0 mm) and the smallest
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distance, 13.0 mm, was seen in two specimens. The average distance from nasion to the frontal sinus was 6.2 mm (range 2.0–10.0 mm) and the smallest distance, 2.0 mm, was seen in three specimens. Based on their findings they recommended the following: (1) place the pin to a depth of no more than 8 mm into bone, (2) place pin 5–10 mm inferior to soft tissue nasion and (3) place pin in an antero–superior to postero–inferior direction (i.e. roughly perpendicular to the nasal dorsum). When these anatomic guidelines are followed, one would expect minimal morbidity associated with the placement of external reference point pins.

Schwestka et al.20 investigated the three-dimensional repositioning of the maxilla during orthognathic surgery. Twenty patients were included in a study by using a three-dimensional double splint method combined with a surgical face bow; the position of the maxilla before and after the surgery was analysed. The aim of this study was to investigate the practical application of the model repositioning instrument and the three-dimensional double splint method for orthognathic surgical treatment with condylar position control. As a precondition for the application, the models must be in exact centric relation in the articulator for model surgery and the centric relation of the condyles must be preserved in centric relation throughout the actual surgery. The results of this 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 position of the maxillary complex. They found also that this approach is less time-consuming than other methods. In addition, the stability of achieved results was found to be high. They stated in their study that by this method, it is possible to achieve intraoperative repositioning of the maxilla with an accuracy of ±1 mm in the sagittal and horizontal plane.

The reproducibility of the inferior medial canthus as an external reference point for the positioning of the maxillary complex in orthognathic surgery was also investigated. Stefanova and Stella21 used the medial canthus as an external reference point to control the vertical dimension in orthognathic surgery, they included 10 patients with class II malocclusion and anterior open bite, and no facial asymmetry patients were included. Their method was based on the measurement of the distance from the inferior medial canthus to the maxillary orthodontic arch wire on the central incisors by using a large caliper. The results of their study indicated that in seven of 10 patients, the maxillary vertical dimension was the same as predicted. Based on the results from this study, the authors argued that the medial canthus provides a predictable and stable external reference point to assist the control of vertical positioning of the maxilla, there was no attempt in this study to analyse the position of the maxilla in antero–posterior and horizontal planes.

The defect of the previous study in terms of improper control of the maxillary movements in horizontal plane was covered in the same year and by the same authors. Stefanova and Stella22 used intermediate splint to transfer all the movements, except the vertical, from the model surgery to the patient intraoperatively. The results of their study showed that in two patients out of 10 there were some discrepancies but less than 2 mm, in the other eight patients, there was no difference between the predicted and the achieved position of the maxilla in all planes, except the vertical, which was controlled by external reference points. They concluded that the use of intermediate splint in combination with external reference point can accurately transfer the maxillary movement from the model surgery to the operation.

An actual three-dimensional complete system of model surgery and navigation was introduced by Gert Santler23 (three-dimensional computerised operation simulation and model operation system, Austria). This system has many components, the three-dimensional model planning table, the transferring devices and a software for the analysis of the cephalograms. All these components were especially designed for this system. The analysis and transferring of the model surgery to the operating theatre requires special training and skills on this system. The author believes that the mechanical navigation method described in his study is able to lead the maxilla to the pre-planned position, gives higher accuracy and enables the surgeon to cross-check the position of the maxilla following the osteosynthesis.

A study by Renzi et al.24 on patients with maxillo-mandibular asymmetries aimed at a simple, non-invasive intraoperative technique that is useful for the repositioning of the maxilla accurately and with more stability. They used the inferior border of the infraorbital nerve and the neck of maxillary canine and first molar tooth in both sides of the face as reference points. The distance between the points was measured using a caliper. They mentioned that the vertical repositioning of the maxilla in facial asymmetry patients must be assessed intraoperatively to ensure the absolute precision of the surgical restoration and the right degree of surgical correction.

They concluded that the technique described in their study permits careful evaluation of the vertical dimension of maxilla during Le Fort I osteotomy and therefore, allows the surgeon to eventually correct the planning from model surgery and it is ideal for cases with obvious facial asymmetry and proved to be simple and non-invasive.

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All authors contributed to the conception, design, and preparation of the manuscript and the presentation of the manuscript at the final manuscript. All authors abide by the Association for Medical Ethics (AME) ethical rules of disclosure.
The difference between model surgery movement and the actual surgical movement in the horizontal, vertical and transverse directions was evaluated. Kwon et al. used a face bow-bitefork combination system and intermediate splints and three-dimensional coordinates in the dental casts and cephalograms. The results of their study showed that the surgical outcome was different from the planned movements by more than 2 mm in more than 45% of the measured coordinate values. They concluded that although all patients were satisfied with their postsurgical appearance and occlusion, the results showed that further improvement is required in the maxillary positioning systems, mainly the posterior maxillary position. As the error could occur in any stage of the maxillary osteotomy, there is a need for constant interactive visualization and positional confirmation of the repositioned maxilla in every step of the procedure.

Mitsuyoshi et al. investigated the surgical accuracy of two external reference points when repositioning the osteotomized maxilla. They concluded that the external reference point placed into the bone was a more reliable method of positioning the maxilla in the vertical dimension than a point marked on the skin. Their conclusion could be explained by the fact that the skin is more mobile and has a degree of elasticity thus not a stable reference compared with bone.

Gill et al. described a new technique to control the vertical position of the maxilla in maxillary or bimaxillary surgery. Their basic philosophy in the new technique was to use the mandibular tooth while the two jaws were in occlusion. They believe that this technique for maxillary repositioning during two-jaw surgery proved to be effective and predictable, with strong agreement between predictive tracings, model surgery and postoperative results.

In 2011, José Nazareno Gil et al. again emphasized on the accurate reproducibility of the medial canthus as an ideal external reference point for the relocation and positioning of the maxilla in single or double jaw surgery.

**Conclusion**

There was agreement between different studies that the use of external reference points for the control of vertical dimension of the osteotomized maxilla is more reproducible and accurate than the internal ones. Various external reference points have been suggested; most of them used the nasion. Other studies used the inferior medial canthus bone mark on the forehead or glabella, the use of each had certain limitations and disadvantages. On the other hand, the use of internal references proved to be of less reproducibility and accuracy.

Since the early years of practicing orthognathic surgery, it is obvious that there is no single method that is absolutely reproducible in relocating the maxillary position in all directions. This fact emphasizes the need of developing a new non-invasive three-dimensional technique to intraoperatively control the maxillary movements and thus to reduce the overall error rate and achieve better results.

**References**
