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A Validation of Two Orthognathic Model Surgery Techniques

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Abstract. *In order to create an evidence-based orthognathic surgery planning protocol, an investigation of two popular model surgery techniques, the Lockwood keyspacer and the Eastman anatomically-orientated system was carried. This determined (a) the accuracy of positioning of the maxillary cast according to the prescribed treatment plan and (b) the relocation of the maxilla after a simulated Le Fort I down fracture osteotomy using the intermediate wafer as a guide. Fifteen patients—five Class II division 1, five Class II division 2, and five Class III—were included in the study. All the measurements were taken with Erickson's vertically mounted electronic calliper and variations from the treatment plan were analysed.*

The mean model surgery positioning errors ± SD (mm) were: (i) vertical plane—Lockwood –0·8 ± 1·6 and Eastman 0·00 ± 1·0 (P = 0·0001); (ii) anteroposterior plane—Lockwood 1·2 ± 1·8 and Eastman –0·1± 1·4 (P = 0·05); and (iii) transverse plane—Lockwood 0·9 ± 0·9 and Eastman 1·0 ± 0·9 (P = 0·34).

After the simulated osteotomy, the mean errors ± SD were: (i) vertical plane—Lockwood –0·5 ± 1·5 and Eastman 0·3 ± 1·1 (P = 0·001); (ii) in anteroposterior plane—Lockwood 0·8 ± 2·0 and Eastman 0·7 ± 1·0 (P = 0·89); and (iii) transverse plane—Lockwood 0·8 ± 0·6 and Eastman 0·7 ± 0·5 (P = 0·83).

The Eastman technique was relatively better especially in the vertical plane. The variations from the treatment plan were on the whole anatomically small, but in some cases could be clinically significant.

Index words: Model surgery errors, Orthognathic work-up, Simulated osteotomy errors.

Introduction

Surgery of the facial skeleton involves complex three dimensional movements based on a series of non-surgical and surgical procedures. Bimaxillary osteotomies, which change the occlusal level to improve function and enhance physical appearance, require to be planned preoperatively with the help of model surgery.

The early pioneers (Hullihen, 1849; Angle, 1903; Blair, 1907) relied heavily upon their clinical and surgical experience. Kostecka (1931) used unarticulated models to evaluate the pre- and post-operative occlusion for his ostectomy of the ascending rami. Subsequently, segments of the sectioned models were held together with wax and a German silver alloy splint was fabricated for fixation (Wassmund, 1935).

Custom made full scale plastic facsimiles of the mandibular rami to give an accurate three-dimensional (3D) representation of the ramus, condyles and intercondylar distance have also been suggested by Ellis *et al*. (1984), and Krenkle and Lixl (1991). It is claimed that this avoids condyle–meniscus–fossa problems at the time of screw fixation during the operation. However, replication of the cortical plates cannot be predicted with accuracy especially if the sagittal split of the ramus does not go as planned. Heggie (1987) challenged the accuracy of model surgery and suggested the use of a calibrator (modified Vernier calliper) to assess the maxillary position during surgery. The calibrator registers the distance between the nasion, an arbitrary point on the nose and the midline incisor tip. Contrary to established practice, Lindorf and Steinhauser (1978), and Cottrell and Wolford (1994) suggested altering the sequence of bimaxillary model surgery planning and operative procedure. They proposed that in cases of a large mandibular advancement, if the thin-walled maxilla is repositioned first, then a maxillary shift may occur whilst the maxillomandibular fixation is applied. They therefore performed the mandibular surgery first using cephalometric tracings to predict the postoperative position. The mandible is then stabilized with rigid fixation before placing the maxilla into an ideal occlusion.

However, the use of an anatomical articulator with a facebow transfer for bimaxillary osteotomies is essential to achieve accuracy of the maxillary position in space and its relationship to the optimum functional centric occlusion (Hohl, 1978; Bamber and Harris, 1995).

The diagnostic information gained from preoperative clinical and radiographic assessment and model analysis is integrated to establish a treatment plan. This treatment plan is expressed in the model surgery, and the simulated post-operative model relationships are used to fabricate the intermediate and final occlusal wafers. These wafers are

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an essential means of transferring the treatment plan into an accurate surgical procedure. However, there is uncertainty concerning the accuracy of model surgery and in particular the difference between the popular Lockwood keyspacer system (Lockwood, 1974) and the Eastman anatomically-orientated technique (Anwar and Harris, 1990). As small discrepancies can have a significant effect on outcome, it seemed essential to examine this stage of the orthognathic planning process to help create an evidence-based system.

The Lockwood keyspacer system and the Eastman anatomically-orientated model surgery technique are the most widely used techniques in this country. A review by telephone of 60 Oral and Maxillofacial Surgery departments revealed; 13 used the modified Lockwood method, six anatomically-orientated models, four used unidentified techniques, 10 did not use any model surgery, and the remainder (27) did not disclose their technique. Both techniques allow movement of the maxillary and mandibular casts in three spatial planes within the articulator, analogous to the surgical movement of the jaws within the facial skeleton. The Lockwood Keyspacer system incorporates thin plaster or rarely plastic keyspacers (Peretta and Caruso, 1983) at the interface between the upper and lower models, and the articulator plaster mounting assembly. These plaster inserts are usually 7 mm thick and follow the shape of a dental model base. They are held in place with elastics, Esplits plastic 'locks' or sometimes with magnets. Since Lockwood described the technique using casts mounted on a plane line hinge articulator, the technique has been enhanced by using a facebow registration and an anatomical articulator Figure 1a).

The Eastman anatomically-orientated model surgery technique essentially advocates the use of a facebow recording with a supine centric relation record and a semi-adjustable articulator. Horizontal and vertical reference lines are drawn on the mounting plaster to register the pre-operative position of the maxillary and mandibular segments (Figure 1b). Vertical movements are measured between the A line and the cusp reference points, VM = mesial buccal cusp of the last molar tooth, VB = the buccal cusp of a premolar, VC = the canine cusp and VF = the inter-incisor midline at the crown tip if the teeth or the maxilla are asymmetrically rotated the most anterior point at the incisor edge is used for VF. Anteroposterior movements are measured between VF and the articulator pin. The transverse relationship is visually checked using the vertically inscribed lines on the models. The planned movement is then carried out and the segments are reassembled in the postoperative position using sticky wax. If any late adjustments are necessary, the wax can be softened, and the maxillary or mandibular segments repositioned.

We believe the key movement in clinical planning and surgery is the positioning of the maxilla. There is an undoubted error when this is determined by the intermediate wafer based on the rotation of the supine anaesthetized condyle axis. This error represents the difference between the conscious upright centric occlusion or centric relation and the supine anaesthetized centric relation, which is described elsewhere (Bamber *et al*., 1999). This maxillary position error is largely masked or compensated for by the final wafer relating the osteotomized mandible to the maxilla once it has been fixed by bone plates. For this reason, the investigation was designed to validate the accuracy of two popular model surgery techniques in positioning the maxilla.

Aims of the Study

Aims of this investigation were to compare the Lockwood Keyspacer System and the Eastman anatomically-orientated model surgery technique for (a) the accuracy of the maxillary cast position according to the prescribed treatment plan and (b) the relocation of the maxilla after a simulated Le Fort I down fracture osteotomy using the intermediate wafer as a guide, in three skeletal groups.

Patients and Methods

Fifteen osteotomy patients (eight male and seven female; five Class II division 1, five Class II division 2, and five Class III, including one Class III anterior open bite, were included in this investigation. All the patients had bimaxillary osteotomies with a one piece Le Fort I procedure except one, who had a Le Fort I down fracture and an anterior segmental procedure with a midline split. The treatment plan was agreed by the surgeon and orthodontist.

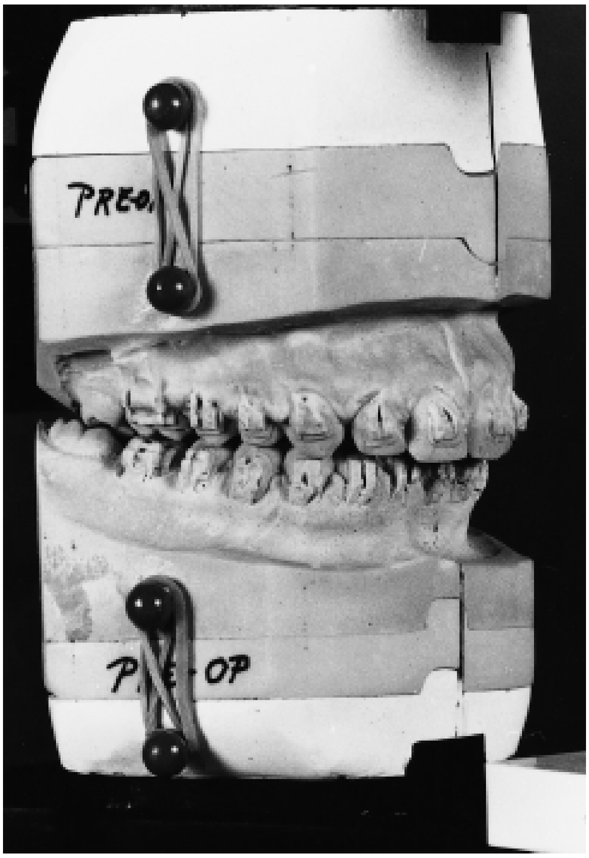
Upper and lower impressions, a facebow registration, a facial midline recording, an occlusal record and clinical measurements, following a standard orthognathic protocol (Bamber, 1995; Bamber *et al* 1996, 1999), were recorded for each patient. The impressions were cast in class two dental stone and the models triplicated.

One set of models was anatomically mounted and retained for the mock surgery (Figure 1c). The remaining two sets were mounted for the Lockwood and the Eastman model surgery technique. Although the original Lockwood Keyspacer technique description does not use a facebow registration the Denar facebow and anatomical articulator (Denar Corporation, USA) were used for both techniques to ensure a common starting point. Baseline measurements of both mounted models were taken and the model surgery carried out according to the treatment plan. The models were transferred to the Erickson measuring apparatus and any variations in the maxillary position from the treatment plan were computed (see Figure 2).

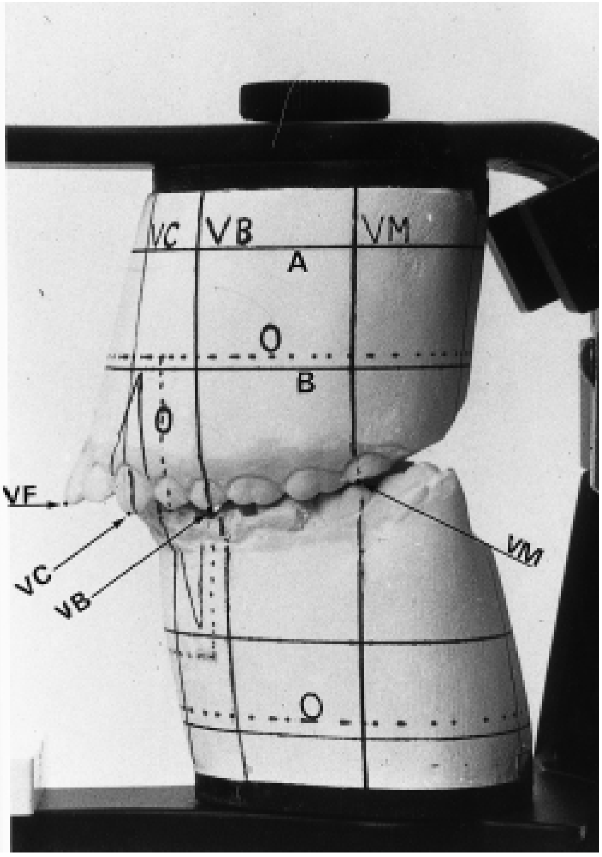
An intermediate occlusal wafer (Figure 3a,b) was fabricated for each patient for both techniques using high impact acrylic (Associated Dental Products Ltd., UK).

A simulated surgical procedure was then carried out on the patient's anatomically articulated preoperative models (Figure 1c) in the laboratory. After recording the pre-operative position, the maxilla was sectioned at the Le Fort I level, just above the apices of the maxillary teeth, with an electric band saw and an appropriate amount of dental plaster removed from above the osteotomy line to allow for the planned movements of the maxilla. Then using each intermediate wafer in turn (Lockwood versus Eastman), in a consecutive manner, the maxilla was repositioned and fixed with model cement. The mounted maxillary models were again transferred to the measuring apparatus and errors after the simulated surgery were computed.

The Erickson's model surgery platform employs a screw base plate on the model block identical to the articulator so that the models can be mounted on it with a mounting screw and indexing pins in a reproducible manner (Ellis,



(a)



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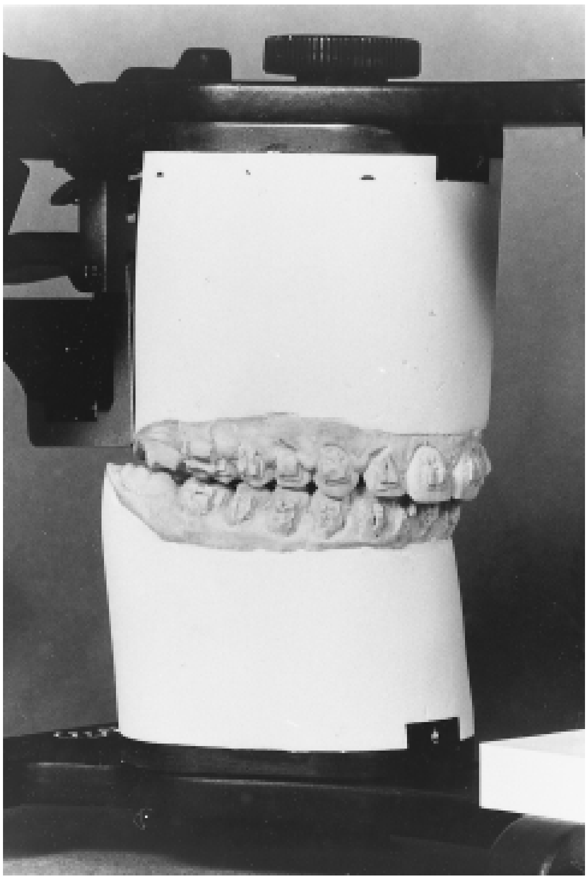


(c)

FIG. 1 Models mounted in preoperative position on the Denar articulator, using the Slidematic facebow and centric occlusal records. (a) The Lockwood keyspacer model surgery technique with preoperative keyspacers. (b) The Eastman anatomically-orientated model surgery technique in pre-operative positions showing the cusp reference points (as pointed out with arrows) used for pre- and post-operative measurements for this investigation. VM = mesial buccal cusp of the last molar tooth; VB = the buccal cusp of a premolar; VC = the canine cusp; and VF = the interincisor midline at the crown tip, unless the teeth or the maxilla are asymmetrically rotated in which case the most anterior point at the incisor edge is used. It usually coincides with the facial midline. Note: the A and B base lines, O = osteotomy line and the vertical reference lines. (c) The 'model patient' prior to surgery.

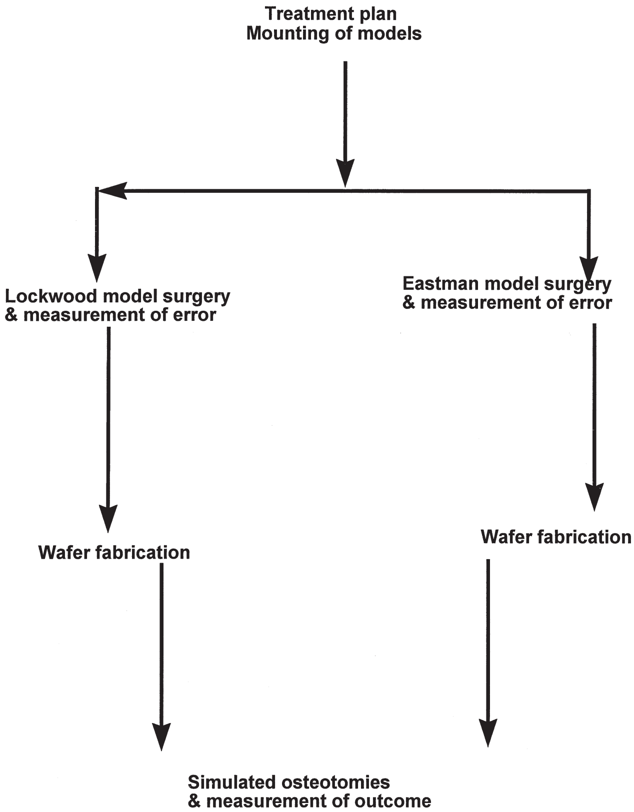


FIG. 2 Flow chart showing methods and stages of the investigation.

1990; Figure 3c). This was used to measure changes in the three planes, its metric electronic calliper gives a digital display read out with an accuracy of 0·01 mm, (Great Lakes Orthodontic Products Ltd., Tonawanda, New York, USA).

The pre- and post-operative positions of the maxillary model were recorded in the vertical, anteroposterior, and transverse (mediolateral) planes, at the following reference points; VM, VB, VC, and VF described earlier (Figure1b). These reference points provide seven measurements per case, and a potential total of 105 pre- and post-operative measurements, except with differential impaction or rotating movements where only VF and VM were used.

The actual movements achieved in three planes by each method, after the model and the simulated surgery, were calculated and compared with the patient's original treatment plan.

Results

Model surgery error

Descriptive statistics (mean ± SD) of the differences between the planned and actual model surgery movements are presented in Table 1a,b, where $P < 0.05$ is significant. The mean absolute errors of model surgery movements ignoring the direction can be seen graphically in Figure 4a.

There was no difference in error when the skeletal groups were compared with each other for both model surgery techniques apart from the Lockwood vertical movements: Class II division 1 versus Class II division 2, $P = 0.00$; Class II division 1 versus Class III, $P = 0.01$; Class II division 2 versus Class III, $P = 0.001$.

Simulated osteotomy error

The mean errors of the simulated osteotomies are presented in Table 2 and a graphical presentation of the mean absolute values of the errors in Figure 4b.

The maximum variations in errors were: (i) the vertical plane—Lockwood –3·8 mm and Eastman 2·8mm; (ii) the anteroposterior plane—Lockwood –3·2 mm and Eastman 1·8 mm; and (iii) the mediolateral plane—Lockwood 2·9 mm and Eastman 2·0 mm, all of which would be clinically significant.

TABLE 1 (a) *Shows the magnitude and direction of error (mm) following model surgery. The minimum and maximum errors are noted for both techniques. A minus sign (–) indicates that the movement was less than the plan*

	Mean	SD	Min	Max	*n*	*P* value
Eastman vertical plane	0·0	1·0	–2·3	2·4	94	0·0001
Lockwood vertical plane	–0·8	1·6	–4·8	2·6	94	
Eastman AP plane	–0·1	1·4	–2·9	1·6	14	0·05
Lockwood AP plane	1·2	1·8	–3·6	3·6	14	
Eastman ML plane	1·0	0·9	0·0	2·1	84	0·34
Lockwood ML plane	0·9	0·9	0·01	2·0	84	

Key: Eastman = Eastman technique, Lockwood = Lockwood technique, AP = anteroposterior, ML = mediolateral (transverse), *n* = number of measurements. *P* value = paired *t*-test, $P < 0.05$ is significant.

TABLE 1 (b) *Shows the mean (mm), standard deviation, minimum and maximum model surgery errors for each skeletal group. There were five patients per group*

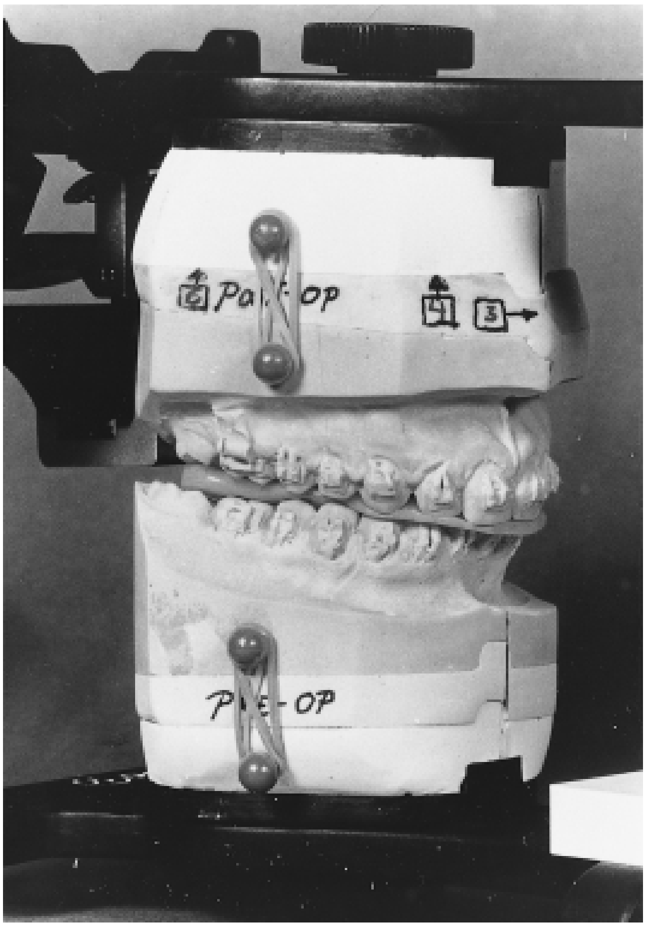
		Mean	SD	Min.	Max.	*n*
Eastman vertical	Class II division 1	0·2	1·0	–1·8	1·7	30
	Class II division 2	0·02	1·1	–2·3	2·0	33
	Class III	0·1	0·7	–1·8	2·4	31
Lockwood vertical	Cl.II division1	–0·01	1·3	–3·3	2·6	30
	Class II division 2	–1·6	1·4	–4·8	0·8	33
	Class III	–0·7	1·5	–4·2	2·5	31
Eastman AP	Class II division 1	0·5	0·5	–0·1	1·1	4
	Class II division 2	–0·1	1·2	–1·7	1·3	5
	Class III	–0·6	1·9	–2·9	1·6	5
Lockwood AP	Class II division 1	1·9	0·8	1·1	2·9	4
	Class II division 2	1·4	1·8	–1·1	3·6	5
	Class III	0·4	2·4	–3·6	2·1	5

Key: Eastman = Eastman technique, Lockwood = Lockwood technique, AP = anteroposterior plane, N = number of measurements.

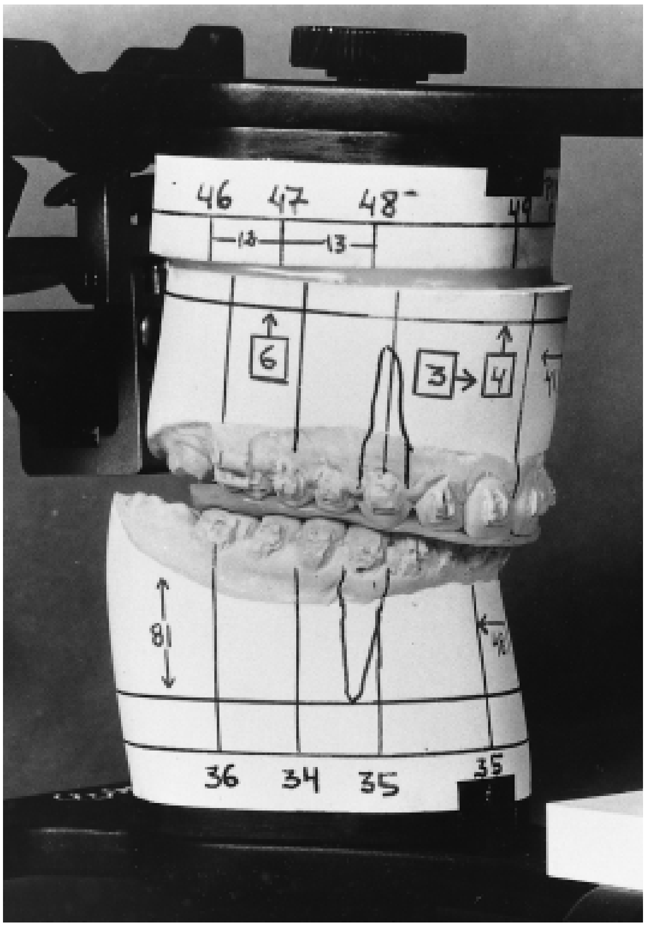
TABLE 2 *Shows the magnitude and direction of error (mm) following simulated osteotomy for both techniques. Results of the student's t-test, and Lockwood versus Eastman technique*

	Mean	SD	Min	Max	*n*	*P* value
Eastman vertical	0·3	1·1	–1·3	2·8	93	0·001
Lockwood vertical	–0·5	1·5	–3·8	2·6	93	
Eastman AP	0·7	1·0	–1·6	1·8	14	0·89
Lockwood AP	0·8	2·0	–3·2	3·1	14	
Eastman ML	0·7	0·5	0·02	2·0	84	0·83
Lockwood ML	0·8	0·6	0·02	2·9	84	

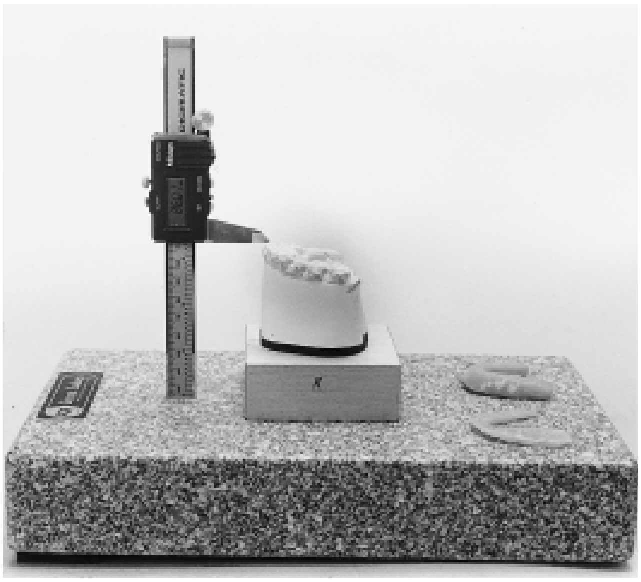
Key: Eastman = Eastman technique, Lockwood = Lockwood technique, AP = anteroposterior, ML = mediolateral (transverse), *n*= number of measurements. $P < 0.05$ is significant.



(a)



(b)



(c)

FIG. 3 Both model surgery techniques with intermediate occlusal wafers. (a) The Lockwood technique with its maxillary post-operative keyspacer. (b) The Eastman technique showing the repositioned maxillary model fixed to the plaster base. (c) The Erickson's Model Surgery Platform and the Model Block with a vertically mounted digital Vernier gauge. This figure shows the method of measuring the movements of the maxillary incisors in the vertical plane. Note the calliper tip in close contacts with the incisal edge.

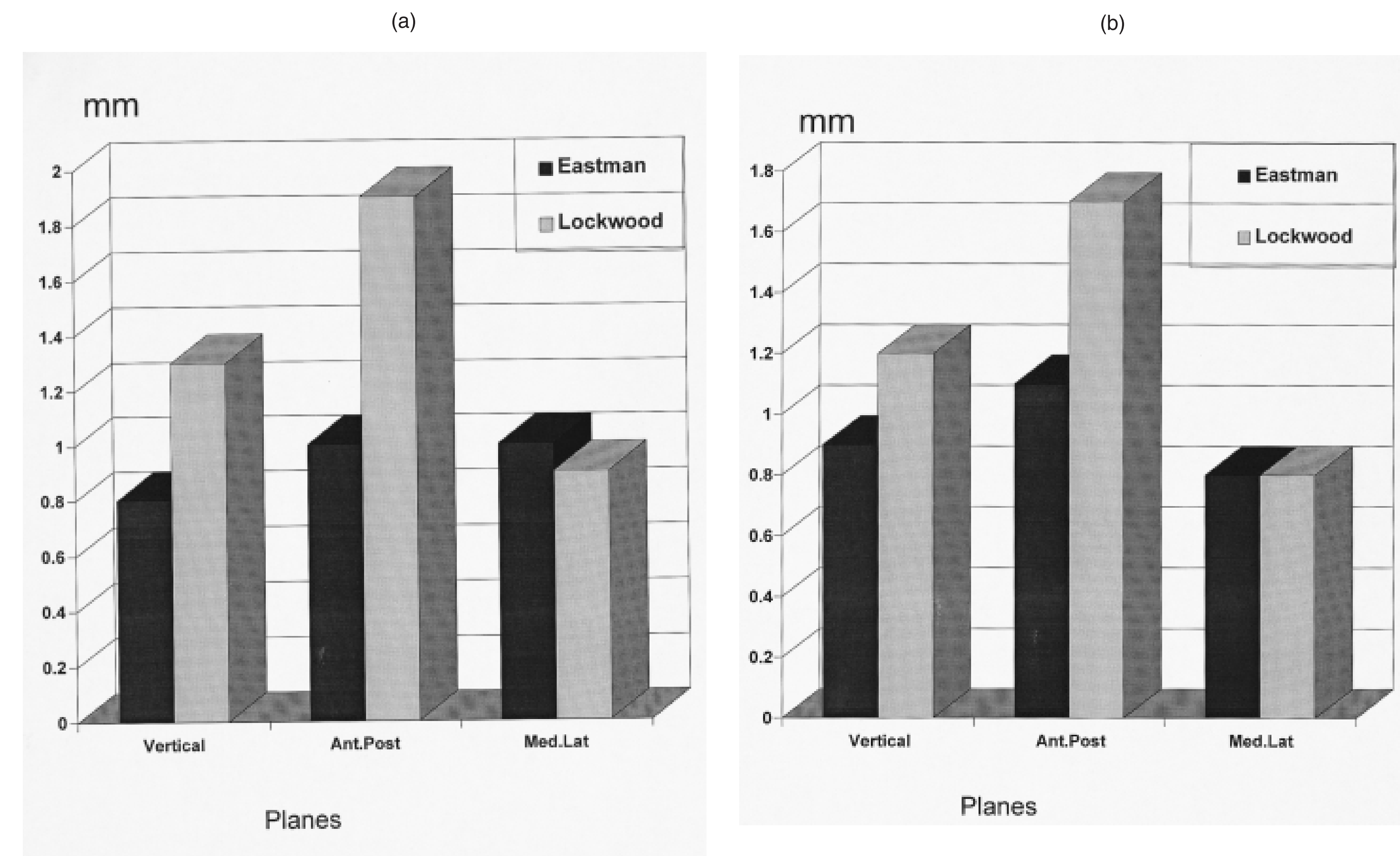


FIG. 4 (a) Mean absolute errors after the model surgery ignoring the direction of the error. (b) Mean absolute errors as measured on the 'model patient' after simulated surgery ignoring the direction of the errors.

Discussion

In the vertical plane the Lockwood technique had an overall mean impaction that was less than that planned. This measured up to 5 mm, whereas the Eastman technique showed no bias in either direction.

In the anteroposterior plane, the Eastman technique was also better than the Lockwood, whereas in the mediolateral (transverse) plane there was no difference.

The results of each skeletal group, presented in Table 1b, showed no significant difference between skeletal types using the Eastman technique ($P > 0{\cdot}05$). However, in the Lockwood technique differences in the vertical plane, between the three skeletal groups, were significant ($P < 0{\cdot}05$). The Class II division 2 group had the most errors in the vertical plane, with the impaction being generally less than planned.

Two-way analyses of variance showed that differences between the patients in the vertical and anteroposterior plane were highly significant ($P < 0{\cdot}001$) after the model surgery. These differences were not related to skeletal type, but to the amount of movement; the larger the movement the greater the error.

These results show that both the Lockwood and the Eastman model surgery techniques have inherent inaccuracies with both deviating from the treatment plan. However, as previously stated, the Eastman technique was significantly better than the Lockwood technique in the vertical plane.

Errors were higher in those cases where the planned movements were high (6–10 mm), and also where there was a planned differential maxillary impaction between the anterior and the posterior segments. These findings are similar to those of Ellis (1990), Cottrell and Wolford (1994), and Bamber and Harris (1995). Each technique had its disadvantages, for example, mounting the models with the facebow registration was troublesome when using the Lockwood technique for patients with a steep occlusal-Frankfort plane angle and requiring large vertical movements. This is because the Lockwood's plaster keyspacers needed to be at least 10 mm thick on top of the model base thickness, so the mounting space within the articulator became inadequate. This problem was encountered in two cases, resulting in the maxillary model base requiring trimming to the minimum thickness. The Angle trimmed edges that serve as reference points for the measurement of the horizontal movements, which are the essence of the Lockwood technique, were therefore lost. We also found that the prescribed keyspacer thickness of 7 mm in the Lockwood technique was inadequate in cases requiring large maxillary impactions.

The Lockwood technique has the theoretical advantage over the Eastman technique of having Angle trimmed parallel sides, which reveals undesired transverse shifts of the maxillary model. The Lockwood technique also does not require a second set of mounted models for the final post-surgical relationship.

Keyspacers were fabricated and the models mounted using plaster mixed with anti-expansion solutions, but even so some degree of dimensional change due to plaster expansion could possibly affect the accuracy of the model surgery in the Lockwood technique. This is not a problem with the Eastman method. In both techniques, segments were held in the post-operative position with sticky wax, which contracts on cooling and thus may have altered the final position of the jaws or segments, introducing some dimensional inaccuracies. This may be the reason for relatively higher error in the vertical plane.

The errors after the simulated surgery were not significantly greater than the model surgery errors, regardless of whether the Lockwood or Eastman wafer was used. In fact, in some cases the simulated osteotomy errors were less than the model surgery error. The direction of the errors was unpredictable, and in some cases the model surgery errors and the simulated surgery errors compensated each other, and resulted in less overall error, as might occur in clinical practice.

Ellis (1990) has also reported statistically significant model surgery errors (absolute values), mean (mm) ± SD: in the anteroposterior plane, $1{\cdot}2 \pm 0{\cdot}9$; the vertical plane, $1{\cdot}1 \pm 1{\cdot}2$; and mediolateral plane, $1{\cdot}9 \pm 0{\cdot}7$. These errors are much higher than the Eastman technique, but less than the Lockwood, as recorded by this study.

It is obvious from the results of previous clinical studies (Pospisil, 1987; Sarver and Weissman, 1991; McCance *et al.*, 1992) that, despite inaccuracies, model surgery planning is essential for operative reproducibility of the treatment plan.

Conclusions

This investigation showed that neither of the two model surgery techniques could carry out the prescribed treatment plan with absolute accuracy. The Eastman technique was relatively better than Lockwood in the vertical and the anteroposterior plane, although the mean differences were small, e.g. less than 1 mm.

The Lockwood technique, in its original form with a simple hinge articulator, is useful for single jaw and segmental surgical procedures, but in bimaxillary osteotomies requiring large complex movements, it was inadequate and unable to record the vertical facial changes accurately. By incorporating a facebow registration and an anatomical articulator in the Lockwood technique for bimaxillary osteotomies the technique is substantially improved. However, for large vertical movements it is inappropriate and does not fit easily within the vertical constraints of the articulator, especially in cases with a steep occlusal-Frankfort plane angle.

Some of the variations from the treatment plan were statistically significant, although anatomically small, but the vertical errors could be clinically significant, i.e. up to 5 mm in the vertical plane with the Lockwood technique. If the planning, surgical, and fixation errors are all within the condyle-meniscus-fossa envelope of adaptation, the anticipated centric occlusion can be achieved. However, if these errors summate, the outcome will result in a postoperative malocclusion. Hence, the need to ensure each stage in the orthognathic process is as accurate as possible. For this reason we do not recommend the modified Lockwood technique.

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