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Comparison of three facebow/semi-adjustable articulator systems for planning orthognathic surgery

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SUMMARY. **Our aim was to measure the steepness of the occlusal plane produced by three different semi-adjustable articulators: the *Dentatus Type ARL, Denar MkII*, and the *Whipmix Quickmount 8800*, and to assess the influence of possible systematic errors in positioning of study casts on articulators that are used to plan orthognathic surgery. Twenty patients (10 skeletal class II, and 10 skeletal class III) who were having pre-surgical orthodontics at Liverpool University Dental Hospital were studied. The measurement of the steepness of the occlusal plane was taken as the angle between the facebow bite-fork and the horizontal arm of the articulator. This was compared with the angle of the maxillary occlusal plane to the Frankfort plane as measured on lateral cephalometry (the gold standard). The *Whipmix* was closest to the gold standard as it flattened the occlusal plane by only 2° (P<0.05). The results of the *Denar* and *Dentatus* differed significantly from those of the cephalogram as they flattened the occlusal plane by 5° and 6.5° (P<0.01), respectively. Clinicians are encouraged to verify the steepness of the occlusal plane on mounted study casts before the technician makes the model.**

INTRODUCTION

Articulators are of interest to the joint maxillofacial and orthodontic team as they facilitate the planning of combined orthodontic treatment and orthognathic surgery.

Facebows were developed in conjunction with articulators to relate the maxillary arch to the axis of the condylar hinge in three planes of space. A facebow is a mechanical device which uses tripod localization by two posterior references approximating each of the temporomandibular joints, and an anterior reference point to relate the maxillary cast vertically to the selected horizontal reference plane. The most commonly used posterior reference is the Beyron point, a point 13 mm anterior to the most posterior angle of the tragus of the ear on a line from the centre of the tragus to the outer canthus of the eye[1] and the orbitale is used for the anterior reference, resulting in the 'axis-orbital' horizontal plane.

Most publications about facebow design have focused on the validity of the chosen posterior and anterior reference points. Arbitrary posterior reference points are of sufficient accuracy for most cases,[1–4] and only rarely has their routine use been criticized. Schallhorn concluded that arbitrary posterior references are accurate within 5 mm radius of the kinematic hinge axis for 95% of patients with normal jaw relationships. This conclusion leads us to question: whether the arbitrary centre should still be advocated in patients with adverse jaw relationships (those having facial abnormalities corrected).

The selection of an anterior reference point governs the horizontal plane of reference, and in turn, the steepness of the occlusal plane that is reproduced by the articulator. Incorrect reproduction of the steepness of the occlusal plane affects both function and aesthetics. A change in the vertical position of the anterior reference point of about 6 mm altered the condylar guidance angle by about 9° and resulted in further changes to cuspal inclines and heights: such an increase in steepness of the occlusal plane would increase the risk of failure. Bailey and Nowlin measured the angle of the occlusal plane to the Frankfort horizontal on the *Hanau* articulator and compared this with lateral cephalometric films; they found a mean difference of 5°, which corresponds to a 70% error. Repeat facebow transfer procedures, on the same subjects, resulted in both good and poor reproducibility. The three dimensional accuracy of the position of the upper first molar was highly variable using four different *Hanau* facebows.

Planning orthognathic surgery by model surgery on a semi-adjustable articulator offers advantages over simpler instruments (Table 1).[11,12] Marko described circumstances under which a simple-hinge articulator would be considered 'adequate' and those under which a semi-adjustable type would be indicated (Table 2). An anatomical hinge-axis to incisor relationship, such as one produced by a semi-adjustable articulator, is necessary where mandibular autorotation is relied on during the operation. This is important in maxillary single-jaw surgery, when the occlusion of teeth with the repositioned maxilla requires mandibular autorotation, and in bimaxillary surgery when autorotation of the maxillo-mandibular complex complete with acrylic wafer helps to dictate the position of the maxilla before the mandibular osteotomy is completed. The mathematical difference between maxillary impactions of 5 mm planned on a

Table 1 – Areas of model surgery facilitated by a semi-adjustable articulator

Checking validity of planned bone cuts and magnitude of movements including autorotation of the mandible;
Practising the osteotomy cuts;
Assessing outcome in terms of dynamic occlusion and aesthetics;
Construction of intermediate and final interpositional acrylic wafers to check that surgical movements match planned movements.

simple-hinge articulator (such as the *Galetti*) as opposed to a semi-adjustable type (such as the *Hanau*) resulted in an antero-posterior error of 2 mm on the *Galetti* and 0.2 mm on the *Hanau*.[11]

Accuracy of model surgery, construction of splints[13–15] and the articulator systems (calliper platform,[16] reverse surgical sequencing[17]) have all been described previously. The most cited model surgery techniques are the '*Lockwood key-spacer system*'[18] and '*The Eastman Technique*'.[19] Bamber *et al.* (A comparative study of two orthognathic model surgery techniques. Paper presented at the British Society for Dental Research, 1996) compared the accuracy of these two techniques using duplicate casts of 15 patients with different malocclusions requiring Le Fort I osteotomy planned on the *Denar Mark II* articulator. They found neither technique to be absolutely accurate, but the Eastman technique was significantly better for vertical and anteroposterior movements.

Model surgery is subject to discrepancies; significant differences between planned and surgical jaw movements can result from the difference between the true and simulated centres of mandibular rotation as well as from the erroneous transfer of reference lines and points between model surgery and operation.[20] The centre of autorotation is likely to be posterior and inferior to the centre of the condyle,[21] and therefore autorotation is difficult to mimic on an articulator that rotates around its metallic condyle and not around a point posterior and inferior to it.

We aimed to investigate possible differences in anteroposterior steepness (cant of the occlusal plane) between three semi-adjustable articulators, whether differences in skeletal pattern have any influence on the steepness of the occlusal plane, and finally whether these differences affect the surgical planning for maxillary or mandibular osteotomies. Local ethics committee approval was given.

SUBJECTS AND METHODS

Patients who were to have orthognathic presurgical assessment were invited to participate in the clinical study at the Liverpool University Dental Hospital's department of orthodontics (Table 3). The inclusion criteria were patients who required correction of their skeletal class II or III malocclusion by osteotomy; either a recent lateral cephalometric radiography (at beginning or end of presurgical orthodontics) or the need for a future film for surgical planning and therefore no need for additional radiography and written consent.

Table 2 – Indications for types of articulator for various osteotomy procedures[11]

Simple-hinge adequate:
- Mandibular advancement, set-back, or subapical surgery;
- Maxillary subapical surgery (where no change in the vertical plane of space is proposed);
- Maxillary transverse expansion or contraction (*subject to the following constraints*):
  - Anterior and vertical orientation of the anterior maxilla is assessed first by cephalometric measurements;
  - Feasibility of mandibular autorotation is studied first by cephalometric measurements;
  - Maxillary occlusal plane is not canted appreciably;
  - Tripod occlusal stability exists between the maxillary and mandibular models (no large edentulous spaces will prevent proper model orientation).

Semi-adjustable indicated:
- When the case fails to satisfy any of the constraints listed above;
- Maxillary impaction and mandibular autorotation;
- Fabrication of an intermediate splint;
- To ensure coincidence of dental and facial midlines;
- Mandibulofacial asymmetries;
- When excursions of the proposed occlusion are to be studied.

Table 3 – Study sample group of patients before orthognathic procedures

Sex	No. of patients	Age (years)		Skeletal pattern	
		Mean	(SD)	Class II	Class III
Male	7	20.9	(6.7)	5	2
Female	13	19.5	(6.6)	5	8
Total	20	20.0	(6.5)	10	10

Patients who had already been operated on, had facial asymmetry, or who had inadequate clinical records were excluded. The sample was recruited from sequential patients taken from the waiting list for treatment, or from those attending orthognathic planning clinics at the end of presurgical orthodontics, and had, by definition, severe skeletal class II or III deformities.

The three facebows studied were the Denatus type ARL (Denatus International, Hagersten, Sweden), the Denar Mask II (Denar Corporation, Anaheim, California, USA), and the Whipmix Quickmount 8800 (Whipmix, Louisville, Kentucky, USA). Each facebow was registered in turn according to the manufacturer's instructions. The operator (AO'M) was trained in all three types by an experienced restorative dentist (AM) to ensure that his technique was correct. All records for each subject were completed on the same day by the same operator.

Each facebow was mounted on to its respective articulator, which was placed on an optically levelled platform. This was done by placing two bubble gauges at right angles to each other, ensuring that the articulator base (lower arm) and upper arm were parallel with the true horizontal. This allowed measurement of the maxillary occlusal plane angle by putting the

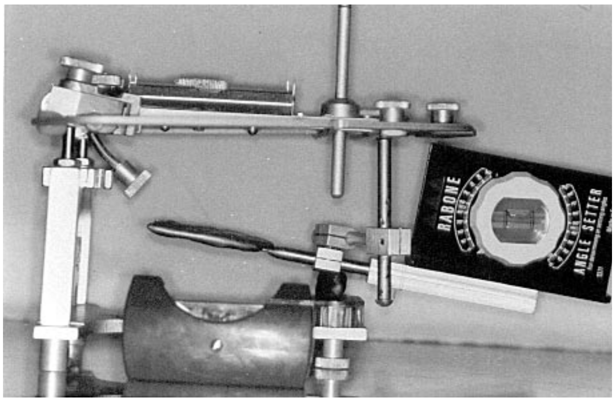

Fig. 1 – *Whipmix* facebow and articulator on levelled platform with *Rabone angle setter* measuring the steepness of the occlusal plane regulated by the bite-fork extension.

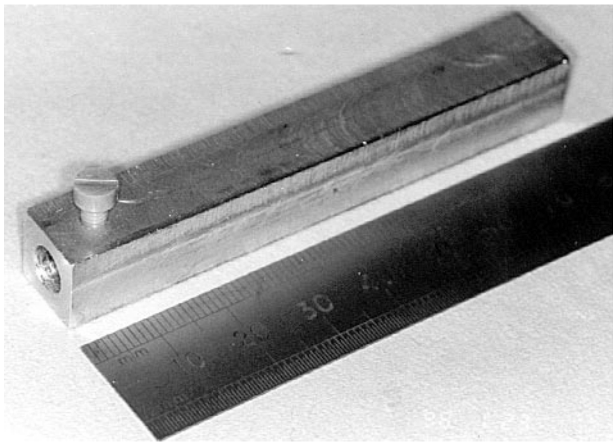

Fig. 2 – Photograph of the custom-made bite-fork extension with nylon fixing screw.

Rabone angle setter (Rabone, England) on a custom-made 80-mm extension to the bite-fork (Figs 1&2). This was made of 12 mm square aluminum with a centric core drilled to fit over the bite-forks as a sleeve with a line scored parallel with its longitudinal axis. The upper arm of the articulator was also levelled at true horizontal using a small spirit level.

Measurements

The angle between the bite-fork and the upper articulator arm was measured to indicate the steepness of the maxillary occlusal plane. The upper articulator arm was horizontal and therefore parallel to the Frankfort plane. The angle between the bite-fork extension and the upper articulator arm was measured with a *Robone angle setter* positioned on the extension. The angle setter is based on the principle of a bubble-gauge within a rotating core to an angular scale.

Cephalometric analysis

Cephalometric tracing done by hand on fine acetate sheets in a darkened room by the same operator who did the clinical study. The angle on the cephalogram that reproduced the angle measured clinically on the articulator was Frankfort plane to maxillary occlusal plane (Fp/MOP). The Frankfort plane is a line between the machine porion and orbitale, and the maxillary occlusal plane is between first molar mesiobuccal cusp and the incisor edge.

Statistical analysis

The significance of differences between measurements was assessed using the Statistical Package for the Social Sciences software (SPSS) on the University of Liverpool Unix system. Continuous data were analysed by the appropriate parametric test. Differences between groups were analysed by one-way analysis of variance (ANOVA).

Error of the method

A random selection of five out of the 20 cases had their measurements repeated to establish the SE of the method. This was done by removing the facebows from their articulators and re-mounting them 24 hours later to repeat readings. The cephalograms were also retraced for these subjects to test reproducibility.

RESULTS

Twenty patients were recruited to the study, 10 in each surgical category of skeletal class II and III (Table 3). The mean time lapse between the pre-orthodontic treatment radiography and collecting facebow records was 3.2 months (range 1–7) but the interval between commencement of orthodontic treatment and taking facebow records was one month.

The anteroposterior and vertical skeletal parameters are presented individually for skeletal classes II and III in Table 4. Most patients required bimaxillary procedures to correct their skeletal disproportion and malocclusion (Table 5). Only two patients could be treated by mandibular surgery alone.

The angle between occulusal plane measured from bite-fork extension to upper articulator arm was compared with the traced Frankfort plane to maxillary occlusal plane angle. The ‘gold standard’ was therefore the cephalometric angle, which for the group was 14.6° with a relatively large SD (Table 6).

Table 4 – Mean (SD) orthodontic and skeletal measurements (°) made on cephalograms (n = 10 in each group)

Angle	Skeletal II	Skeletal III
ANB	6 (2.9)	–4.6 (2.8)
FMPA	35.7 (9.9)	36.5 (7.4)
MMPA	32.1 (8.2)	28.8 (4.3)

Table 5 – Categories of operation by skeletal pattern (numbers of patients in each group)

Category	Skeletal II	Skeletal III
Maxilla only	1	1
Mandible only	2	0
Bimaxillary	7	9
Total	10	10

The mean angle for the *Whipmix* articulator group came closest to the gold standard, meaning that the *Whipmix* tended to position the maxillary occlusal plane almost 2° shallower than on the cephalogram. This was significantly different from the gold standard (P<0.05). The *Denar* and *Dentatus* angle means were similar to each other, but differed more from the gold standard. The effect of this was to reduce the steepness of the occlusal plane on these articulators more severely than the gold standard (5.2° for the *Denar* and 6.5° for the *Dentatus*).

It was necessary to investigate any influence that presurgical orthodontics may have had on the angle Fp/MOP, as six subjects had not started presurgical orthodontics. The patients were divided into two groups: the six who had not started presurgical orthodontics, mean Fp/MOP=12.1° (12.3) and the 14 who had completed their presurgical orthodontics, mean Fp/MOP=15.7° (6.9). An unpaired t test (t = –0.85), confirmed that this variable had no effect on the cephalometric measured gold standard.

We also investigated the influence of the anteroposterior and vertical skeletal patterns on steepness of the occlusal plane. There were no significant differences between patients in the skeletal class II and III categories in the Fp/MOP angle (unpaired t test). In terms of the vertical plane, the categorical division of 'low' 'medium' or 'high' skeletal pattern was applied to the angle Fp/MOP (Table 7). Of the 20 subjects, nine were in the 'medium' and 10 in the 'high'-angle categories, confirming that there was a tendency towards high angles in the sample. A one-way ANOVA showed that the high-angle category had a significantly higher Fp/MOP angle (P<0.05).

Overall, the *Whipmix* and *Denar* systems were similarly reproducible, the *Dentatus* being slightly less so.

DISCUSSION

The 20 subjects were evenly split between skeletal classes II and III. All subjects were preparing to undergo orthognathic surgery and so have extremes of the angle ANB, compared with the class I normal 2–4° range (Table 4). Most subjects tended to have increased vertical proportions with a predominance of high angle cases reflecting the genetic factors that contribute to this skeletal pattern in the Mersey region (Tables 4 and 7). When a patient has a 'high-angle' skeletal pattern, it is not surprising to find a relatively steep occlusal plane. This is consistent with the pattern of increasing divergence of facial planes in high angle cases that was described by Sassouni.[23]

The results shown in Table 5 indicate that most of the study sample required maxillary surgery, either alone or in combination with mandibular surgery. As highlighted in Table 2, semi-adjustable articulators are indicated in planning operations involving the maxilla, either as a single jaw or bimaxillary procedure. Clearly, the choice of articulator in these cases would be a key factor in minimizing a potential source of inaccuracy in elective procedures.

Our results showed that all three semi-adjustable articulators position the occlusal plane *less* steeply to the Frankfort plane than that measured on the cephalogram. The *Whipmix* was closest to the cephalogram, showing a mean difference of –1.9°, which was significantly different (P<0.05). The *Denar* and *Dentatus* flattened the occlusal plane more severely on the articulator (by 5.2° and 6.5°, respectively). The only previously published similar work that we know of found a mean error of greater than 5° for the *Hanau* articulator when the occlusal was compared with the Frankfort plane.[6] The *Whipmix* uses a nasion relator, unlike the *Dentatus* and *Denar*, which may account for its more accurate reproducibility of the occlusal plane.

Previous studies have suggested that articulators that use the axis-orbital or Frankfort plane as their horizontal reference will position the occlusal plane too steeply in the articulator.[22] Our results show an *opposite* mean effect on the occlusal plane. The earbow method for locating the posterior reference points used by the *Whipmix* and *Denar* is easier to do, and the greater reproducibility of these systems is in accordance with previous work.[4] The reproducibility of re-mounting the same facebow record was assessed for in this study to establish the error of the method but the reproducibility of repeated facebow recordings and cephalogram tracings was not.

The limitations of a lateral cephalogram image relate to comparison of three-dimensional objects with the two-dimensional cephalograph, and any mesiolateral cant of the maxillary occlusal plane is

Table 6 – Steepness of maxillary occlusal plane on articulator compared with cephalometric gold standard (Fp/MOP)

Type of articulator	Mean (SD) angle on articulator (°)	Mean (SD) cephalometric gold standard (Fp/MOP)	Paired t-test t	P	Mean (SD) difference between articulator and cephalometry
Whipmix	12.7 (6.4)	14.6 (8.7)	2.26	0.04	–1.9 (3.8)
Denar	9.4 (6.3)	14.6 (8.7)	5.06	<0.001	–5.2 (4.7)
Dentatus	8.1 (9.0)	14.6 (8.7)	6.03	<0.001	–6.5 (4.8)

Table 7 – Effect of vertical skeletal pattern on steepness of occlusal plane

Vertical skeletal pattern	No. of patients Skeletal II	Skeletal III	Mean Fp/MOP (°)
Low	1	0	9.0
Medium	5	4	9.6
High	4	6	19.8*
Total	10	10	14.6

* $P<0.05$.

not seen on the lateral cephalograph. None the less, the cephalometric gold standard fundamental to this study (Fp/MOP) is as reliable as many commonly accepted tracing angles, such as ANB. Cephalometric accuracy is more important in longitudinal than cross-sectional studies, particularly when data are used to indicate a therapeutic effect. That is not the case with this study and, as has been shown, the statistics for reliability are within an acceptable range. The machine as opposed to the anatomical porion was chosen for construction of the Frankfort plane because it identifies the landmark more accurately. Significant occlusal changes are unlikely to have occurred in the one month between the start of orthodontic treatment and taking the facebow record.

Our findings have clinical implications throughout dentistry, but we shall concentrate on the use of semi-adjustable articulators in orthognathic surgery. In an articulator, steeper occlusal planes present a practical difficulty because of the fixed vertical distance between the upper and lower articulator arms. Some manufactures have responded to this by providing an increased distance to cope with such an effect (the *Whipmix series 8800* provides an additional 1/2″ of space for mounting the upper cast, and is useful for patients with a steep plane of occlusion). Shallow occlusal planes present no such practical difficulties as the models fit into the space between the upper and lower articulator arms.

The critical question that relates to the choice of an articulator is: are semi-adjustable articulators of sufficient accuracy in orthognathic planning, or are they inadequate because they were designed using values derived from skeletal norms?

We have no conclusive evidence from this study to answer this question, but our results indicate the degree of inaccuracy likely to result in a typical orthognathic subject. Much has been written by prosthodontists about the effects of angular and linear variables on dynamic occlusion, but there is little about the relevance of these effects in orthognathic surgery. The need to achieve dynamic occlusal harmony after repositioning maxillary segments and mandibular autorotation has been emphasized.[24]

During model surgery, planning errors may occur if the articulator incorrectly reproduces the occlusal plane. For every 1° that the occlusal plane is flattened on the articulator compared with reality, the upper incisors look 1° more proclined and lower incisors 1° more retroclined on the articulator.

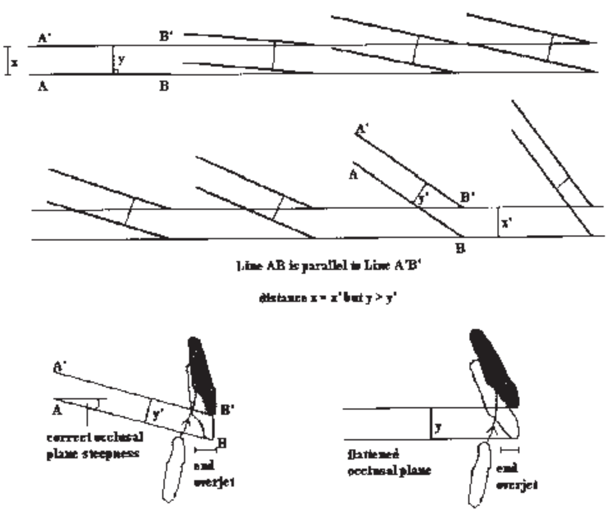

Fig. 3 – Diagram to show the effect of altering the steepness of the occlusal plane on mandibular autorotation. (A) Where line AB is the existing occlusal plane, and line A'B' is the new occlusal plane following a mandibular impaction of given distance x. Distance y is the perpendicular distance separating the two occlusal planes and indicates the distance the mandible is permitted to autorotate. Notice how distance y reduces to y' as the steepness of the occlusal plane increases; (B) The clinical relevance of this geometric effect on autorotation: model surgery on a flattened occlusal plane predicts greater autorotation than during the actual operation.

The position of the upper incisors is the key to orthognathic planning. If the occlusal plane is artificially flattened, as suggested by our results, then the position of the upper incisors will have lost its relationship to true horizontal and vertical references. For example, a Le Fort I vertical impaction with 6-mm change in the position of the upper incisors involves planned vertical movements perpendicular to the horizontal arms of the articulator and not perpendicular to the occlusal plane. Although it seems to be a straight vertical movement on the models, the movement becomes both vertical and *anterior* because of the discrepancy between the patient's and the articulator's reference planes. Mathematically, for a 10° Frankfort to maxillary occlusal plane positioning error, a 6-mm impaction results in an unwanted and *unnoticed* 1-mm anterior shift (16% error). A steeper than correct occlusal plane would result in the opposite effect. Simple anteroposterior incisor changes (such as maxillary advancement in class III), made on an articulator with an incorrect occlusal cant would have an 'unnoticed' vertical component and would therefore affect the amount of upper incisor that shows.

Mandibular errors may occur in addition to maxillary errors. During model surgery for a maxillary impaction, the upper cast is repositioned, which creates a space between upper and lower casts that permits the mandible to autorotate. As the occlusal plane is flattened on the articulator compared with the cephalogram, the perpendicular distance between the upper and lower study casts increases geometrically (Fig. 3A). The resulting effect is *less* mandibular autorotation at operation than predicted by the model (Fig. 3B). A further theoretical problem in procedures during which the ramus remains intact is that, because the centre of autorotation of the mandible is unchanged, autorotation leads to premature contact anteriorly with a tendency for a posterior open-bite. It is apparent that most of the inaccuracies described are small and may not be clinically relevant.

The relevance of correct replication of the angle on the articulator has consequences on maxillary movements and mandibular autorotation. This has not previously been reported to our knowledge. The concept of validating the position of study casts on an articulator is a relatively new one.[25] Whatever articulator clinicians use, we encourage them to check the accuracy of mounted study casts, in particular the steepness of the occlusal plane, before the technician makes the model.

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References

1. Beyron H. Orienterings problem vid protetiska rekonstruktioner och bettstudier. Svensk Tandlakara Tidskrift 1942;35:1–55.
2. Schallhorn RG. A study of the arbitrary centre and the kinematic centre of rotation for facebow mountings. J Prosthet Dent 1957;7:162–169.
3. Weinberg LA. An evaluation of the facebow mounting. J Prosthet Dent 1961;11:32–42.
4. Teteruck WR, Lundeen HC. The accuracy of an ear facebow. J Prosthet Dent 1966;16:1039–1046.
5. Gonzales JB, Kingery RH. Evaluation of planes of reference for orienting maxillary casts on articulators. J Am Dent Assoc 1968;76:329–336.
6. Bailey JO, Nowlin TP. Accuracy of the Frankfort plane transfer of the Hanau articulator. J Dent Res 1981;60(special issue): Abstract 885;531.
7. Gold BR, Setchell DJ. An investigation of the reproducibility of facebow transfers. J Oral Rehabil 1983;10:495–503.
8. Bowley JF, Michaels GC, Lai TW, Lui PP. Reliability of a facebow transfer procedure. J Prosthet Dent 1992;67:491–498.
9. Palik JF, Nelson DR, White JT. Accuracy of an earpiece facebow. J Prosthet Dent 1985;53:800–804.
10. Goska JR, Christensen LV. Comparison of cast positions by using four facebows. J Prosthet Dent 1988;59:42–44.
11. Marko JV. Simple hinge and semi-adjustable articulators in orthognathic surgery. Am J Orthod Dentofacial Orthop 1986;90:37–44.
12. Proffit WR, White RP Jr. Surgical orthodontic treatment. St Louis: CV Mosby, 1991.
13. Ellis E. Modified splint design for two-jaw surgery. J Clin Orthod 1982;16:619–622.
14. Wong BW. Innovations in orthognathic splint construction. J Clin Orthod 1985;19:750–756.
15. Shwestka R, Engelke D, Zimmer B, Kubein-Meesenburg D. Positioning control of the upper incisors in orthognathic surgery. Eur J Orthod 1991;13:367–371.
16. Ellis E. Accuracy of model surgery: evaluation of an old technique and introduction of a new one. J Oral Maxillofac Surg 1990;48:1161–1167.
17. Cottrell D, Wolford LM. Altered orthognathic surgical sequencing and a modified approach to model surgery. J Oral Maxillofac Surg 1994;52:1010–1020.
18. Lockwood H. A planning technique for segmental osteotomies. Br J Oral Surg 1974;12:102–105.
19. Anwar M, Harris M. Model surgery for orthognathic planning. Br J Oral Maxillofac Surg 1990;28:393–397.
20. Nattestad A, Vedtofte P. Pitfalls in orthognathic model surgery. Int J Oral Maxillofac Surg 1994;23:11–15.
21. Nattestad A, Vedtofte P. Mandibular autorotation in orthognathic surgery: a new method of locating the centre of mandibular rotation and determining its consequence in orthognathic surgery. J Cranio Maxillofac Surg 1992;20:163–170.
22. Pitchford JH. A re-evaluation of the axis-orbital plane and the use of orbitale in a facebow transfer record. J Prosthet Dent 1991;66:349–355.
23. Sassouni V. The Face in Five Dimensions, 2nd edn. Morgantown: West Virginia University School of Dentistry Publications, 1962.
24. Hohl TH. The use of an anatomical articulator in segmental orthognathic surgery. Am J Orthod Dentofac Orthoped 1978;73:428–442.
25. Omura T, Glickman RS, Super S. Method to verify the accuracy of model surgery and prediction tracing. Int J Adult Orthod Orthognath Surg 1996;11:265–270.

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