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A prospective optical surface scanning and cephalometric assessment of the effect of functional appliances on the soft tissues

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SUMMARY The aim of this study was to evaluate the effect of different functional appliances on the soft tissues as assessed by cephalometry and optical surface scanning. Forty-two patients were randomly allocated to Bass, Twin Block (TB), and Twin Block + Headgear (TB + Hg) groups. Lateral cephalograms and optical surface scans were recorded before and after the 10-month study period. ANOVA was used to test the cephalometric variables for differences at the 5 per cent level.

The optical surface scanning and cephalometric results were consistent in the sagittal dimension. In the vertical dimension, however, the optical surface scans consistently recorded a greater increase compared with cephalometric values. No differences were detected with regard to cephalometric values at the 5 per cent level. However, the Bass appliance produced greater forward positioning of soft tissue pogonion as assessed by optical surface scanning.

Introduction

Studies on the effects of functional appliances have tended to focus on hard tissue changes as opposed to the soft tissue profile despite the fact that the soft tissue profile is the ultimate determinant of treatment success (Harvold and Vargervik, 1971; McNamara *et al*., 1985; Malmgren *et al*., 1987). The reason for this is that it has been difficult to investigate the three-dimensional (3D) soft tissues with a reliable and reproducible method. Some studies have investigated the soft tissue effects of the activator, Fränkel and Herbst appliances in two dimensions using cephalometric radiographs. Forsberg and Odenrick (1981) reported that lip retrusion and forward movement of soft tissue pogonion were significantly larger in 47 subjects treated with the activator. A retrospective study of activators and 30 patients treated with the Begg technique and four first premolar extractions (Looi and Mills, 1986) found that the upper incisal edge was retracted by 4 mm more in the Begg group, but there was only a difference of 1 mm in lip position.

Changes in the soft tissues profile with the Fränkel appliance have been studied by a number of authors (Remner *et al*., 1985; Haynes, 1986; Battagel, 1989, 1990). Haynes (1986) did not find any improvement in the position of soft tissue pogonion, but noted anterior positioning of upper and lower lips in a sample of patients treated with a modified Fränkel appliance when compared with a control group. The lower lip improved by 3.4 mm with no change in the controls. Battagel (1989) reported that a Fränkel appliance produced a more ideal relationship of the lips to the aesthetic plane when compared with a group treated with extraction of first premolars and edgewise mechanics. Pancherz and Anehus-Pancherz (1994) examined the effect of the Herbst appliance on the facial profile, and found that the upper lip generally became more retrusive in relation to the E-line, whilst the lower lip remained unchanged.

There are several problems in assessing the soft tissues cephalometrically (Hillesund *et al.*, 1978). First, there are reproducibility errors associated with the landmarks most commonly used when assessing the soft tissue profile. Hillesund *et al.* (1978) produced soft tissue envelopes of error as had been described previously for the hard tissues (Baumrind and Frantz, 1971). Only three of the soft tissue landmarks studied exhibited good reliability in both the horizontal and vertical planes. Other landmarks showed an acceptable degree of reproducibility in the horizontal plane, but poor reproducibility in the vertical plane. This is to be expected as a point situated on a curve with a wide radius will show good accuracy in the anteroposterior direction, but will be ill-defined in a vertical direction.

Secondly, in many studies only a cursory mention is made of lip posture or position. Burstone (1967) referred to two postural positions of the lips—the so-called 'relaxed' and 'closed' positions. In the former, the lips are relaxed and apart with no effort made at lip contraction. In the closed position, the lips are lightly touching to produce an anterior oral seal. Hillesund *et al.* (1978) examined the reliability of some soft tissue landmarks in the relaxed versus closed lip positions. Not surprisingly, there was a considerable reduction in upper lip thickness (2.5 mm) in patients with a large overjet when the lips were changed from relaxed to closed position. In the normal group, both the upper and lower lips showed a reduction in thickness in the closed position. This would obviously tend to camouflage the lip response to upper incisor retraction especially if one had a large overjet.

The effects of the Bass appliance (Bass, 1982) on the soft tissue profile have only been examined in two studies (Malmgren *et al.*, 1987; Morris *et al.*, 1998). The effects of the Twin Block appliance (Clark, 1982) on the soft tissue profile have been examined by Morris *et al.* (1998), although the effect, if any, of the addition of high-pull headgear to the Twin Block has not been elucidated. The use of headgear in combination with functional appliances has been advocated by a number of authors as a means of controlling the vertical dimension (Pfeiffer and Grobéty, 1972; Teuscher, 1978; van Beek, 1982; Bass, 1982; Lagerström *et al.*, 1990). Teuscher (1978) emphasized the necessity of controlling the vertical dimension to avoid the 'clockwise response'. This refers to the fact that as the mandible rotates posteriorly, there is a reduction in 'effective mandibular length' (Root, 1975).

Until recently, the assessment of soft tissue form has involved examining a two-dimensional (2D) image of a 3D object. Over the years a number of techniques have been utilized in order to produce a 3D image of the face. These include physioprint, morphanalysis, holography, Moiré contourography, telecentric optics, and stereophotogrammetry. All of these methods have their limitations, not least of which is that they do not produce a digital output for the computer analysis of facial form. More recently, an optical surface scanning system has been developed, which provides a non-invasive method of examining the face in three dimensions (Arridge *et al.*, 1985; Moss *et al.*, 1989). Optical surface scanning has been used most extensively in the assessment of maxillofacial surgical results (Moss *et al.*, 1988, 1994; McCance *et al.*, 1992a,b, 1993). Despite its obvious potential in assessing soft tissue changes, there are only a few reports on the use of optical surface scanning in monitoring the effects of functional appliance treatment. Moss *et al.* (1993) reported on a comparison between magnetic and non-magnetic Twin Blocks, with Morris *et al.* (1998) comparing the Bass, Bionator, and Twin Block appliances.

The aims of this study were:

1. to compare the 2- and 3D soft tissue profile changes, using cephalometry and optical surface scanning, produced by different functional appliances;
2. to evaluate the effect of the addition of high-pull headgear to the Twin Block appliance.

Subjects and methods

Sixty-two patients with a Class II division 1 malocclusions who fulfilled the following criteria

Table 1 Age and sex distribution of the final sample.

	Bass			TB + Hg			TB		
Treatment	Total	M	F	Total	M	F	Total	M	F
No.	17	6	11	13	6	7	12	7	5
Age (years)	12.0	12.1	11.9	12.2	12.1	12.2	11.7	11.8	11.6
SD	1.1	1.0	1.1	1.4	1.8	1.1	1.8	1.6	2.2

were randomly allocated to Bass and Twin Block (TB) groups:

1. Caucasian;
2. Skeletal II dental base relationship;
3. mandibular retrognathia contributing to skeletal discrepancy;
4. overjet > 7 mm;
5. no relevant medical history;
6. no previous orthodontic treatment;
7. no extraction of permanent teeth or fixed appliance therapy during the course of the study.

High-pull headgear was randomly assigned within the Twin Block sample (TB + Hg). Twenty subjects failed to complete the study. These were excluded due to failure to return for appointments or refusal to wear the appliance. The distribution of the subjects is presented in Table 1. The period of the study was 10 months.

Appliance design

Bass appliance. This consists of three separate parts (Bass, 1982, 1983, 1994).

1. Maxillary portion which consists of a removable splint with a torquing bar for the incisors. A midline expansion screw facilitates widening of the upper arch to accommodate the mandible. High-pull headgear was attached to achieve vertical control, the force per side not exceeding 350–400 g in this study.
2. Mandibular portion which had two lingual pads suspended from the splint.
3. Soft tissue screens for interaction with the buccal and labial musculature.

The appliance was constructed with a mandibular advancement of 3 mm. A training ledge was used initially to hold the mandible in a postured position. This is an acrylic extension to the upper splint that allows incisor contact in a forward position. The lingual pads were fitted subsequently and the training ledge removed. The pads were advanced by 2 mm every 6 weeks. The patients were instructed to wear the appliance full time, but to remove it whilst eating.

TB appliance. This consisted of upper and lower removable appliances with bite blocks interlocking in a protruded position (Clark, 1982, 1988). A labial bow was not added to the upper appliance. This was omitted in order not to limit the degree of possible orthopaedic change. The lower appliance was retained by ball ended clasps on the lower incisors and clasps on the first premolars. The first molars were also clasped in high angle cases to allow attachment of occlusal stops to prevent eruption of the second molars. Trimming of the appliance was kept to a minimum during the period of the study. Flyover tubes were included in the region of the second premolars to facilitate the attachment of high-pull headgear. A force of 300–350 g per side was used in those patients allocated to the TB + Hg cohort.

Cephalometric analysis

Lateral cephalograms were taken at the start and end of the 10-month study period. The lateral

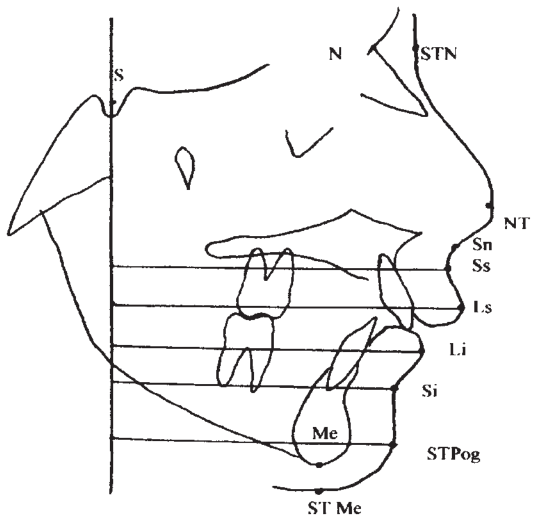

Figure 1 The cephalometric landmarks recorded. Except for those listed below, points, lines and planes conformed to British Standard definitions (British Standard Institution, 1983). N, nasion; S, sella; Me, menton; STN, soft tissue nasion, the point of greatest concavity between the nose and forehead in the midline; NT, nasal tip, the most anterior point on the soft tissue outline of the nose; Sn, subnasale, the point where the lower border of the columella meets the upper lip in the midline; Ss, sulcus superioris: the deepest point of the concavity of the soft tissue outline of the upper lip. Ls, labrale superioris: the most prominent point on the on the soft tissue outline of the upper lip. Si, sulcus inferioris: the deepest point of the concavity of the soft tissue outline of the lower lip. Li, labrale inferioris: the most prominent point on the soft tissue outline of the lower lip. STPog, soft tissue pogonion, the most prominent point on the soft tissue outline of the chin in the midsagittal plane; ST Me, soft tissue menton, the point at which a vertical line from bony menton crosses the soft tissue outline of the chin.

cephalograms were taken by one radiographer who had been instructed in obtaining the radiograph with the subject biting lightly on the back teeth and the lips in a relaxed posture. A vertical reference line, in relation to a horizontal 7 degrees below the sella–nasion line (Burstone *et al*., 1978), was constructed through sella. The radiographs were digitized directly with the digitizing error established by the program at 0.2 mm. The points recorded are shown in Figure 1. The angular and linear measurements are described in Table 2.

Cephalometric error

Twenty-four randomly selected radiographs were digitized on three separate occasions (Houston, 1983) by one operator (SMcD). The first two recordings were made on the same day with a third recording performed 1 month later. Paired *t*-tests revealed no statistically significant differences. Dahlberg's formula (Dahlberg, 1940) and Midtgård's coefficient of reliability (Midtgård *et al*., 1974) were applied in order to calculate the method error. Dahlberg errors ranged from 0.34 mm (upper lip to E-line) to 0.90 mm (soft tissue upper face height) for linear variables, and from 0.53 degrees (Holdaway angle) to 2.38 degrees (nasolabial angle) for angular variables. Midtgård's coefficient of reliability exceeded 10 per cent for the nasolabial and labiomental angles, and these measurements should therefore be treated with caution. The reduced reliability reflects that these measurements are based on points that are not only on large curves, but also relatively near one another.

Statistical analysis

The data were analysed using SPSS/PC+ (Norusis, 1986). In view of the small number of subjects involved, male and female data were combined. Analysis of variance (ANOVA) was used to compare the three groups with Scheffé's method of multiple comparisons to test the significance of individual groups.

Optical surface scanning technique

The optical surface scans were recorded as described by Moss *et al*. (1989). The system developed is based on the principle of triangulation and utilizes a 3D optical surface scanning system. The rotary optical system produces a beam of light that is fanned into a vertical line 0.7 mm wide by a lens and is then projected onto the face. The data collected consists of between 20,000 and 60,000 3D co-ordinates of points lying on the anatomical surface. This data is stored in the computer memory and is available for subsequent analysis. The precision of this technique is better than 0.5 mm (Moss *et al*., 1989).

Table 2 Linear and angular measurements.

Variable	Definition
Linear (mm)	
Ss–S Vert.	The distance from sulcus superioris to a constructed vertical line through sella
Ls–S Vert.	The distance from labrale superioris to a constructed vertical line through sella
Si–S Vert.	The distance from sulcus inferioris to a constructed vertical line through sella
Li–S Vert.	The distance from labrale inferioris to a constructed vertical line through sella
STPog.–S Vert.	The distance from soft tissue pogonion to a constructed vertical line through sella
ST TFH	Soft tissue total face height, the distance from soft tissue nasion to soft tissue menton
ST LFH	Soft tissue lower face height, the distance from subnasale to soft tissue menton
ST UFH	Soft tissue upper face height, the distance from soft tissue nasion to subnasale
Upper Lip–E line	The distance from labrale superioris to a line joining the nasal tip and soft tissue pogonion
Lower Lip–E line	The distance from labrale inferioris to a line joining the nasal tip and soft tissue pogonion
Angular (degrees)	
Nasolabial angle	The angle subtended by nasal tip, subnasale, and labrale superioris
Labiomental angle	The angle subtended by labrale inferioris, sulcus inferioris, and soft tissue pogonion
Holdaway's harmony ('H') angle	The angle subtended by soft tissue nasion, soft tissue pogonion, and labrale superioris
Merrifield's 'Z' angle	The angle between the Frankfort plane and a line connecting soft tissue pogonion and labrale inferioris

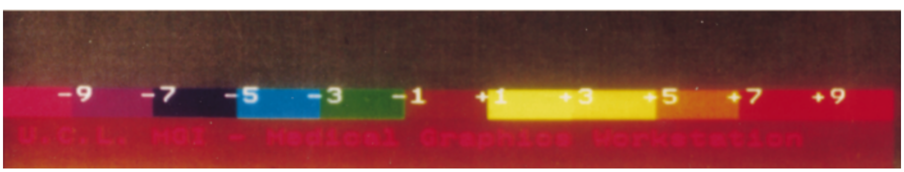

Figure 2 Optical scan colour scale (mm) chart.

All scans were taken by one author (SMcD) who ensured that the lips were in the relaxed position. The subject was seated in a chair that was rotated under computer control as the fanned beam of light was projected onto the face. Up to 60,000 3D co-ordinate points were recorded, whilst the subject sat still in the chair for the 10-second duration of the scan. A blurred image indicated movement by the subject and the scan was repeated.

Scans of patients were averaged using 10 landmarks across the eyes, nose, and lips with a further 5 points mathematically constructed on the forehead. An average scan was then produced from all the scans in a particular functional appliance group by the software program. Male and female data were combined in this study. Pre- and post-treatment average scans were superimposed on the 10 landmarks across the eyes and forehead. The best-fit match of the landmarks was obtained using a least-means-squared procedure with an error of less than 0.5 mm. The landmark points were compared and edited if there was more than 0.5 mm difference between points. The two scans were then compared using a computer graphics program in which the differences are displayed in colour using a millimetre scale. A positive change is denoted by progressively warmer colours yellow to red, and a negative change by colder colours green to purple. The shades progress in increments of 2 mm. No difference between areas on the face is denoted by a neutral brown colour. The scale is shown in Figure 2.

Optical surface scanning error

The reproducibility of optical surface scanning over an interval of a few days has been examined (Moss *et al*., 1989) and expressed as a percentage

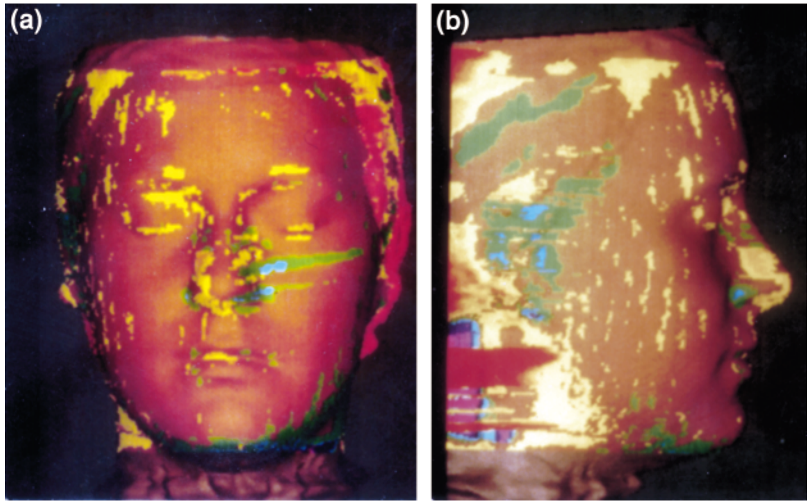

Figure 3 (a,b) Frontal and profile error scans.

of the midline profile length that showed variations between successive scans. Measurements showed that 85 per cent of the profile length had differences of less than 0.2 mm, 12 per cent differences of between 0.2 and 0.5 mm, 2 per cent differences between 0.5 and 1 mm, and 1 per cent differences greater than 1 mm. A mean difference of <0.5 mm for each co-ordinate in all three planes of space was reported by McCance *et al*. (1992a, 1997), but Coward *et al*. (1997) described a 3D mean difference in landmarks examined of between 1 and 2.5 mm. There was a mean difference of 2 mm or less for 15 of the 21 landmarks examined in this study, but many of the points in Coward *et al*.'s (1997) investigation related to the ear and are therefore not directly comparable. Aung *et al*. (1995) compared the accuracy of optical surface scanning to direct facial anthropometric measurements and found that optical surface scan measurements of the nose and circumoral area were reliable (1.0–1.5 mm difference). However, that horizontal linear measurements and those associated with tragion were unreliable (>2.0 mm difference).

For the purposes of this study, error in landmark identification was assessed by scanning 10 adult subjects twice on the same day. Superimpositions were produced to assess the accuracy of the optical surface scanning equipment. The error study scans are presented in Figure 3a,b. Areas of less than 1.0 mm difference are represented by neutral brown. There is some discrepancy related to the alars of the nose, which is explained by the effect of nasal breathing. A difference was also recorded in the area of soft tissue menton and the submandibular tissues. This was due to variation in vertical positioning of the head. Most of the areas examined in this study (i.e the lips and chin), however, revealed no difference due to method error of the scanning technique.

Results

Cephalometric

The means and standard deviations for the start, finish and change in soft tissue cephalometric varaibles are presented in Tables 3, 4 and 5. The only difference observed between groups with regard to the cephalometric data that was statistically significant, using ANOVA, at the 5 per cent level was the Holdaway angle start variable. Scheffé's method of multiple comparisons revealed that the TB group differed from the Bass and TB + Hg samples. There were no statistically significant differences between groups with regard to the finish or start-finish variables.

Table 3 Start of treatment measurements. Significant differences detected by one-way ANOVA.

	Bass		TB + Hg		TB	
Variable	Mean	SD	Mean	SD	Mean	SD
Linear						
Ss–S Vert	75.9	4.6	76.3	6.6	75.5	5.9
Ls–S Vert	79.5	5.6	80.2	7.3	78.8	6.8
Si–S Vert	62.2	5.7	61.6	7.1	61.2	7.9
Li–S Vert	71.9	6.4	71.8	7.4	70.0	6.9
STPog–S Vert	64.5	6.7	63.2	7.7	63.1	7.9
ST TFH	109.9	6.7	111.4	6.4	111.8	7.0
ST LFH	60.1	5.7	60.7	5.3	61.3	3.4
ST UFH	49.8	4.4	50.7	2.8	50.6	4.7
Upper Lip–E line	0.0	1.8	1.8	2.0	0.1	1.9
Lower Lip–E line	–0.3	2.9	0.7	2.2	–1.0	1.7
Angular						
Nasolabial angle	120.7	7.4	119.0	14.8	122.1	9.1
Labiomental angle	114.3	13.2	116.9	11.8	121.1	14.2
Holdaway angle	24.3*	3.6	25.3*	2.8	22.3*	3.7
Merrifield's 'Z' angle	66.2	10.6	63.7	6.0	68.8	6.7

*$P < 0.05$.
Scheffé's test shows that Twin Block was significantly different from other appliances.

Table 4 End of treatment measurements. No significant differences.

	Bass		TB + Hg		TB	
Variable	Mean	SD	Mean	SD	Mean	SD
Linear						
Ss–S Vert	77.8	4.9	77.1	7.3	76.0	6.9
Ls–S Vert	80.4	5.5	80.3	8.0	79.0	7.8
Si–S Vert	66.5	5.7	65.6	7.4	64.7	9.3
Li–S Vert	75.2	6.7	75.0	7.9	73.4	9.2
STPog–S Vert	68.6	6.6	66.3	7.7	66.2	9.7
ST TFH	113.8	7.3	116.6	7.6	115.4	8.2
ST LFH	62.1	5.9	63.8	6.0	63.2	4.6
ST UFH	51.8	4.2	52.8	2.5	52.3	4.7
Upper Lip–E line	–2.3	2.9	–1.0	3.0	–1.6	1.6
Lower Lip–E line	–1.2	3.0	0.2	2.3	–0.3	2.1
Angular						
Nasolabial angle	125.0	10.3	122.6	11.7	125.9	9.9
Labiomental angle	124.7	14.5	131.8	13.5	125.4	11.9
Holdaway angle	20.8	5.1	21.1	4.4	20.0	3.9
Merrifield's 'Z' angle	70.2	8.8	66.3	6.2	68.5	8.5

Optical surface scanning

Bass start versus Bass finish (Figure 4a,b). Chin point and sulcus inferioris were positioned forward by 3–5 mm. There was no change in the maxillary area. The anterior positioning at sulcus inferioris was recorded with all three appliances and is explained by the unfurling of the lower lip that occurs when the lower lip rests labially to the upper incisors. The vertical dimension was increased by 5–7 mm at menton.

Table 5 Changes during treatment. No significant differences.

Variable	Bass		TB + Hg		TB	
	Mean	SD	Mean	SD	Mean	SD
Linear						
Ss–S Vert	1.6	1.9	0.8	1.7	0.5	1.5
Ls–S Vert	0.9	2.3	0.1	2.6	0.1	1.6
Si–S Vert	4.3	2.8	4.0	3.0	3.4	3.5
Li–S Vert	3.3	3.8	3.2	3.5	3.4	3.8
STPog–S Vert	4.1	2.8	3.1	2.9	3.1	3.1
ST TFH	4.0	2.6	5.2	2.9	3.6	2.5
ST LFH	1.9	1.9	3.1	2.7	1.9	2.3
ST UFH	2.0	1.9	2.1	1.2	1.7	1.2
Upper Lip–E line	–2.3	2.9	–2.8	2.2	–1.7	1.5
Lower Lip–E line	–1.0	2.6	–0.5	2.0	0.7	1.7
Angular						
Nasolabial angle	4.2	7.2	3.5	5.5	3.8	6.1
Labiomental angle	10.2	15.0	14.9	14.8	4.3	12.5
Holdaway angle	–3.5	4.2	–4.2	3.3	–2.3	2.2
Merrifield's 'Z' angle	4.0	6.2	2.6	4.9	–0.3	5.7

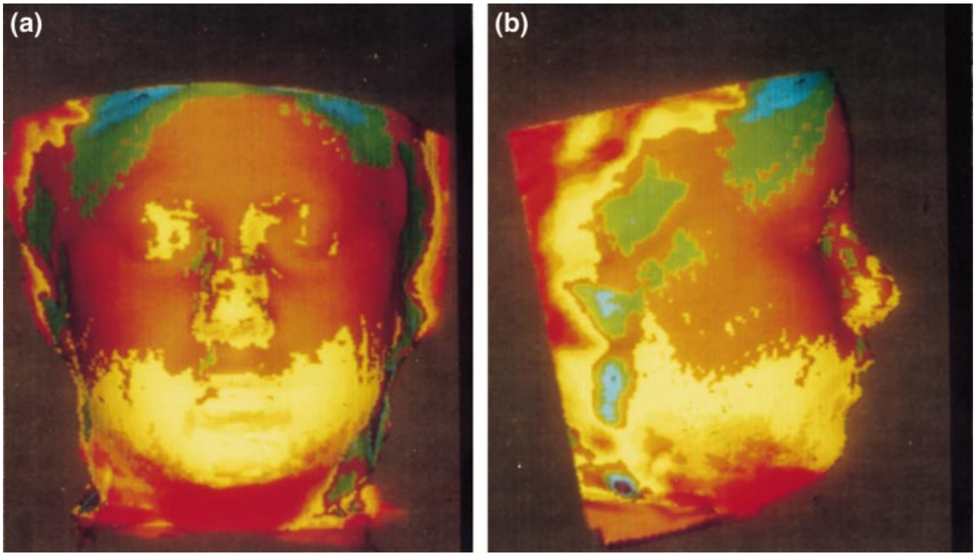

Figure 4 (a,b) Bass start versus Bass finish frontal and profile scans.

The submandibular tissues were increased by 9 mm.

TB start versus TB finish (Figure 5a,b). There was limited forward movement of the chin point by 1–3 mm. An increase in lower face height of 5–7 mm was recorded. This was larger than that obtained cephalometrically, also highlighting a discrepancy between the optical surface scanning equipment and cephalometry in measuring the submental region.

TB + Hg start versus TB + Hg finish (Figure 6a,b). This comparison highlighted the retraction of

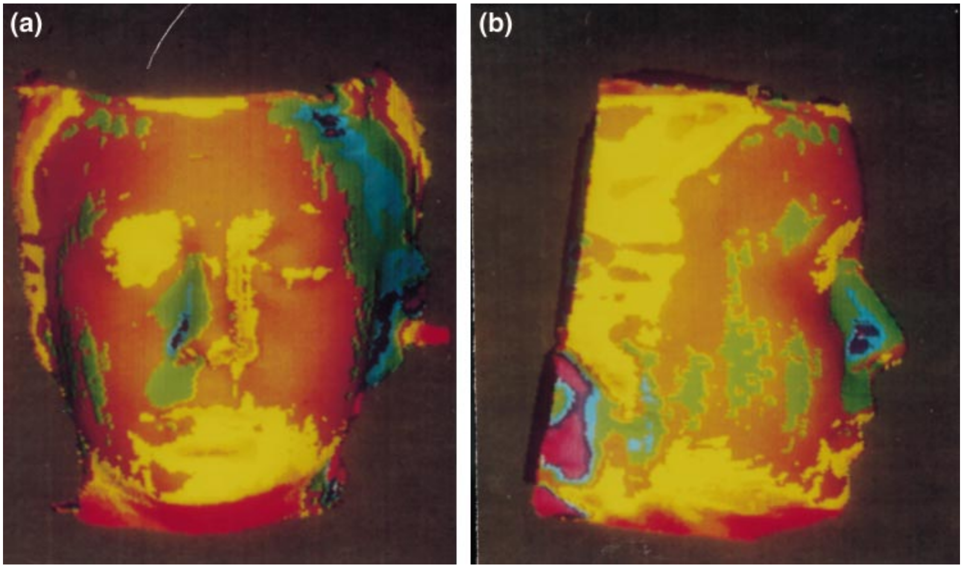

Figure 5 (a,b) TB start versus TB finish frontal and profile scans.

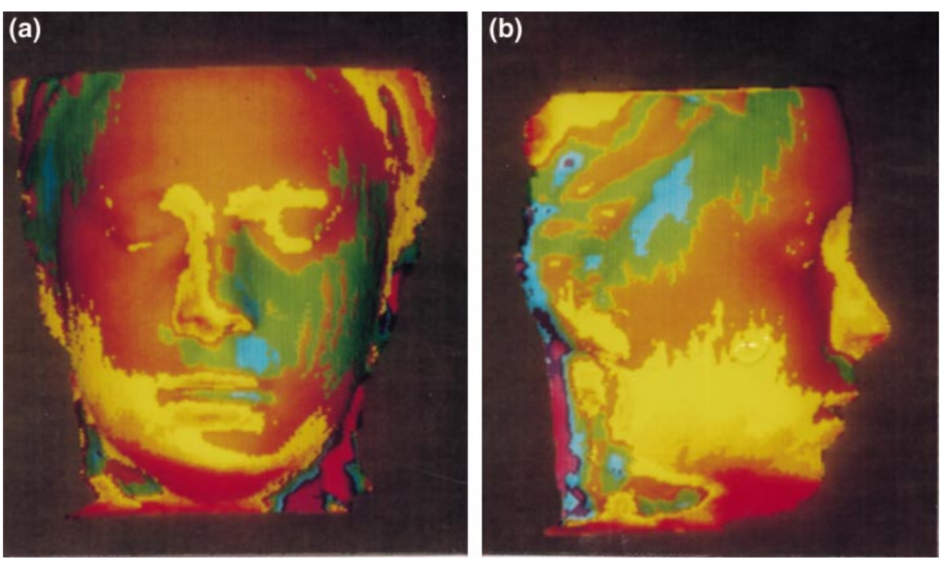

Figure 6 (a,b) TB + Hg start versus TB + Hg finish frontal and profile scans.

the upper lip that had occurred (1–3 mm). This may be explained by the fact that the upper incisors were retracted most in this group due to the addition of headgear. There was an increase in face height of 7–9 mm. This was the largest recorded of the three appliances.

Discussion

Twenty subjects failed to complete the study (13 Bass, seven TB). These patients were excluded due to failure to return for appointments or refusal to wear the appliance. In any prospective study of functional appliances, there will always be a certain amount of 'natural wastage'. This compares to a 20 per cent drop-out previously reported with the Bass appliance (Malmgren *et al*., 1987). With any drop-out of subjects, there is obviously a potential for the introduction of bias. One would presume that if treatment is progressing well with a noticeable reduction in overjet that the subject is more likely to return for appointments. Similarly, patients who have become frustrated by a perceived lack of progress may be more likely not to wear the appliance or return for appointments and thus be excluded from the final analysis. Problems of compliance with the use of functionals and/or headgear are well recognized (Tulloch *et al*., 1997).

As noted previously, the only statistically significant difference between groups shown by the cephalometric data was in the Holdaway angle at the start, which was reduced in the TB group. The nasolabial and labiomental fold angles increased in all three groups, although these measurements should be treated with caution due to the large method error. When the 2D soft tissue cephalometric findings were compared with the 3D optical surface scanning results, the optical surface scans corresponded well with the cephalometric data.

Although not statistically significant, the Bass appliance tended to produce the greatest improvement in the soft tissue profile as assessed two-dimensionally (cephalometrically). This differs from the findings of Morris *et al*. (1998), where the TB was found to produce the greatest change when compared with a control group. The largest increase in STPog–S Vert. was recorded in the Bass group (4.1 ± 2.8 mm), which compares favourably with the increase shown by Morris *et al*. (1998) in their study (2.1 ± 2.1 mm). Labrale inferioris was also positioned further forward in the Bass group (4.3 ± 2.8 mm), but Malmgren *et al*. (1987) reported less forward positioning of the lower lip (1.4 ± 1.5 mm) with the Bass appliance. These measurements correspond well with the 3D (optical surface scanning) findings in which a 3–5 mm increase was shown in the areas corresponding to soft tissue pogonion and labrale inferioris.

There was a smaller increase in forward positioning of soft tissue pogonion in the TB (3.1 ± 3.1 mm) and TB + Hg (3.1 ± 2.9 mm) groups. This was similar to the increase recorded by Morris *et al*. (1998) in their TB sample (2.7 ± 2.3 mm). The optical surface scanning recorded a 1–3 mm increase at soft tissue pogonion and labrale inferioris. In all three groups there was more forward positioning of sulcus superioris compared with labrale superioris suggesting a straightening of the upper lip.

The second aim of the study was to evaluate the effect of the addition of headgear to the TB appliance. Surprisingly, the largest increase in the soft tissue total face height occurred in this TB + Hg group (5.2 ± 2.9 mm). This is despite the addition of high pull headgear to the Twin Block appliance in an attempt to control the vertical dimension. Clark (1995) has previously reported an increase of 6.3 mm in the hard tissue total face height over a 1-year period with TB therapy, which is interesting in view of the perceived benefit of this appliance in high angle cases. The headgear caused the greatest retroclination of the upper incisors resulting in the upper and lower incisors contacting in a more open position with a consequent increase in the lower anterior face height. There was no incisal coverage on the TB to control the height of the upper incisors in this study. Optical surface scanning showed a larger increase of 7–9 mm in soft tissue menton compared with the cephalometric data in the TB + Hg group. This may be explained by a difference in strain in the submental soft tissues caused by a variation in vertical positioning of the head between scans. The increase in soft tissue face height in the TB sample (3.6 ± 2.5 mm) was less than recorded by Morris *et al*. (1998) in their TB cohort (4.5 ± 1.9 mm).

Conclusions

1. All three appliances produced an improvement in the soft tissue profile and there were no statistically significant differences between them.
2. The addition of headgear to the TB, without incisal coverage, did not control the vertical dimension.
3. Optical surface scanning produced a 3D image of the changes occurring during functional

appliance therapy that could not be obtained from 2D cephalometry.

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