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# Skeletal and dental changes following surgically assisted rapid palatal expansion

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SUMMARY The purpose of this study was to analyse the changes produced by surgically assisted rapid palatal expansion (SARPE) longitudinally on 14 patients aged between 18 and 41 years. A pre-fabricated Hyrax appliance was cemented prior to the surgical intervention, which consisted of a maxillary buccal corticotomy with pterygoid separation. Models and postero-anterior (PA) headfilms were taken before expansion (T1), at the end of expansion (T2), at the end of retention (T3) and at least 1 year post-surgery (T4). Overall expansion and relapse were measured directly on the casts.

Transverse distances increased more at the first molars (8.7 mm) and premolars (8.1 and 8.3 mm) than in the canine (5.2 mm) and second molar (5.5 mm) region. Minimal relapse occurred during the retention phase. The arch width decreased more during the post-retention period, with more pronounced reduction at the teeth used as anchorage during the expansion procedure (–2.0 mm for the first premolars and –2.6 mm for the first molars). The mean total dental relapse was 28 per cent. PA radiographic analysis for angular changes showed 9.6 degrees of lateral tipping per side during expansion. One-third of this movement relapsed during the retention period (–3.3 degrees) and this trend (–6.0 degrees) continued during the post-retention phase to reach practically the original value at T1. Skeletal changes monitored on the PA headfilms were minimal with great individual variation. The mean expansion measured in the proximity of the osteotomy site was only 1.3 mm. From this amount, 0.4 mm was lost during the retention and post-retention periods. Based on these findings, it appears that maxillary skeletal expansion by SARPE is mainly a lateral rotation of the two maxillary halves with only minimal horizontal translation.

## Introduction

Adult patients presenting posterior crossbite due to maxillary constriction often demonstrate an arch length deficiency. The consequent crowding of the anterior teeth results in a deterioration of dental frontal harmony and leads them to seek orthodontic treatment. Maxillary expansion is an excellent means to provide space for all the teeth and to improve aesthetics by eliminating the negative spaces and is, therefore, the treatment of choice. Posterior crossbite correction is also achieved and may prevent further tooth abrasion and periodontal deterioration in the long-term.

Minor transverse discrepancies can be corrected without surgery after skeletal maturity (Capelozza *et al.*, 1996; Northway and Meade, 1997; Handelman *et al.*, 2000). The relapse tendency, however, tends to increase with skeletal maturation, as less bony displacement and more dento-alveolar movements are observed (Moss, 1968; Wertz, 1970). This can lead to many problems in adults, including pain upon activation of the appliance, extrusion of teeth, and periodontal complications (Betts *et al.*, 1995). Therefore, large transverse discrepancies in adults are preferably corrected by combined surgical orthodontic treatment.

Post-treatment results following Le Fort I multiple-piece osteotomies to widen the maxilla are disappointing. A large amount of relapse usually occurs, and the risk of compromising the palatal mucosa and its vascularity exists when excessive widening is performed (Turvey, 1985; Phillips *et al.*, 1992; Bailey *et al.*, 1997).

Surgically assisted rapid palatal expansion (SARPE), on the other hand, is a simple, very effective, and stable procedure in the correction of severe maxillary transverse deficiencies (Bays and Greco, 1992; Pogrel *et al.*, 1992; Vanarsdall, 1994; Northway and Meade, 1997; Berger *et al.*, 1998). It not only increases intermolar distance and palatal width but, in certain cases, can improve nasal respiration (Northway and Meade, 1997). An overall increase in nasal airway has been observed in younger patients as an effect of rapid maxillary expansion (Wertz, 1968; Warren *et al.*, 1987; Betts *et al.*, 1995) and is directly related to the nasal width increase which occurs during expansion and persists several years into retention (Krebs, 1958; Skieller, 1964; Berger *et al.*, 1998). A similar response has also been more recently observed in older individuals following SARPE (Basciftci *et al.*, 2002).

The surgical component of SARPE normally consists of a subtotal Le Fort I osteotomy. Some authors (Lines, 1975; Lehman *et al.*, 1984; Pogrel *et al.*, 1992; Betts *et al.*, 1995) recommend additional palatal osteotomies, while others feel that releasing the lateral resistance, such as the zygomatico-maxillary buttress and the maxillary articulations, is sufficient (Glassmann, 1984; Epker and Fish, 1986; Alpern and Yurosko, 1987; Bays and Greco, 1992). To avoid involvement of the palatal mucosa while splitting the palatal suture, Betts *et al.* (1995) and Cureton and Cuenin (1999) recommended separating the maxillae by malleting a thin osteotome between the central incisors.

SARPE can also be carried out unilaterally if required. In such cases, the maxillary width increase is primarily confined to the operated side, while the opposite side serves as anchorage (Mossaz *et al.*, 1992). Non-surgical skeletal expansion in growing individuals seems to be maintained in the long term as reported by numerous authors and more recently by Cameron *et al.* (2002). However, reports on stability following SARPE are limited. Berger *et al.* (1998) found similar trends over time in orthopaedic and surgically assisted rapid maxillary expansion with overall stable results. Northway and Meade (1997) found that 12 per cent of the intermolar expansion was lost during the following 2 years in a small group who underwent a buccal corticotomy, as opposed to a 5.5 per cent relapse in a non-surgical sample. The aim of this study, therefore, was to examine the skeletal and dental effects of SARPE during and following expansion and the stability at least 1 year later.

## Subjects and methods

### *Sample*

The sample consisted of 14 subjects, 11 males and three females, with either unilateral or bilateral crossbite. The ages ranged between 18 years 6 months and 41 years 8 months (mean 27 years 2 months).

The subjects were patients from the private practices of the two authors as well as from the University of Geneva Dental School. The same orthodontic technique and surgical procedure was used for all cases.

### *Expansion procedure*

A pre-fabricated Hyrax appliance was cemented to the upper first premolars and first molars prior to the surgical intervention. Under general anaesthesia an incision was made bilaterally in the vestibule and a buccal corticotomy was performed from the piriform aperture to the pterygoid fissure. Below the anterior nasal spine the maxilla was separated by malleting a thin osteotome between the central incisors. Pterygoid separation was also performed on both sides. Immediately after, the expansion appliance was activated four quarter turns (1 mm) by the surgeon.

The subjects were instructed to start activation of their appliance 3 days later with a one-quarter turn per day until the necessary amount of expansion was achieved (3–5 weeks). It was decided to 'over-expand' 2 mm at the upper first molar level.

Upon completion of the expansion, the Hyrax appliance was left in place for 12 weeks as a fixed retainer and then replaced by a conventional maxillary removable retainer for a further period of 3 months. All patients underwent conventional fixed appliance therapy thereafter. No transpalatal arch was used.

### *Records*

Models, occlusal radiographs and postero-anterior (PA) headfilms were obtained before the expansion procedure (T1), at the end of expansion (T2), at the end of retention (fixed and removable retainers) (T3), and at least 12 month post-surgery (following fixed appliance therapy) (T4). A clinical evaluation, including a count of teeth in crossbite, was also performed at least 1 year out of any type of retention (T5).

For each headfilm, the patients were positioned in a cephalostat with the vertical and horizontal nose position recorded in order to standardize the procedure. Individual pre-fabricated vertical pins were inserted at that time in the upper first molar tubes and slots to monitor angular changes (Figure 1).

### *Measurements*

The distances between the canines (cusp tips), the premolars, and the molars (occlusal crown centre) were recorded twice on the casts and averaged using a dial calliper, measuring to 1/1000 mm.

On the PA headfilm, a midline reference point (MRP) was determined on the line (CRL) connecting each orbit at the intersection between the greater wing of the sphenoid bone and the inner cortex of the orbit at a landmark described as the 'latero-orbitale' (Lo). The face was divided into right and left sides by a line (ML) connecting the MRP to the middle of the narrowest inferior part of the nasal septum (NS).

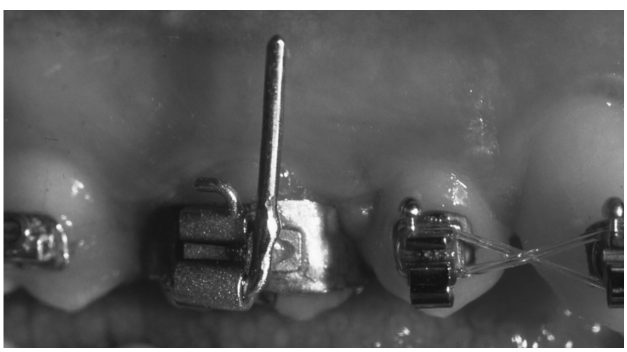

**Figure 1** Individual vertical pins inserted in the two buccal tubes of the upper first molar bands.

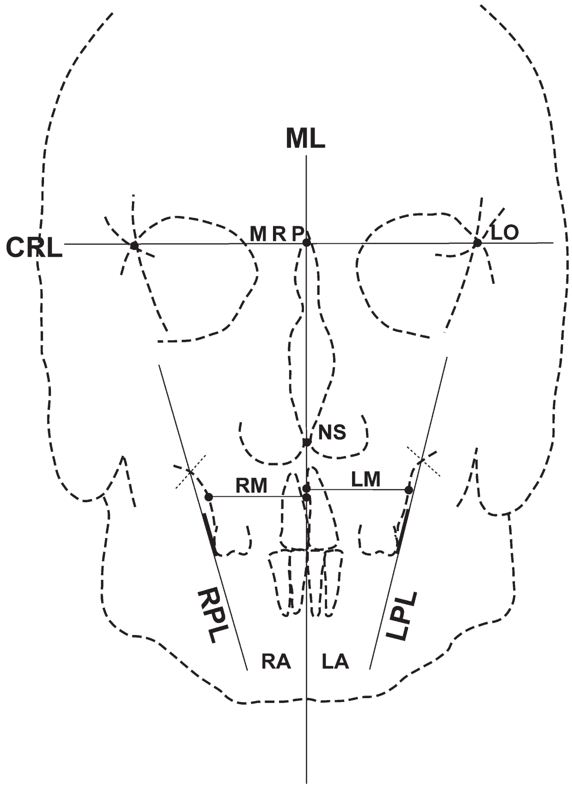


**Figure 2** Postero-anterior tracing and analysis. Skeletal expansion and angular changes measured separately on both sides: Lo, latero-orbitale; MRP, midline reference point; NS, nasal septum, middle of the narrowest inferior part of the nasal septum; CRL, cranial base reference line; ML, constructed midline; RPL, LPL, right and left lines extended from the pins; RM, LM, right and left maxillary skeletal distances measured 5 mm above the inserted pins; RA, LA, right and left maxillary first molar angles.

From the midline (ML), two perpendicular lines were drawn 5 mm above the inserted pin and were measured (RM, LM) to monitor the skeletal expansion for each side.

The changes in angulation were analysed at the angle (RA, LA) formed between the extension traced from the pin on each side (RPL, LPL) and the midline (Figure 2).

All measurements were made twice by the same individual (CFM) with a time interval of 6 months or more, and averaged.

The reliability of all measurements was evaluated by the double assessments method using the formula: ME = $\sqrt{\Sigma d^2/2n}$, where $n$ is the number of measurements and $d$ is the difference between duplicate measurements (Dahlberg, 1940).

The method was considered quite reliable for the model analysis (ME = 0.29 mm) and the angular measurements made on the PA headfilms (ME = 1.09 degrees). It was, however, more questionable when measuring the limited amounts of skeletal expansion on the PA headfilms (ME = 0.28 mm).

## Results

### *Clinical findings*

Initially the number of teeth in crossbite was 126. One year post-retention (T5) only three teeth, two second molars and one first premolar, were in crossbite.

### *Model analysis (Table 1)*

During the expansion period (T1–T2), the increase in the transverse dimension between the first premolars (8.1 mm), the second premolars (8.3 mm), and the first molars (8.7 mm) was greater than between the canines (5.2 mm) and the second molars (5.5 mm).

The relapse during the retention phase (T2–T3) was less than 1 mm, with a maximum of 0.7 mm at the first premolars. It was more severe during the post-retention period and also more pronounced for the first premolars (2.0 mm) and the first molars (2.6 mm) than for the canines (0.9 mm), the second premolars (1.4 mm), and the second molars (1.5 mm).

The mean total dental relapse was 28 per cent. The teeth which tended to relapse the most were the first molars (36 per cent) and the premolars (33 per cent). The second premolars were more stable with a relapse of only 16 per cent (Table 1, Figure 3).

### *PA cephalographs (Tables 2 and 3)*

The skeletal expansion was measured at a level above the apices of the teeth, very close to the osteotomy site. The expansion as well as the subsequent relapse were

**Table 1** Mean interdental distances measured on the models (mm).

| | T1 | SD | T2 | SD | T2–T1 | SD | T3 | SD | T3–T2 | SD | T4 | SD | T4–T3 | SD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Canines | 31.41 | 3.15 | 36.59 | 2.92 | 5.19 | 2.28 | 36.59 | 3.07 | –0.2 | 0.77 | 35.54 | 2.49 | –0.94 | 2.3 |
| First premolars | 34.29 | 3.63 | 42.37 | 4.67 | 8.08 | 1.78 | 41.72 | 5.36 | –0.65 | 1.72 | 39.77 | 4.99 | –2.02 | 2.37 |
| Second premolars | 37.84 | 4.22 | 46.1 | 4.44 | 8.26 | 2.48 | 46.1 | 4.57 | 0 | 1.13 | 44.69 | 5.61 | –1.38 | 2.7 |
| First molars | 43.39 | 4.04 | 52.11 | 4.85 | 8.73 | 1.49 | 51.58 | 4.86 | –0.54 | 1.19 | 49.21 | 4.91 | –2.62 | 1.8 |
| Second molars | 50.56 | 5.46 | 56.47 | 5.94 | 5.48 | 2.53 | 56.24 | 6.01 | –0.23 | 1.75 | 54.58 | 6.13 | –1.48 | 0.98 |

T1, before expansion; T2, the end of expansion; T3, the end of retention; T4, minimum 1 year post-surgery.

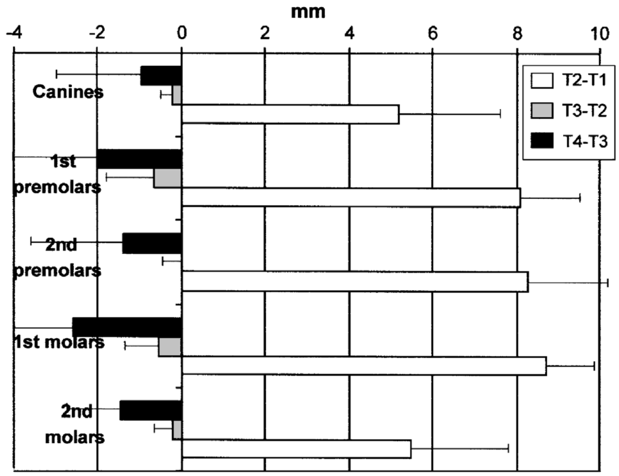


**Figure 3** Mean transverse changes measured on the models.

**Table 2** Molar angular changes (degrees).

| Expansion (T2–T1) | | Retention (T3–T2) | | Post-retention (T4–T3) | |
|---|---|---|---|---|---|
| Mean | SD | Mean | SD | Mean | SD |
| 9.63 | 7.41 | –3.33 | 5.05 | –6.04 | 8.29 |

T1, before expansion; T2, the end of expansion; T3, the end of retention; T4, minimum 1 year post-surgery.

very small. The minimal skeletal increase (1.31 mm) also showed great variability. This decreased very slightly during the retention (–0.11 mm) and post-retention (–0.25 mm) phases, with significant variation between patients (Figure 4).

Unilateral angular measurements showed 9.6 degrees of tilting of the upper first molars during the expansion procedure. This change was not stable and relapsed (–3.3 degrees) during the retention period and returned almost completely to the initial value during the post-retention phase (–6.0 degrees). All these measurements showed great variation among the subjects (Figure 5).

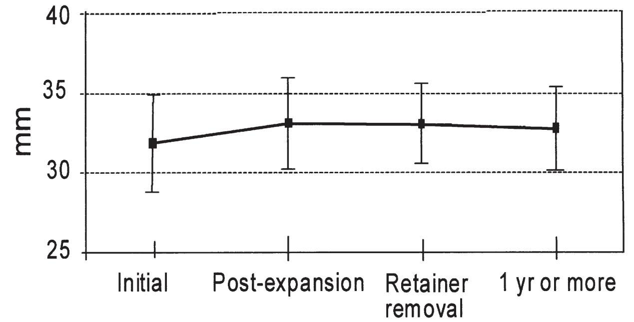


**Figure 4** Skeletal changes measured on the postero-anterior headfilm: mean unilateral distances between ML and RM and between ML and LM, 5 mm above the inserted pin.

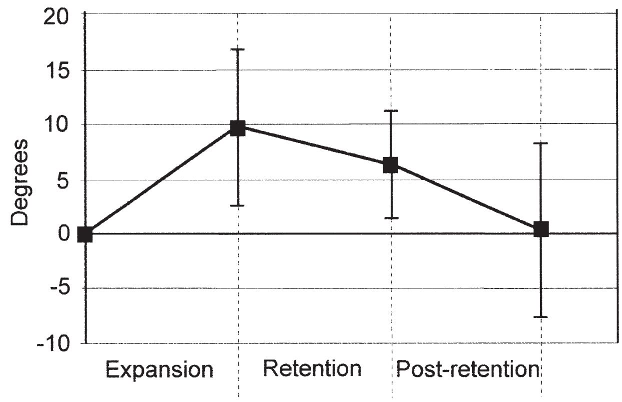


**Figure 5** Mean unilateral angular changes measured on the postero-anterior headfilm.

## Discussion

In adults, the amount of maxillary expansion needed and the nature of the crossbite, dental, skeletal, or both, appear to be the deciding factors for surgically supporting maxillary widening. As a general agreement, more than 5 mm of maxillo-mandibular discrepancy is considered as the indication for surgery (Betts *et al.*, 1995, Handelman *et al.*, 2000). In the present study, all patients exceeded this amount.

**Table 3** Skeletal expansion and relapse measured on the postero-anterior radiographs (mm).

| Initial (T1) | | Post-expansion (T2) | | Retainer removal (T3) | | 1 year or more post-surgery (T4) | | Difference from start of treatment (T4–T1) | |
|---|---|---|---|---|---|---|---|---|---|
| Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| 31.81 | 3.17 | 33.12 | 2.9 | 33.01 | 2.73 | 32.77 | 2.67 | 0.96 | 1.03 |

T1, before expansion; T2, the end of expansion; T3, the end of retention; T4, minimum 1 year post-surgery.

Only in young adults, or when a small amount of expansion is needed, can adjunct surgery be avoided (Betts *et al.*, 1995). In these cases, however, one has to deal with possible extended periods of pain, palatal lesions, increased amounts of dental tipping (Capelozza *et al.*, 1996), and significant gingival recession (Northway and Meade, 1997).

Skeletal and dental Class II patients may present a correct occlusal transverse centric relationship, but protruded in Class I, they find themselves in an end-to-end or crossbite situation. For Class III malocclusions, the opposite can be observed with less real transverse discrepancy to be corrected than intra-orally detected.

In two subjects of the present sample, maxillary sagittal or vertical corrective surgery was also carried out as a second procedure following SARPE and orthodontic preparation. The two surgical procedures could have been technically reduced to a single two-piece Le Fort I surgery with the necessary maxillary expansion. The decision, however, was based on the observations made by Phillips *et al.* (1992), who found transverse relapse as high as 40 per cent when performing a multiple-piece Le Fort I osteotomy, and by Silverstein and Quinn (1997), who highlighted the risk of compromising the vascular pedicle when the maxilla was fragmented. A limit in the amount of possible expansion has also been described in this type of procedure (Betts *et al.*, 1995). In two patients, the negative aspect was not only the need for two general anaesthesiae, but also the total treatment time, which was lengthened by 6 months.

The surgical technique applied for SARPE has been widely discussed in the literature. Major resistance to expansion in the maxilla seems to be in the maxillary articulations (Isaacson and Ingram, 1964; Kennedy and Bell, 1976; Bell and Epker, 1976; Bays and Greco, 1992). Shetty *et al.* (1994), however, considered the midpalatal suture as the principal obstruction to maxillary expansion as demonstrated by their experiments on a human photo-elastic analogue skull. For surgical intervention, some authors recommend an additional midpalatal (Northway and Meade, 1997) or para-midline osteotomy (Turvey, 1985), together with the lateral osteotomies. This seems particularly important in subjects presenting with palatal suture ossification or palatal exostosis (Bell and Epker, 1976). In order to avoid direct contact with the midpalatal suture and its covering mucosa, an instant midpalatal split by malleting an osteotome between the central incisors via anterior access was chosen. In order to prevent damage or absence of bone adjacent to one of the central incisors, Cureton and Cuenin (1999) also recommended separating their roots from each other with fixed appliances prior to surgery if there is inadequate space between them at the start of treatment.

Lateral osteotomies were additionally performed on both sides with separation of the pterygoid plates. This technique is described by most authors (Bell and Epker, 1976; Glassmann, 1984; Lehmann *et al.*, 1984; Kraut, 1984; Alpern and Yurosko, 1987; Bays and Greco, 1992; Pogrel *et al.*, 1992; Betts *et al.*, 1995; Berger *et al.*, 1998). It involves a risk of intra-operative bleeding (Silverstein and Quinn, 1997) and normally necessitates general anaesthesia, which can be avoided when the pterygo-maxillary junction is not invaded (Glassmann, 1984; Bays and Greco, 1992). There was no bleeding in the present sample.

The total amount (mean) of molar expansion in this study was 5.6 mm after debanding, which corresponds with previous findings (Pogrel *et al.*, 1992; Bays and Greco, 1992; Northway and Meade, 1997; Berger *et al.*, 1998), who also took records at least 1 year post-expansion. The total relapse of 36 per cent measured at least 1 year post-surgery seems high at first sight, in comparison with the above-mentioned studies, which were around 5–8 per cent. A large reduction in the transverse dimension was also measured at the premolars, the canines, and the second molars. The final measurements were recorded after removal of the fixed appliances. An explanation for the measured relapse could be that not all teeth were in a similar crossbite relationship before treatment. Over-correction was not mentioned in most of the previous studies. In the present procedures all intermolar distances were over-expanded approximately 2 mm on each side and allowed to relapse later during fixed appliance therapy until the transverse situation of all teeth was completely normalized. These findings are confirmed by the molar buccal tipping measured unilaterally on the PA headfilms after expansion (9.63 degrees), which almost entirely relapsed during fixed appliance therapy (–9.37 degrees) with the use of rectangular archwires to control buccal root torque. The high degree of variability in the angular measurement at the post-retention recording (± 8.29 degrees) reflects the differences in crossbite situations at the start of treatment. These findings are similar to the amount of molar tipping reported by Northway and Meade (1997), yet measured via a different method. This has also been shown in the past by Wertz (1970) following rapid palatal expansion on growing patients. Using a similar method of angular measurement on young patients, Mossaz-Joëlson and Mossaz (1989) reported comparable results for molar tipping after slow maxillary expansion.

The largest amount of relapse following SARPE was recorded at the first molars as they were used as anchorage through the Hyrax appliance during both expansion and the first 3 months of retention. Angular changes are obviously dependent on the stiffness of the appliance used and, in general, these do not seem to be sufficiently rigid (Braun *et al.*, 2000), thus allowing dental tipping (Figure 6).

**Figure 6** Lateral view at the end of the retention period with premolar bands and Hyrax appliance removed. Buccal tipping was more pronounced at the first premolars and first molars.

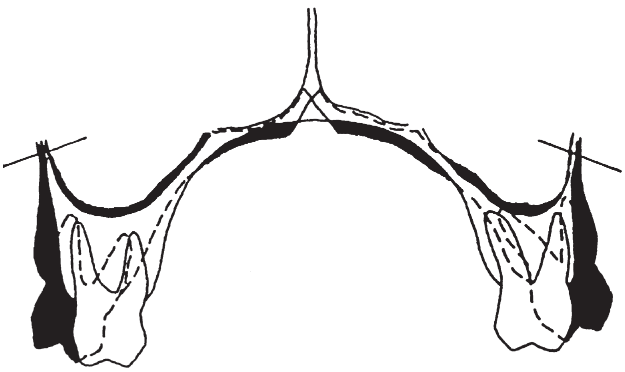

**Figure 7** Schematic drawing representing the lateral rotation of the two maxillary halves.

Important changes in molar angulation are not due to dental tipping alone. If this was the case, a large amount of gingival recession, as well as tooth mobility, would be observed buccally. The overall expansion measured is the result of dental tipping and lateral rotations of the two maxillary halves freed from resistance (Figure 7). This hypothesis was confirmed by the findings regarding the skeletal expansion measured near the osteotomy site. Only minimal change occurred (1.31 mm), which reveals very little lateral translation of the two maxillary halves. It was also characterized by a great variability among the subjects. Berger *et al.* (1998) reported more reliable results with an increase of 3.13 mm in skeletal expansion. This could be explained by the lower mean age in their sample (19 years) compared with the present group (27 years), and reflects the increased bone rigidity with advancing age.

Finally, when clinically evaluating the effectiveness of SARPE, it is also important to consider the individual number of teeth initially in crossbite which were subsequently corrected and which relapsed into their initial position. In the present sample, only 3 per cent of these teeth were recorded in that initial position at the 1 year follow-up.

## Conclusions

Over recent years, SARPE has proved to be clinically effective and stable for the correction of maxillo-mandibular transverse discrepancies. However, this study has demonstrated that real skeletal expansion through translation is only minimal. Tipping produced by the force exerted on the teeth by the palatal expander is also due to the lateral rotation of the two maxillary halves. This suggests that the total relapse in tipping observed was not only dental but also skeletal.

New techniques using osseointegrated implants as anchorage, or expanders fixed directly to the maxillary bones, as described by Mommaerts (1999) and Matteini and Mommaerts (2001), should improve the skeletal component of the expansion and could demonstrate more overall stability.

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## References

Alpern M C, Yurosko J J 1987 Rapid palatal expansion in adults with and without surgery. Angle Orthodontist 57: 245–263

Bailey L J, White R P, Proffit W R, Turvey T A 1997 Segmental LeFort I osteotomy for management of transverse maxillary deficiency. Journal of Oral and Maxillofacial Surgery 55: 728–731

Basciftci F A, Mutlu N, Karaman A I, Malkoc S, Küçükkolbasi H 2002 Does the timing and method of rapid maxillary expansion have an effect on the changes in nasal dimensions? Angle Orthodontist 72: 118–123

Bays R A, Greco J M 1992 Surgically assisted rapid palatal expansion. Journal of Oral and Maxillofacial Surgery 50: 110–113

Bell W H, Epker B N 1976 Surgical-orthodontic expansion of the maxilla. American Journal of Orthodontics 70: 517–528

Berger J L, Pangrazio-Kulbersh V, Borguis T, Kaczynski R 1998 Stability of orthopedic and surgically assisted rapid palatal expansion over time. American Journal of Orthodontics and Dentofacial Orthopedics 114: 638–645

Betts N J, Vanarsdall R L, Barber H D, Higgins-Barber K, Fonseca R J 1995 Diagnosis and treatment of transverse maxillary deficiency. International Journal of Adult Orthodontics and Orthognathic Surgery 10: 75–96

Braun S, Bottrel J A, Lee K-G, Lunazzi J J, Legan H L 2000 The biomechanics of rapid maxillary sutural expansion. American Journal of Orthodontics and Dentofacial Orthopedics 118: 257–261

Cameron G C, Franchi L, Baccetti T, McNamara Jr J A 2002 Long term effects of rapid maxillary expansion: a posteroanterior cephalometric evaluation. American Journal of Orthodontics and Dentofacial Orthopedics 121: 129–135

Capelozza L, Cardoso Neto J, Gabriel Da Silva O, Ursi W J S N 1996 Non-surgically assisted rapid maxillary expansion in adults. International Journal of Adult Orthodontics and Orthognathic Surgery 11: 57–66

Cureton S L, Cuenin M 1999 Surgically assisted rapid palatal expansion: orthodontic preparation for clinical success. American Journal of Orthodontics and Dentofacial Orthopedics 116: 46–59

Dahlberg G 1940 Statistical methods for medical and biological students. George Allen and Unwin, London, pp. 122–132

Epker B N, Fish L C (eds) 1986 Transverse maxillary deficiency. In: Dentofacial deformities: integrated orthodontic and surgical correction, Volume II, 3rd edn. Mosby, St Louis, pp. 818–875

Glassmann A S 1984 Conservative surgical orthodontic adult rapid palatal expansion: sixteen cases. American Journal of Orthodontics 86: 207–213

Handelman C S, Wang L, BeGole E A, Haas A J 2000 Nonsurgical rapid maxillary expansion in adults: report on 47 cases using the Haas expander. Angle Orthodontist 70: 129–144

Isaacson R J, Ingram A H 1964 Forces produced by rapid maxillary expansion: forces present during treatment. Angle Orthodontist 34: 261–270

Kennedy J W, Bell W H 1976 Osteotomy as an adjunct to rapid maxillary expansion. American Journal of Orthodontics 70: 123–137

Kraut R A 1984 Surgically assisted maxillary expansion by opening the midpalatal suture. Journal of Oral and Maxillofacial Surgery 42: 651–655

Krebs A 1958 Expansion of the midpalatal suture studied by means of metallic implants. Transactions of the European Orthodontic Society, pp. 163–171

Lehman J A, Haas A J, Haas D G 1984 Surgical orthodontic correction of transverse maxillary deficiency: a simplified approach. Plastic and Reconstructive Surgery 73: 62–66

Lines P A 1975 Adult rapid maxillary expansion with corticotomy. Angle Orthodontist 67: 44–56

Matteini C, Mommaerts M Y 2001 Posterior transpalatal distraction with pterygoid disjunction: a short term model study. American Journal of Orthodontics and Dentofacial Orthopedics 120: 498–502

Mommaerts M Y 1999 Transpalatal distraction as a method of maxillary expansion. British Journal of Oral and Maxillofacial Surgery 37: 268–272

Moss J P 1968 Rapid expansion of the maxillary arch Part II. Journal of Practical Orthodontics 11: 215–223

Mossaz C F, Byloff F K, Richter M 1992 Unilateral and bilateral corticotomies for correction of maxillary transverse discrepancies. European Journal of Orthodontics 14: 110–116

Mossaz-Joëlson K, Mossaz C 1989 Slow maxillary expansion: a comparison between banded and bonded appliances. European Journal of Orthodontics 11: 67–76

Northway W M, Meade J B 1997 Surgically assisted rapid maxillary expansion: a comparison of technique, response, and stability. Angle Orthodontist 67: 309–320

Phillips C, Medland W H, Fields H W, Proffit W R, White R P 1992 Stability of surgical maxillary expansion. International Journal of Adult Orthodontics and Orthognathic Surgery 7: 139–146

Pogrel M A, Kaban B L, Vargervik K, Baumrind S 1992 Surgically assisted rapid maxillary expansion in adults. International Journal of Adult Orthodontics and Orthognathic Surgery 7: 37–41

Shetty V, Mendoca Caridad J, Caputo A A, Chaconas S J 1994 Biomechanical rationale for surgical-orthodontic expansion of the adult maxilla. Journal of Oral and Maxillofacial Surgery 52: 742–749

Silverstein K, Quinn P D 1997 Surgically-assisted rapid palatal expansion for management of transverse maxillary deficiency. Journal of Oral and Maxillofacial Surgery 55: 725–727

Skieller V 1964 Extension of the midpalatal suture by removable plates analysed by the implant method. Transactions of the European Orthodontic Society, pp. 143–158

Turvey T A 1985 Maxillary expansion: a surgical technique based on surgical-orthodontic treatment objectives and anatomical considerations. Journal of Maxillofacial Surgery 13: 51–58

Vanarsdall R L 1994 Periodontal/orthodontic relationships. In: Graber T M, Vanarsdall R L (eds) Orthodontics: current principles and techniques, 2nd edn. Mosby, St. Louis, pp. 712–749

Warren D W, Hershey H G, Turvey T A, Hinton V A, Hairfield W M 1987 Nasal airway following maxillary expansion. American Journal of Orthodontics and Dentofacial Orthopedics 91: 111–116

Wertz R A 1968 Changes in nasal airflow incident to rapid maxillary expansion. Angle Orthodontist 38: 1–11

Wertz R A 1970 Skeletal and dental changes accompanying rapid midpalatal suture opening. American Journal of Orthodontics 58: 41–66