Craniofacial Changes in Patients with Class III Malocclusion treated with the RAMPA System

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Abstract:

Objective: The underlying etiology of Class III malocclusion may be associated with cranial base morphology. The aim of this study is to test the efficacy of a Right-Angled Maxillary Protraction Appliance (RAMPA) System in Asian subjects with Class III malocclusions.

Materials and Methods: 27 homologous landmarks were digitized from lateral cephalographs for 10 pre-pubertal Japanese children (mean age 95 months) with skeletal Class III malocclusion prior to and after RAMPA treatment. The mean, pre- and post-treatment craniofacial configurations were computed using Procrustes superimposition, and subjected to principal components analysis (PCA), and finite-element analysis (FEA).

Results: The mean treatment time was 22.5 months. All patients showed significant craniofacial change with correction of anterior and/or posterior crossbite. The mean, pre- and post-treatment craniofacial configurations were statistically different when tested using PCA (p < 0.001), with the first two principal components accounting for 97% of the total shape change. Using FEA, the anterior cranial base showed a relative 12-32% increase in size. The midfacial and mandibular regions, as well as the oropharyngeal airway showed large relative size-changes.

Conclusion: This study suggests that the anterior cranial base may be targeted in the correction Class III malocclusions.

Introduction

Class III malocclusions are characterized by relative mandibular excess, maxillary deficiency or a combination of both.[1-2] Singh et al.[3] noted that cranial base morphology is also a fundamental feature of Class III malocclusions, concluding that Class III malocclusions are due, in part, to deficient orthocephalization, which is a failure of the cranial base to flatten during development.[4] Thus, deformations of the anterior cranial base were observed in children with Class III malocclusions.[5] Moreover, the incidence of Class III malocclusion seems to be higher in Asian populations.[6] Korean children appear to develop Class III malocclusions because of smaller anterior cranial base and midfacial dimensions.[7] Therefore, a sphenoethmoidal mechanism of midfacial retrognathism appears to be implicated in the development of Class III malocclusions. These ideas have been reviewed by Singh.[8]

During the development of Class III malocclusions, growth of the jaws in a sagittal direction, together with rotation of the mandible, produces an insufficient anterior nasal spine area and inferior displacement of the base of the nasal cavity.[9] Thus, common developmental patterns of the maxillofacial area[10] suggest that the bone remodeling pattern in Class III malocclusions is different from that during normal development. Consequently, improving the antero-superior growth direction of the midfacial area may be a plausible modality for the correction of Class III malocclusions. Orthopedic treatments for Class III malocclusion include: growth modification with a chin-cap; maxillary protraction, and orthognathic surgery. Recently, Haraguchi et al.[11] suggested that a maxillo-mandibular osteotomy may also be effective. However, mandibular setback alone causes post-operative instability, and a bimaxillary osteotomy is recommended, as it is thought to produce stable results when the maxilla is relocated antero-superiorly. But, this latter procedure is contraindicated for patients presenting with a "long face" (high mandibular plane angle). Ironically, Japanese patients with Class III malocclusions tend to have a high mandibular plane angle, so that an antero-superior displacement of the maxilla cannot be easily performed.

In view of the above limitations, the first author (YM) designed the Right Angle Maxillary Protraction Appliance (RAMPA) System. It is a craniomaxillary protraction protocol developed to resolve the midfacial deficiency in Class III malocclusions. Most of the

previously reported maxillary protraction procedures have often caused an increase in facial height associated with an increase in the mandibular plane angle.[12-13] Oktaya and Ulükayab[14] also suggested that the dimensions of the upper airway can be increased using maxillary protraction. Thus, a craniomaxillary protraction technique was developed to putatively convert a vertically-developing craniofacial pattern into the sagittal direction, in which the facial height is shortened as the midfacial region is induced to grow in a more horizontal direction, while inhibiting posterior rotation of the mandible. Therefore, the aim of this study is to determine the craniofacial effects of the RAMPA System in Japanese subjects with Class III malocclusions. The null hypothesis is that the RAMPA System does not change postnatal craniofacial morphogenesis in Japanese subjects.

Materials and Methods

In this retrospective, longitudinal study, 10 pre-pubertal Japanese children (mean age 95 months ± 16; 5 male, 5 female) with skeletal Class III malocclusions were treated with the RAMPA System after informed consent was received. They were all consecutive, care-seeking patients who attended the office of a single clinician (YM) in Tokyo, Japan. All children were examined but the study sample was selected based on the following inclusion criteria: Japanese ethnicity; prepubertal age (5-11years); skeletal Class III malocclusion and informed consent/willingness to participate in the study. Exclusion criteria for sample selection were: Age >11 years; Class I or Class II malocclusions; history of previous orthodontic treatment; history of oral/maxillofacial surgery; facial injury that resulted in hospital attendance; congenital craniofacial malformation (such as cleft lip/palate), and lack of informed consent or willingness to participate in the study. All those that qualified for the study were treated by the same clinician (YM).

The RAMPA System consists of a maxillary expansion appliance (MEA, Fig. 1), the Right-Angled Maxillary Protraction Appliance (RAMPA, Fig. 2), and an active bow (AB, Fig. 3), which connects the RAMPA and MEA together. Due to the elasticity of this system, the maxilla is putatively protracted in the horizontal direction, utilizing the growth potential of the anterior cranial base. The RAMPA System uses a rigid, acrylic-bonded expansion appliance to cover the occlusal plane, utilizing semi-rapid expansion (Magnum Stainless Steel Expansion Screw, Dentarum, Germany). The MEA for the RAMPA System can be classified into Type A: A modified, removable appliance based on the Biobloc Stage 1 appliance[15] (Fig. 1a);
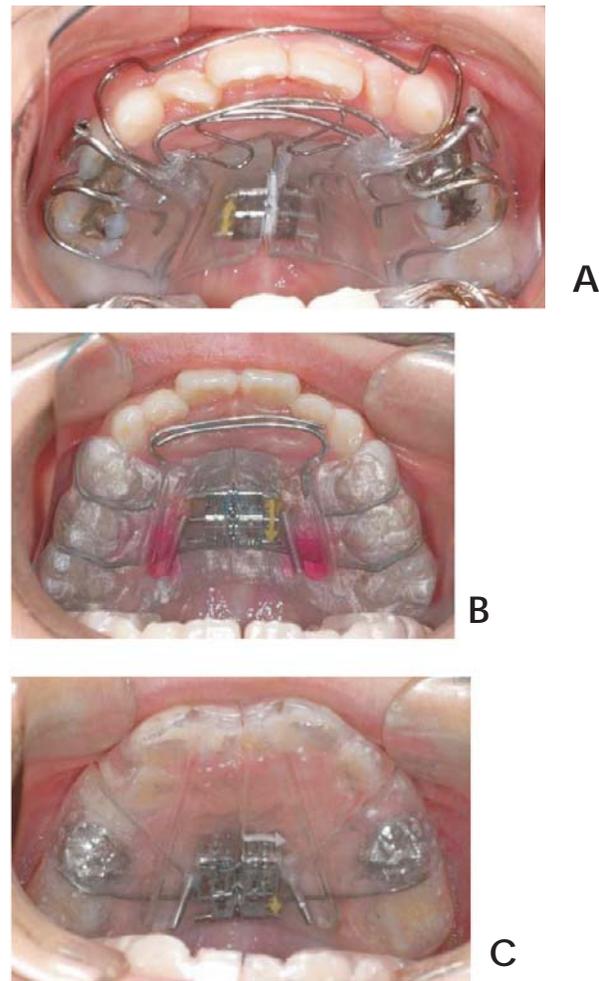
Figure 1 - The RAMPA System consists of a maxillary expansion appliance (MEA). In this study three variants were used. Type A: A modified, removable appliance based on the Biobloc Stage 1 appliance (a); Type B: A molar, occlusal, acrylic-bonded appliance (b), and Type C: A modified occlusal acrylic-bonded 3-D expansion appliance (c).

Type B: A molar, occlusal, acrylic-bonded appliance (Fig. 1b), and Type C: A modified occlusal acrylic-bonded 3-D expansion appliance (Fig. 1c). Parents were instructed to rotate the screw 0.125 (1/8) of a turn per day for a child in the mixed dentition or 0.125 (1/8) of a turn every other day for a child with eruption of the first premolars or for children with a permanent dentition. Each child/parent was informed that some sense of discomfort/mild pain may occur for the first few days while wearing the appliance. The anterior expansion screws were rotated until the anterior cross bite was reversed. Laterally, arch expansion was undertaken until the intermolar width of the first permanent molars at the palato-cervical margin showed a clinical width of 40mm. Expansion was continued until the palatal vault accommodated the tongue easily.

The RAMPA System consists of the MEA, the RAMPA appliance (Fig. 2), and an Active Bow (AB, Fig. 3). The AB is a connector developed for protraction of the maxilla during clockwise rotation. The direction of traction of the Horizontal Elastic (HEL) of the RAMPA System runs parallel and is approximately 10mm superior to the occlusal plane. Figure 4 shows the anterior vector of force (Fa) and the inferior vector of force (Fi) that result from traction with the HEL of the RAMPA System. But, Fi causes inferior displacement of the anterior teeth; therefore, this force is offset by the vector F2, resulting from the direction of traction of the Vertical Elastic (VEL) to promote antero-superior craniomaxillary growth. In addition, the turning moment resulting from clockwise rotation of the maxilla can be produced by making a right angle (90⁰) bend at the intersection of the HEL and VEL components. Although the ratio of the HEL and VEL may vary depending on the patient's requirements, the ideal traction force results in the range of ratios of HEL:VEL of 3:1 and 2:1.

The types of appliances used in this study were Type A: For patients in the primary or mixed dentition; HEL with 300–350g of force; VEL with 150–200g of force; Duration of 10–12h/day. Type B: For patients with mildly insufficient dental arch length in the mixed dentition; HEL with 350–450g of force; VEL with 200–300 g of force; Duration of 12h/day or longer. Type C: For patients during all stages; HEL with 350g or more of force; VEL with 200g or more of force; Duration of 12h/day or more. (In principle, 15h or longer i.e. full-time wear during the permanent dentition stage.)

Maxillary development obtained by the RAMPA System was continued until the overjet reached a maximum amount of approximately 15mm. Then the MEA was removed and a Biobloc Stage 2 appliance[15] was used as a retainer. Because deficiency in arch length and anterior crowding was observed in most cases, a Biobloc Lower Stage 1 appliance[15] was used in the lower arch to address these problems. Next, the anterior surface of the mandibular arch was remodeled labially, and the first permanent molars were displaced buccally to maintain tongue space. After verification of sufficient tongue space, a Biobloc Stage 3 or 4 appliance[15] was fabricated to the construction bite position, which allowed achievement of lip seal. The lip seal permitted correct formation of the maxillo-mandibular dental arches.

Standardized lateral cephalographs were taken for all patients prior to and after RAMPA treatment. Next, using appropriate software, 27 homologous landmarks (Fig. 5) were digitized and the mean, pre- and post-treatment craniofacial configurations were computed using Procrustes superimposition, and were subject to principal components analysis (PCA) and finite-element analysis (FEA).

Results

The amount of transverse maxillary expansion obtained was approximately 10mm in all patients. Some patients experienced pain that lasted for the 1-2 days after the appliance was inserted. The mean traction time (Table 1) was 112 days in 6 patients with a Type A appliance, who wore the appliance for a mean duration of 12h 45m/day. Three patients with a Type B appliance wore it for 76 days with a mean duration of 11h 54m/day. One patient wore the Type C appliance for 49 days with a duration of 16h/day.

Overall, the mean treatment time, calculated as the time of the second cephalograph, was 22.5 months ± 21.4. During this time, all patients showed significant craniofacial change (Fig. 6) and correction of anterior

Table 1

| Subject	Case #	Age (yr-month)	Sex	Meat Type	Period (days)	Duration/day (hr-min)	HEL (g)	VEL (g)	Other appliances
TO	2	7-1	M	A	98	11-46	270	150	Wire LS1
MU	11	9-0	F	A	125	16-00	300	100	LS1
YM	13	5-8	F	A	122	12-44	300	100	LS1 S3
YO	17	8-6	M	A	150	11-00	350	250	LS1 S3
CS	21	6-2	F	A	150	13-00	300	100	S3
TT	23	8-4	M	A	91	12-00	350	180	LS1 S3
NT	25	8-11	F	B	83	10-52	400	250	None
IT	26	7-6	F	B	75	12-00	400	200	LS1
KS	28	10-0	M	C	49	16-00	450	350	None
SH	30	7-8	M	B	71	12-48	400	200	LS1

HEL = Horizontal Elastic
VEL = Vertical Elastic
LS1 = Lower Biobloc Stage 1
S3 = Biobloc Stage 3
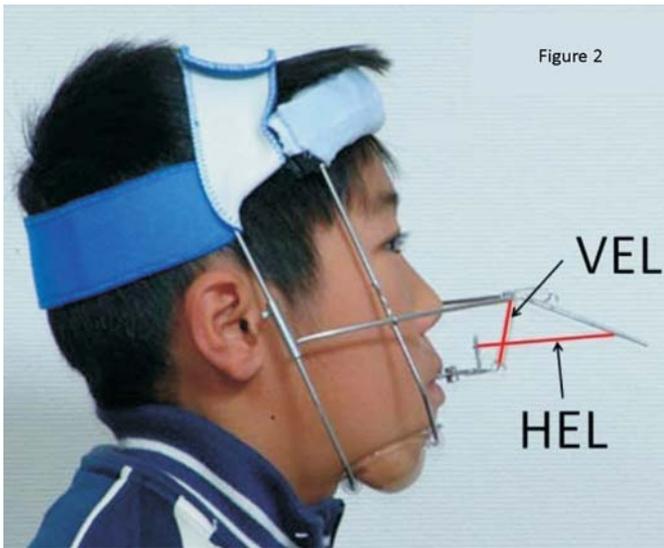
Figure 2 - The Right-Angled Maxillary Protraction Appliance (RAMPA) used in this study. HEL = Horizontal Elastic. VEL = Vertical Elastic


**Figure 3 -** Active bow (arrowed) that connects the RAMPA to the MEA.
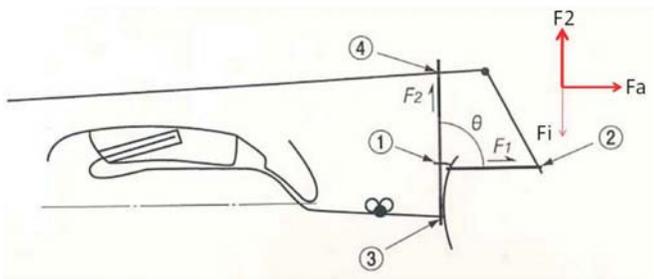
Figure 4 - The anterior vector of force (Fa) and the inferior vector of force (Fi) result from traction with the HEL of the RAMPA System. Fi causes inferior displacement of the anterior teeth; this force is offset by the vector resulting from the direction of traction of the Vertical Elastic (VEL) of the RAMPA System (F2). In addition, the turning moment resulting from clockwise rotation of the maxilla can be produced by making the angle formed at the intersection of the two HEL and VEL components into a right angle (90⁰).
1 = Active Bow (AB) Horizontal hook
2 = RAMPA Horizontal hook
3 = AB Vertical hook
4 = RAMPA Vertical hook
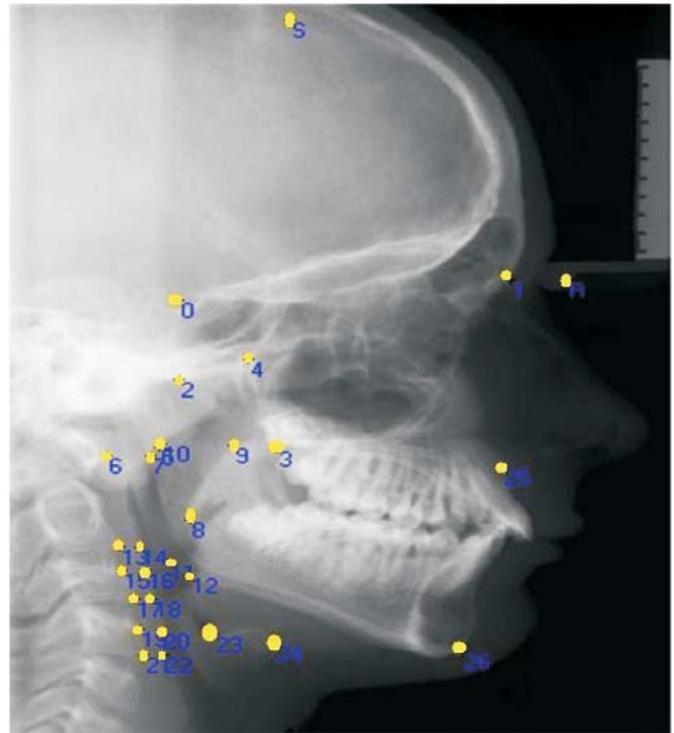
Figure 5 - Homologous landmarks employed for evaluation of craniofacial changes.
  0 = Sella
  1 = Nasion
  2 = Posterior Cranial Base
  3 = Posterior Nasal Spine
  4 = Superior Pterygomaxillare
  5 = Inferior Pterygomaxillare
  6 = Anterior-most point on anterior process of the Atlas.
  7 = Anterior-most point on posterior pharyngeal wall in the horizontal plane directly opposing Atlas
  8 = Most inferior point on the tip of the uvula.
  9 = Point of maximum convexity on the dorsum of the uvula
 10 = PPW1: Point directly opposing PNS in the horizontal plane on the posterior pharyngeal wall
 11 = Gonion
 12 = Most posterior point on the posterior surface of the dorsum of the tongue.
 13 = Lowest point of the C2 inter-vertebral disk.
 14 = Point on the surface of the posterior pharyngeal wall in the horizontal plane directly opposite point 13
 15 = Highest point of the inter-vertebral disk of C3.
 16 = Point on the surface of the posterior pharyngeal wall in the horizontal plane directly opposite point 15
 17 = Third cervical vertebra lower: Lowest point of the C3 inter-vertebral disk.
 18 = Point on the surface of the posterior pharyngeal wall in the horizontal plane directly opposite point 17
 19 = Fourth cervical vertebra: Highest point of the inter-vertebral disk of C4.
 20 = Point on the surface of the posterior pharyngeal wall in the horizontal plane directly opposite point 19
 21 = Lowest point of the inter-vertebral disk of C4.
 22 = Point on the surface of the posterior pharyngeal wall in the horizontal plane directly opposite point 21
 23 = Superior tip of Epiglottis
 24 = Anterior-most point on body of hyoid bone
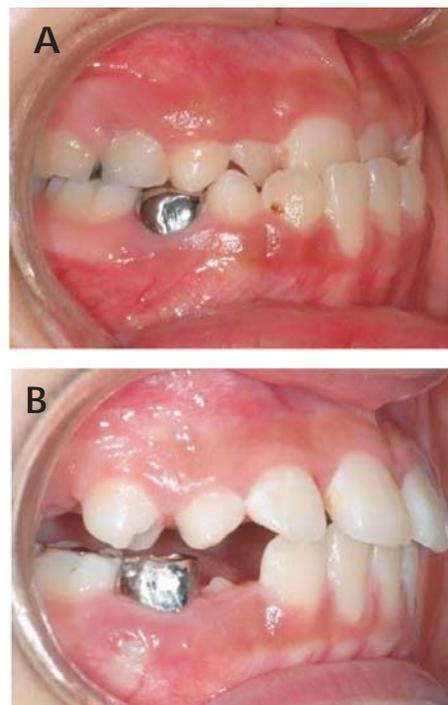 25 = Anterior nasal spine
 26 = Gnathion
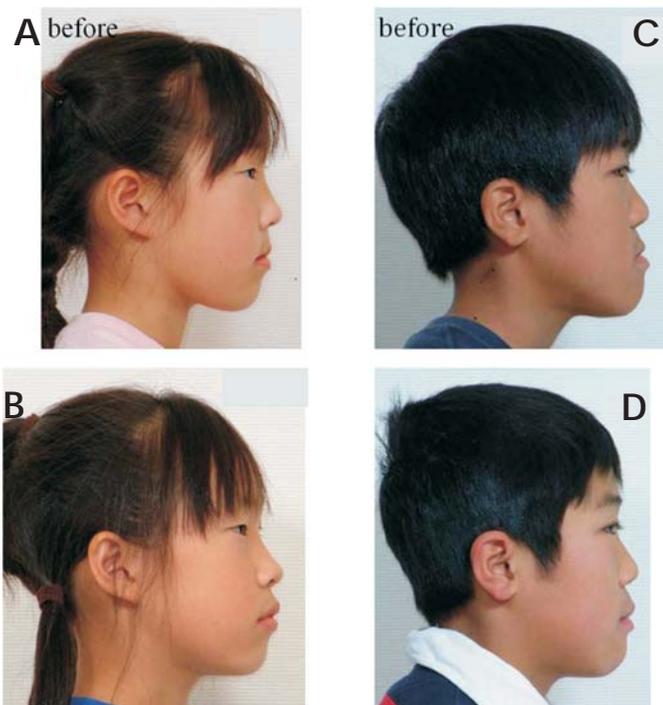
Figure 6 - (A)   A 9 year old female prior to RAMPA treatment. (B) The same female 16 months later. (C) A 10 year old male prior to RAMPA treatment. (D) The same male 4 months later.

Figure 7 - (A) The occlusion of a 9 year old female prior to RAMPA treatment. (B) The same patient 16 months later with correction of the anterior crossbite.

and/or posterior crossbite (Fig. 7). The mean, pre- and post-treatment craniofacial configurations were statistically different when tested using PCA (p < 0.001), with the first two principal components accounting for 97% of the total shape change (Fig. 8). Using FEA, the anterior cranial base showed a relative 12-32% increase in size (red coloration, Fig. 9). The direction of change was mostly horizontal (green coloration, Fig. 10). The midfacial region showed a conspicuous four-fold relative size-increase (purple coloration, landmarks 3-9, Fig. 8) allied with a 30% decrease elsewhere (blue coloration, Fig. 9). The direction of change was about 45^0 (blue coloration, landmarks 3-9, Fig. 10). Similarly, the mandibular region showed a two-fold relative size-increase (purple coloration, landmarks 11-12, Fig. 9) allied with a 20% decrease elsewhere (blue coloration, Fig. 9). There were also large, conspicuous four-fold improvements in oropharyngeal airway area (purple coloration, landmarks 8-13-14, Fig. 9).

Discussion

Although this study was conducted on a small sample, craniomaxillary protraction with the RAMPA System appears to be a promising treatment for Class III malocclusions in Japanese patients. It aims to resolve the problem of increased facial height during treatment for Class III malocclusions, which has been a

concern for a long time. Simultaneously, the RAMPA System seems to improve the morphological problems associated with a short anterior cranial base. It is based on the notion that the corrective midfacial growth direction is upwards and outwards, and thus it aims to provide craniomaxillary protraction and promotes horizontal craniofacial growth. Although long-term follow-up after debond was not available in this particular study, geometric morphometrics on cephalographs taken after, say, 2 years could be used to verify long-term growth and stability. Nevertheless, the major difference between the RAMPA System and conventional maxillary protractive appliances is in the protractive vector; while the former is a system developed for sagittally-directed upward and forward growth; the latter commonly exerts a downward and forward pull. This difference is based on the finding that malocclusion is often characterized by vertical maxillofacial growth.[16] However, the septal cartilage may be deformed by the downward displacement of the anterior maxilla. Thus, the posterior nasal spine may descend lower than the anterior nasal spine with inferior displacement of the maxilla. Therefore, conventional traction may cause counterclockwise rotation of the maxilla, an increase in the mandibular plane angle, and an increase in the height of the lower face. In other words, in a conventional maxillary protraction system, the horizontal elastic has a downward component acting 20-30° in relation to the functional occlusal plane. In response to this vector, PNS will be displaced downward in comparison to

ANS. Thus, Point A will be displaced antero-superiorly, with the maxilla appearing to rotate in a counter-clockwise direction. Conversely, the mandible will appear to rotate in a clockwise fashion, opposite to that of the maxilla, thus resulting in lower facial height lengthening. In contrast, using the RAMPA system,
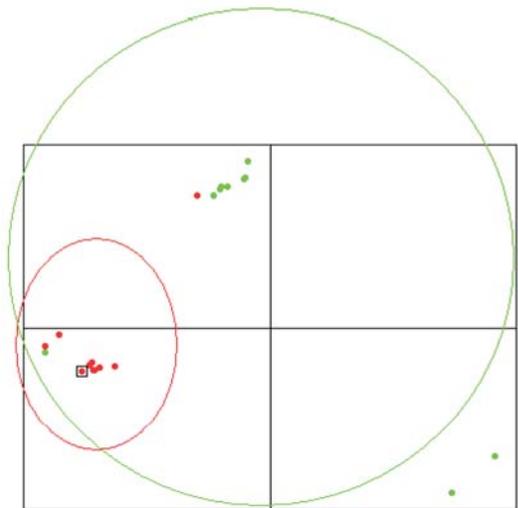

Figure 8 - Principal components analysis comparing 2-D facial morphology of patients prior to (red dots) and after RAMPA treatment (green dots). Using the first two principal components, which account for 97% of the total shape change, a significant difference was detected (p < 0.001).
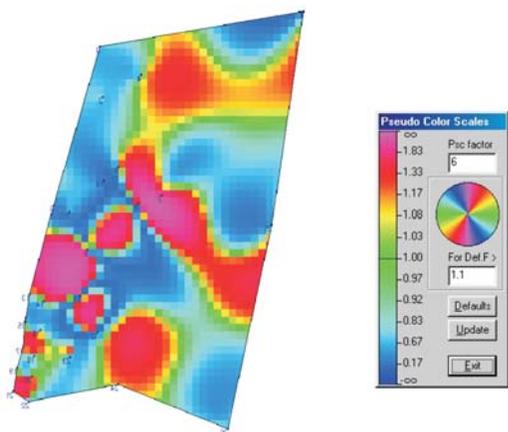
Figure 9 - Finite-element analysis comparison of mean craniofacial configurations prior to and after RAMPA treatment for size change. Using the vertical pseudo-color scale bar, the anterior cranial base (putative spheno-ethmoidal synchondrosis and fronto-ethmoidal suture regions) shows a relative 12-32% increase in size (red coloration). The midfacial region shows a conspicuous four-fold relative size-increase (purple coloration, landmarks 3-9) allied with a 30% decrease (blue coloration). The mandibular region shows a two-fold relative size-increase (purple coloration, landmarks 11-12) allied with a 20% decrease (blue coloration). There are also four-fold improvements in oropharyngeal airway area (purple coloration, landmarks 8-13-14).

with protraction of the horizontal elastic (HEL), PNS region moves in the direction shown by F1, being displaced antero-superiorly. The side effect of this vector is that the upper incisors move inferiorly, as shown by F2. However, the vertical elastic (VEL) cancels this downward vector by pulling the upper incisal region upwards. As a result, the RAMPA system differs from conventional maxillary protraction by rotating the maxilla clockwise, resulting in an overall antero-superior movement. In addition, the mandible rotates counterclockwise, which is the opposite of conventional maxillary protraction, also resulting in antero-posterior movement. Nanda[12] investigated force variables during maxillary protraction. He reported an anterior shift of the maxilla and a mesial movement of the maxillary molars. Nanda[12] also stated that the center of resistance in the maxilla was in the vicinity of the apices of the premolars, suggesting paradoxically that the height of the lower face might be shortened through clockwise rotation and horizontal traction of the maxilla. Therefore, in this study, the direction of traction was turned superiorly to the occlusal plane, aiming for clockwise rotation of the maxilla during protraction to inhibit any increase in facial height and promote horizontal craniofacial growth.

The significance of the cranial base in horizontal craniofacial growth extends beyond facial esthetics. Banabilh et al.[17] reported that airway impairments associated with obstructive sleep apnea (OSA) in non-obese Malaysians are predominantly associated with posterior cranial base morphology. In addition, for Class I occlusion, non-cleft children and those with
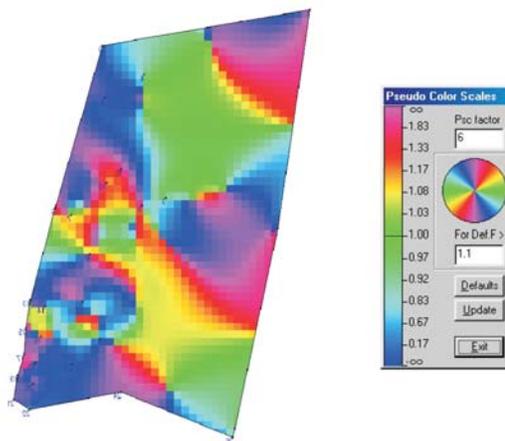
Figure 10 - Finite-element analysis comparison of mean craniofacial configurations prior to and after RAMPA treatment for directionality of change, using the circular pseudo-color scale. Notice that the direction of change in the anterior cranial base is mostly horizontal (green coloration). In the midfcaial region, the direction of change is downward and forwards at an angle of about 45⁰ (blue coloration, landmarks 3-9).

cleft lip/palate show similar craniofacial growth patterns. However, when comparing these two groups in the case of Class III malocclusion, patients with cleft lip/palate show clinically-deficient horizontal craniomaxillary growth. Thus, the morphology of the cranial base appears to be significant in various craniofacial conditions. Kiliç et.al[18] found the coexistence of maxillary counterclockwise rotation and mandibular clockwise rotation after rapid expansion and maxillary protraction. In addition, they noted head position and extension of cervical vertebra; and observed an increase in the nasopharynx and oropharynx. In our present study, we found a four-fold improvement in oropharyngeal airway area (Fig. 9). Airway improvements are also associated with Biobloc treatment in actively growing patients.[19] However, anterior cranial base growth was not demonstrated in that study. Therefore, horizontal craniofacial growth guidance using the RAMPA System might provide preferable consequences in a wide range of craniofacial conditions.

Conclusion

The anterior cranial base may be targeted for horizontal craniofacial growth guidance in the correction Class III malocclusions using the RAMPA System.

Acknowledgements

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