Midface Morphology and Growth in Syndromic Craniosynostosis Patients Following Frontofacial Monobloc Distraction

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Background: Facial advancement represents the essence of the surgical treatment of syndromic craniosynostosis. Frontofacial monobloc distraction is an effective surgical approach to correct midface retrusion although someone consider it very hazardous procedure. The authors evaluated a group of patients who underwent frontofacial monobloc distraction with the aim to identify the advancement results performed in immature skeletal regarding the midface morphologic characteristics and its effects on growth.

Methods: Sixteen patients who underwent frontofacial monobloc distraction with pre- and postsurgical computed tomography (CT) scans were evaluated and compared to a control group of 9 nonsyndromic children with CT scans at 1-year intervals during craniofacial growth. Three-dimensional measurements and superimposition of the CT scans were used to evaluate midface morphologic features and longitudinal changes during the craniofacial growth and following the advancement. Presurgical growth was evaluated in 4 patients and postsurgical growth was evaluated in 9 patients.

Results: Syndromic maxillary width and length were reduced and the most obtuse facial angles showed a lack in forward projection of the central portion in these patients. Three-dimensional distances and images superimposition demonstrated the age did not influence the course of abnormal midface growth.

Conclusion: The syndromic midface is hypoplastic and the sagittal deficiency is associated to axial facial concavity. The advancement performed in mixed dentition stages allowed the normalization of facial position comparable to nonsyndromic group. However, the procedure was not able to change the abnormal midface architecture and craniofacial growth.

Key Words: Craniofacial growth, facial advancement, frontofacial monobloc distraction, syndromic craniosynostosis

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Although there is not a consensus for the correction of large retrusions, frontofacial monobloc distraction (FMD)[1–3] is a traditional form of syndromic craniosynostosis (SC) treatment[4–8] because it allows functional and aesthetic gain with the middle and upper face advancement simultaneously.[9] However, a discussion about the results or even a preference indication of osteotomies comprising facial advancements is smaller than the uncertainties about what anatomical structures are performed and the behavior of this maturing skeletal structure when undergoing these procedures. Different imaging-evaluation technologies have tried to explain some of these doubts and added great contributions to the knowledge of midface morphology since Paul Tessier studied the dissection of corpses and the study of anatomy had its first osteotomies and facial advancements.[10,11] The aim of this study was to 3-dimensionally (3D) assess the midface size and shape of patients with SC compared to a nonsyndromic control group. The surgical treatment outcomes and its craniofacial growth pre- and postsurgically were assessed by tomographic image superimposition and 3D distance measurements.

METHODS

Sixty patients underwent FMD in the Division of Plastic Surgery, University of São Paulo, between 2002 and 2014. The study included 16 patients. The inclusion criteria were: clinical diagnosis of SC through evaluation by the craniofacial and genetics team, mixed dentition age and the presence of computed tomography (CT) scans of the skull and face in digital imaging and communications in medicine (DICOM). The exclusion criteria were: patients outside this age group, with a history of previous procedures in the frontal and midface region, as well as orthodontic or orthopedic treatment.

The CT scans of 16 patients were classified as: time 1 (T1): preoperative and time 2 (T2): postoperative. During the collection of SC group CT scans, the availability was identified from a larger number of tests for some of these patients. Thus, in the evaluation was included the following: time 0 (T0): CT scans done prior to T1, with an interval of at least 1 year for 4 patients and time 3 (T3): CT scans performed after the T2 interval of at least 1 year for 9 patients. Of these, 9 were females, and 7 were males with a mean age of 6 years and 2 months.

A control group of 9 nonsyndromic individuals were included in the sample (5 females and 4 males), with a mean age of 7 years, who

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had not undergone any surgical or orthodontic procedure and with 2 CT cone-beam scans with 1-year intervals during the growing season due another clinical conditions: time 0 (T0) (first CT scan available) and time 1 (T1) (CT scan after the first 1-year interval between them).

According to the surgical protocol of our institution, patients with SC ideally undergo posterior cranial vault decompression before the first year of life, as well as tracheostomy and tarsorrhaphy when necessary. The FMD is ideally performed at around 6 to 7 years in those patients with respiratory impairment due to obstructive sleep apnea and proptosis. Osteotomy of the type Le Fort III is reserved for patients in whom the frontal region is not affected and especially, in adult individuals. The distraction activation begins on the 5th postoperative day at a rate of 1 mm day divided into 2 daily activations until the maxillomandibular discrepancy and eye protection are overcorrected. The consolidation time is about 8 to 12 weeks.

Three-dimensional surface models were created from the DICOM files to evaluate what the study proposed in the following steps: volumetric label map construction: using ITK-SNAP 2.4.0,[12–16] an open-source software (www.itksnap.org), the cranial base face were segmented for the different time scans; using 3D Slicer 4.4 (www.slicer.org), another open-source software,[13–16] the virtual 3D surface models were created from the different time volumetric label maps; the 3D models of all patients were oriented to the same position in the 3D coordinate system[16]; the 3D superimposition registered in the cranial base was performed using the anterior cranial fossa label map as a best fit reference. A fully automated voxel-based registration was performed. The matrix generated was applied to the other scans; and landmarks were placed at surface models of different times using the Q3DC tool in the 3D Slicer 4.4 software, as shown in Supplementary Digital Content, Table 1, http://links.lww.com/SCS/B799 and Figure 1.

Next, 3D distances and the amount of directional changes in each plane of the 3D space (*x*, *y*, *z*: respectively, the mediolateral, antero-posterior, and superior-inferior axes) were measured between the corresponding coordinates of landmarks placed on surface models.

The evaluations for the distances were measured in millimeters (mm) and angles in degrees (°), as described below:

- Maxillary dimensions: the 3D distances for width and length were evaluated for T0 of the control group and T1 of the SC group. The landmarks used for the width and length were MaxR and MaxL, Midpoint pterygoid, and point A, respectively.
- Facial angles: angles were evaluated for control group (T0) and T1 and T2 of the SC group. The angles evaluated were formed from lines among the landmarks: FrontozygR, N, and FrontozygL; OrbR, point A, and OrbL; ZygR, point A, and ZygL and S-N-point A (SNA).
- Distance S: quantitative measures (3D distances) were assessed for control group (T0) and T1 and T2 of SC between the landmarks: S-N; S-FrontozygR; S-FrontozygL; S-OrbR; S-OrbL; and S-point A.
- Advancement: the evaluation of the outcomes of FMD was based on the measurement of 3D distances between corresponding landmarks and components *x*, *y*, and *z* of the corresponding landmarks on the surface models of times T1 and T2 of the SC group. The landmarks used in this evaluation were N, FrontozygR, FrontozygL, OrbR, OrbL, ZygR, ZygL, and point A.
- Growth: the same procedure described above was applied to times T0 and T1 of the SC group to evaluate preoperative growth and to times T2 and T3 of the same group to evaluate postoperative growth. For the control group, times T0 and T1 were used to evaluate craniofacial growth. Color-coded surface distance maps were used to visually demonstrate the overall midface changes in groups. Inter-group comparison tests using Student's *t*-test or its nonparametric equivalent Mann-Whitney test for variables that did not observe normality, were used to evaluate the independent variables.

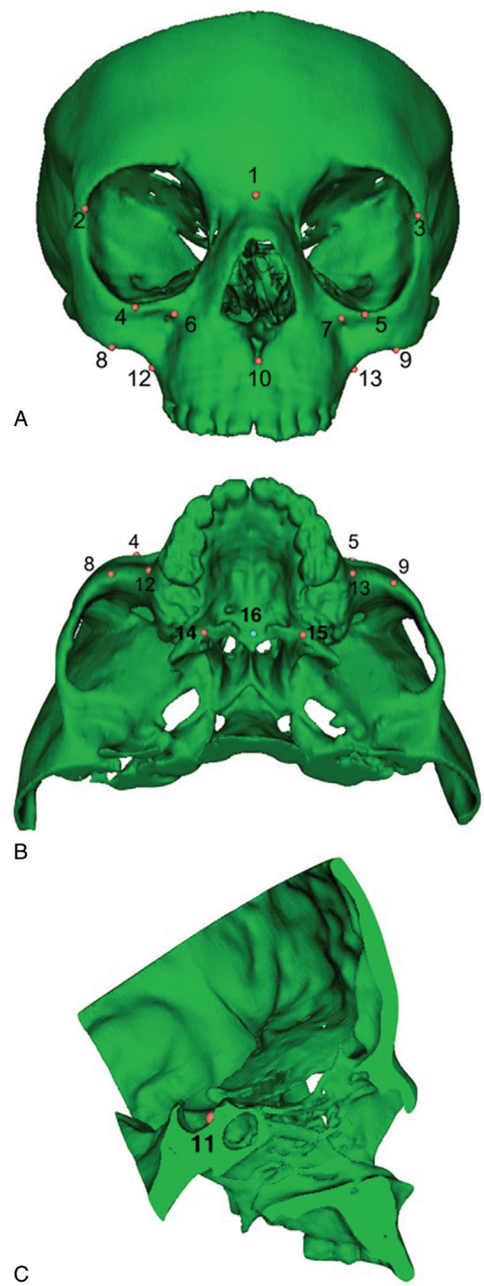

FIGURE 1. Reference points on the surface of the 3-dimensional model. (A) Points on the anterior surface of the face. (B) Maxillary points in lower view. (C) Skull base point in the sagittal view 3-dimensional model sectioned.

RESULTS

The SC group was constituted of 10 patients with Crouzon syndrome (CS), 5 with Apert syndrome, and 1 with Pfeiffer syndrome at mixed dentition age (6years and 2 months mean age). Twelve

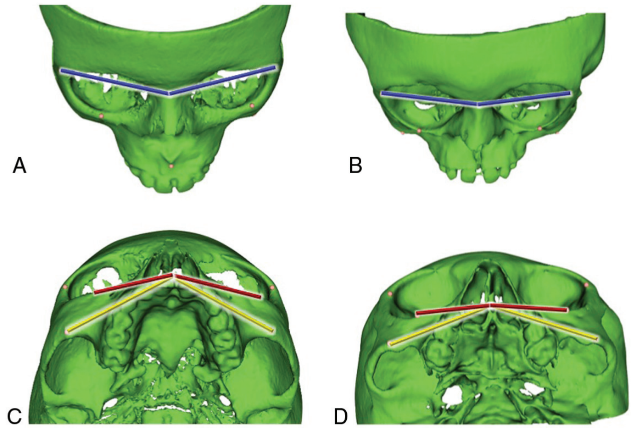

FIGURE 2. Representation of facial angles FrontozygR-Nasion-FrontozygL (blue line), OrbR-pointA-OrbL (red line), and ZygR-pointA-ZygL (yellow line). (A) Control (T0). (B) SC (T1) and SC (T2). (C) Control (T0). (D) SC (T1) and SC(T2).

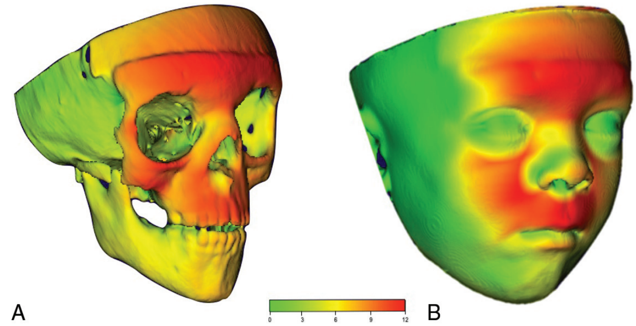

FIGURE 4. Colormaps of 3-dimensional surface models of T1 and T2 superimposition. The color scale shows the average advancement of the SC group in millimeters. Red represents the anterior displacement and green any changes. (A) Result of frontofacial monobloc distraction bone structure. (B) Right soft tissues.

patients used internal device and 8 showed major or minor surgical complications. The advancement measured by point and demographic data about the sample is showed in Supplementary Digital Content, Table 2, http://links.lww.com/SCS/B799.

There was a significant difference between the groups studied for 3D variable maxillary width and length. The syndromic maxilla is smaller in width and length compared to the control group (T0) (Supplementary Digital Content, Table 3, http://links.lww.com/SCS/B799).

A statistically significant difference was observed between the control group (T0) and SC (T1) and the control group (T0) and SC (T2) at the angle formed between OrbR-pointA-OrbL. The angle observed for the SC group (T1) and SC (T2) is more obtuse for than the control group (T0). No difference was observed between the SC groups (T1) and (T2) because this average variable had not changed. The result of the medians of the variable-angle ZygR-pointA-ZygL showed a more obtuse angle in the SC group (T1) compared to the control group (T0). However, a statistical difference was not observed between the SC group (T2) and others (Supplementary Digital Content, Table 4, http://links.lww.com/SCS/B799 and Fig. 2).

The average angle SNA for the control group (T0) was statistically different from the SC group (T1), presented a more acute angle compared to the control group (T0), but no difference was observed between the SC group (T2) and others (Fig. 3).

The results showed that for the variables S-N, S-OrbR, S-OrbL, and S-point A, there was a statistical difference between the control group (T0) and CS (T1), with lower values for the second. There was no significant difference between the control group (T0) and CS group (T2) (Supplementary Digital Content, Table 5, http://links.lww.com/SCS/B799).

The analysis of the mean (± standard deviation) of advancement for each variable was studied at coordinates x, y, z, and 3D (Supplementary Digital Content, Table 6, http://links.lww.com/SCS/B799). Once these were measured in a coordinate system, negative values were found to be lateral, posterior, and inferior. This is important because concerning normal maxillary growth, negative values for the z component are expected. The average for the variable displacement 3D point A was 14.76 mm. The average for the y component was 12.39 mm, and for z was 6.02 mm. The average between the different variables, regardless of location showed very similar displacement (Supplementary Digital Content, Table 6, http://links.lww.com/SCS/B799 and Fig. 4).

For the craniofacial growth, the point A showed a statistical difference between the control group (T0-T1) and SC (T2-T3) for both the Z component as 3D. The CS group (T0-T1) showed no difference between the control group and SC (T2-T3). Numerically, however, whereas the 3D displacement was 2.60 in the control group, in the SC group (T0-T1), it was only 1.3 mm (Supplementary Digital Content, Table 7, http://links.lww.com/SCS/B799). The color maps shown in Figure 5 represent the qualitative assessment of the results described earlier.

DISCUSSION

The FMD is a surgical procedure performed on an abnormal morphologic structure configuration. The results obtained through 3D measurements demonstrated primarily that dimensions of the maxilla are reduced in relation to both width and length. These results converge with the assertion that the lack of maxillary growth and abnormal remodeling pattern results in a bone structure of small size and disorganized architecture, as Kreiborg highlighted.[17–19]

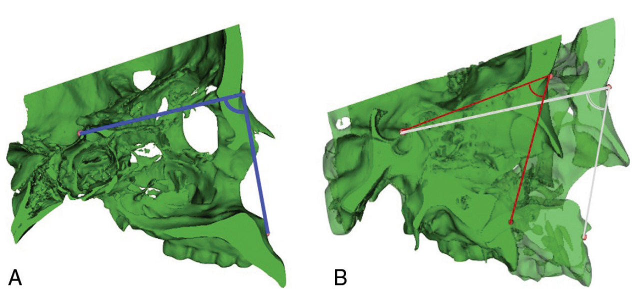

FIGURE 3. Angle representation formed among the Sella-pointA-Nasion points (SNA). (A) Control (T0) (blue line). (B) SC (T1) (red line) and SC (T2) (white line) in image superimpositon.

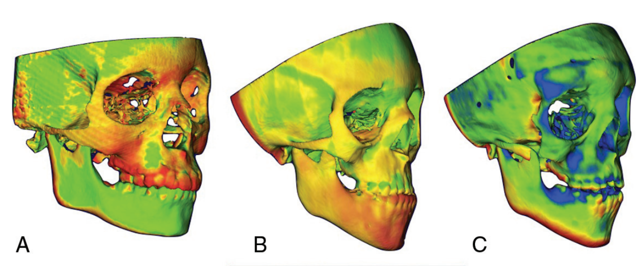

FIGURE 5. Colormaps represent the growth of midface in the studied groups. (A) Control (T0-T1). (B) SC (T1-T2). (C) SC (T2-T3).

Another outcome is the decreased projection of the maxilla in subjects with SC. The angles formed between the orbital points and point A and zygomatic and point A are more obtuse in the SC group. This is important because beyond the obvious facial concavity resulting from the severe maxilo-mandibular discrepancy observed in SC, there is a flattening of the facial projection. This finding could be assigned to SA patients but is not exclusive to this condition. Poor projection of the central portion and a flattened face possibly contributes negatively to the decline in posterior airspace that is implicated as one of the major factors of OSAS in SC.

Ponniah et al[20] claim that concavity can increase even more after FMD due to the plasticity of young bone because there is a tendency of the face to deform in the distractor's site of action. The results of this study disagree with these statements because the angles did not change after surgery regardless of the distractor used. The major difference was observed between the control group (T0) and SC (T1) with respect to point A, showing the abnormal position of the maxilla in relation to the skull base. However, for all distances measured in the SC group (T2), the values were not statistically different with the control group (T0), and there was an alpha 0.05 error, demonstrating that the advancement was sufficient to reach values of normal with high statistical power (Supplementary Digital Content, Table 5, http://links.lww.com/SCS/B799).

The spatial reduction of the maxilla and flattening axial angles invariably exhibits the limitations of FMD front-of-midface dysmorphology. Some authors observing these limitations have proposed associated or alternative osteotomies to normalize the axial recess of the sagittal addition in SC.[20,21–24] Facial bipartition has been indicated by some surgeons to be combined with FMD to provide further advancement of the central face.[6,24,25,26] An osteotomy of Le Fort II associated with the zygomatic repositioning described by Hopper is another example of the continuing search for improved facial contouring in SC.[27,28]

These statements are in direct opposition of those that do not adopt this technique.[1–3,29,30] While some decide on treatment with fronto-orbital advancement at an earlier age and Le Fort III later, others add further osteotomies to sufficiently complex monobloc. The results of this study converge with these surgeons' purposes to correct axial concavity in addition to sagital facial concavity.

The results obtained demonstrated that the advancement achieved a common pattern of horizontal displacement (y component) with associated substantially vertical displacement (z component). These findings were observed for both the lateral and central points (Supplementary Digital Content, Table 5, http://links.lww.com/SCS/B799). Different than what has been described by some authors,[4,20] there was no further movement on the side or central portions of the face both from the evaluation of the distances and the color maps (Fig. 4).

A series of midface advancements, either Le Fort III or monobloc, frequently show that craniofacial growth after surgery is interrupted.[31,32] However, information on craniofacial growth in SC prior to surgery is scarce. Kreiborg and Meazzini[18,19,33] evaluated the preoperative growth of patients with SC from overlay radiographs and cephalometric tracings, and both said that the maxilla does not move forward in relation to the skull base and that the changes observed during the observation period result only from an abnormal remodeling of the bone surface. The results of the measurements and the color maps of the evaluated groups allowed some considerations of craniofacial growth, despite the limitations of the sample size (Fig. 5).

The largest downward displacement observed in nonsyndromic patients coincides with the maxillary behavior during normal facial growth. Similarly, the values found for the 3D linear distance from point A were statistically different between groups, with no difference between the control group and SC (T0-T1); however, in the first, the resultant displacement was 2.60 mm, whereas in preoperative patients, it was only half that at 1.31 mm. Variables with significant differences between the groups showed, although rarely, that when there were differences between groups, the control group presented greater 3D anterior and inferior displacement compared to the others. The color maps of both groups reinforce the numerical results showing the lack of growth of a group relative to another (Fig. 5).

For the SC group (T2-T3), the observed values coincided with the data presented in the literature that advancement is stable after a period of consolidation. It can be seen in 2 recent studies that demonstrate the stability of long-term follow-up despite different degrees of relapse regarding the consolidation time and type of distractor as observed in the systematic review conducted by Bertrand et al with 61 studies and 689 published patients between 1998 and 2018.[34,35] A statistically significant difference for the z component (vertical) and 3D distance from point A was observed between the control group (T0-T1) and SC (T2-T3), showing the loss of growth of these patients undergoing FMD compared to children with normal growth.

Different findings concerning normal maxillary growth like those observed by Bachmayer et al[36] can be questioned because the authors used as reference a point on the posterior skull base, where the growth appears to be less affected. Based on this concept of normal preoperative growth and the absence of normal growth in the postoperative period, authors like McCarthy et al[31,32,37] started to posit that possible injury maxillary growth centers like pterygomaxillary fissures alter this process. What was observed in this study based on tomographic image superimposition is similar to Kreiborg and Meazzini's outcomes. The growth is compromised apparently independently of the surgery.

Different factors converge for the impairment of growth in SC. Recent publications[38–40] have shown that premature fusion structured as sphenooccipital synchondrosis at the skull base accounts for more pronounced retrusions of the midface. Over the past 30 years, distraction osteogenesis has been applied to the spectrum of craniofacial osteotomies and its outcomes are indisputable. At the same time, predictability of outcome, stability and relapse remain challenging, especially in complex procedure such as the FMD.[41]

Some limitations of this study should be considered. The analysis of mixed diagnostic group three syndromes may have differing surgical results**.** Though, the precision of this image software allows a great reliability, cephalometric measurements and manual marking of points were used as methods and measurement errors compromise the results. The control group was matched for age but not for gender. It would be very interesting to have an age and gender matched for each patient but the sample was small and a control sample too.

CONCLUSION

The results presented in this study showed that we are faced with abnormal morphology and an abnormal position, which grows little; after the FMD, its position is corrected without changing its configuration. The progressive knowledge gained from the 3D imaging methods regarding the craniofacial anatomy in SC and the limitations imposed by traditional approaches increasingly challenge craniofacial surgeons to associate osteotomies or reinvent surgical approaches to correct this alteration of the face and achieve better cosmetic results beyond just being functional.

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