Effect of Alveolar Bone Grafting on Nasal Morphology, Symmetry, and Nostril Shape of Patients With Unilateral Cleft Lip and Palate

Melissa Sander, D.D.S., M.Sc., F.R.C.D.(C)., John Daskalogiannakis, D.D.S., M.Sc., F.R.C.D.(C).,
Bryan Tompson, D.D.S., Dip. Ortho., F.R.C.D.(C)., Christopher Forrest, M.D., M.Sc., F.R.C.S.(C).

Objective: **To evaluate nasal morphology, symmetry, and nostril shape in patients with unilateral cleft lip and palate following mixed-dentition alveolar bone grafting.**

Design: **Prospective stereophotogrammetric study.**

Setting: **Hospital-based.**

Patients: **Thirty-nine patients with a history of repaired unilateral cleft lip and palate who received an iliac crest alveolar bone graft were recruited prospectively to participate in the study. Each patient served as his/her own control.**

Interventions: **Partial facial impressions of all patients were acquired before and a minimum of 6 months after the alveolar bone grafting procedure. Image acquisition and analysis of the casts constructed from these models were carried out using three-dimensional stereophotogrammetry.**

Main Outcome Measures: **Surface-based registrations and linear measurements were performed to assess nasal morphology and nostril shape. A modified Procrustes technique was used to determine the change in nasal symmetry. A two-tailed, paired *t* test and an analysis of covariance were used to assess statistical significance.**

Results: **Significant side-to-side asymmetry exists in the nasal region of patients with unilateral cleft lip and palate, both before and after alveolar bone grafting. No significant changes were observed between pre–alveolar bone graft and post–alveolar bone graft images based on linear measurements, asymmetry scores, and registrations. Gender and surgeon were not significant factors.**

Conclusion: **Under the conditions of this study, mixed-dentition alveolar bone grafting appears to have no significant long-term effect on nasal morphology, symmetry, or nostril shape.**

KEY WORDS: *alveolar bone grafting, nasal morphology, nasal symmetry, nostril shape, stereophotogrammetry, unilateral cleft lip and palate*

Neonates with unilateral cleft lip and palate (UCLP) present with significant distortion of the nasal structures, owing to deficiency of tissue, aberrant muscle insertions, and habitual placement of the tongue in the cleft (Atherton, 1967; Latham, 1969; Ross, 2002.) The cleft septorhinoplasty is a procedure commonly performed at the time of initial lip repair, designed to improve the shape, projection, and symmetry of the nose. Despite such surgical intervention, the nostril, nasal tip, dorsum, bridge, ala, and columella typically remain distorted to some degree following the initial cleft nasal repair. In many institutions, nasal revisions are postponed until after bone grafting of the alveolar process (ABG) has been carried out, based on the premise that the ABG will restore the bony defect on the affected side at the piriform rim and elevate the nasal floor, thereby possibly improving nasal form (Bergland et al., 1986; Lilja et al., 1987, 2000; Tolman et al., 1988; Kalaaji et al., 1994, 1996; van der Wal et al., 1997).

Investigations have shown nasal and facial asymmetries to persist following ABG (Millard, 1982; Ross, 1987; Trotman, 1997; Russell, 2000). Only one study was found that evaluated the effect of alveolar bone grafting specifically on the nasal region of nine individuals with unilateral cleft lip, using a photographic technique. The authors concluded that the ABG resulted in improved nasal symmetry, as reflected by a 2.4% increase in the columella index score following the procedure (van der Wal et al., 1997).

Dr. Sander is Associate, Department of Orthodontics, Faculty of Dentistry, University of Toronto, Toronto, Ontario, Canada. Dr. Daskalogiannakis is Assistant Professor, Department of Orthodontics, Faculty of Dentistry, University of Toronto, and Staff Orthodontist, SickKids Hospital, Toronto, Ontario, Canada. Dr. Tompson is Head, Department of Orthodontics, Faculty of Dentistry, University of Toronto, and Director, Division of Orthodontics, SickKids Hospital, Toronto, Ontario, Canada. Dr. Forrest is Head, Division of Plastic Surgery, and Medical Director, Centre for Craniofacial Care and Research, SickKids Hospital, Toronto, Ontario, Canada.

Submitted January 2009; Accepted February 2010.

Address correspondence to: Dr. Melissa Sander, 103-323 Wilson Street E, Ancaster, Ontario, Canada L9G 4A8. E-mail drmsander@gmail.com.

DOI: 10.1597/09-007

The modes of data acquisition for assessment of nasal morphology vary widely in the literature and range in sophistication and reliability. Data may be collected using photographs, radiographs, plaster casts, infrared stroboscopy, video imaging, laser scanning, or stereophotogrammetry. The 3dMD™ system (3dMD, Atlanta, GA) is an example of a commercially available photogrammetric system that uses cameras set at various angles to produce a digital three-dimensional (3D) representation of the subject. Accurate texture mapping is achieved through the simultaneous acquisition of geometry and high-resolution color texture data (Heaston, 2006). The accuracy of the picture is within 1 mm, with a resolution of 40,000 polygons per square inch and a texture image with 24-bit color (Honrado and Larrabee, 2004). Previous studies have used earlier versions of the 3dMD™ system to study patients with cleft lip and palate (CLP) (Singh et al., 2005; Krimmel et al., 2006).

The objective of this study was to assess the change in nasal morphology, symmetry, and nostril shape in patients with UCLP following alveolar bone grafting, using 3D stereophotogrammetry.

Methods

Sample

The subjects for this study were recruited prospectively from the Cleft Lip and Palate Programme at SickKids Hospital in Toronto, Ontario, Canada. The patients had a history of nonsyndromic UCLP and received secondary (mixed-dentition) ABG over a 57-month period (October 2001 to June 2006). Patients who underwent nasal revision or any other type of surgery that could potentially affect the nasal morphology during the experimental period were excluded. In addition, individuals who did not have their initial repairs at SickKids Hospital were excluded to reduce surgical variability. No exclusions were made based on ethnic background, race, or severity of the cleft because each patient would serve as his/her own control.

Ethics approval was obtained from the Research Ethics Board at SickKids Hospital prior to commencing the study. Consent to participate in the study was obtained by the parents or guardians of all patients prior to their participation. The orthodontic records of the patients were searched for relevant information. Age, sex, laterality of the cleft, surgeon, and timing of the bone-grafting procedure were recorded. The sample consisted of 39 individuals who ranged in age from 7 to 14 years at the time of ABG. The mean age of the cleft group was 10.45 years at the first observation (pre-ABG) and 11.37 years at follow-up. The group consisted of 12 girls (30.8%) and 27 boys (69.2%). The cleft was located on the left side in 27 (69.2%) patients and on the right in 12 (30.8%) patients. Of the 39 patients, 21 had complete unilateral clefts, and 18 had incomplete unilateral clefts.

Grafting was performed by placing cortico-cancellous bone from the medial iliac crest into the cleft defect following the repair of the nasal layer and packing it as high as possible, aiming at augmentation of the piriform aperture, per the standard technique used in our hospital. No onlay grafts were placed. Three plastic surgeons were involved in the treatment of these patients. They were all from the same institution and used similar surgical techniques. Figure 1 illustrates the age and sex distribution of the sample.

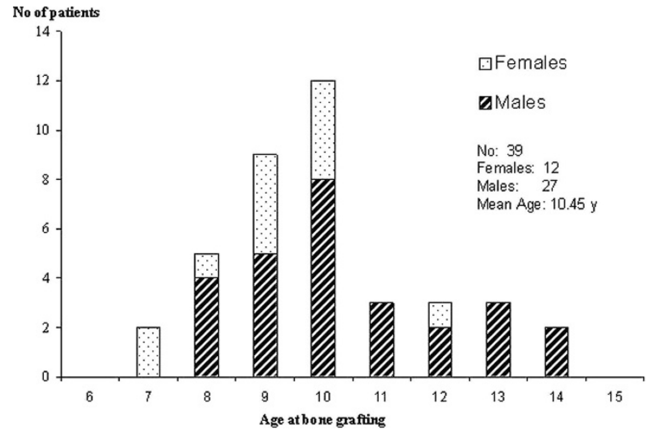

FIGURE 1 Age and sex distribution of the study sample.

Protocol

Partial facial impressions were acquired for each participant at two time registrations: the first at 1 month to 1 week prior to ABG (pre-ABG) and the second a minimum of 6 months after ABG (post-ABG). The impressions were taken with Express C.D. (Heraeus Kulzer, Inc., South Bend, IN), a silicone-based, addition curing elastomeric dental impression material, during one of the patients' scheduled visits to the SickKids Orthodontic Clinic. The light-bodied material was expressed, using the appropriate dispenser, onto an area spanning from the forehead to below the vermilion border of the upper lip, including the inner canthi of the eyes and extending 1 cm lateral to the alar contour. This material combined good accuracy and detail with low viscosity, minimizing any distortion of the nose during its application. Once the light-bodied material had set, a heavy-bodied silicone material was applied over it to increase its firmness, obviating the need for an impression tray. This two-step technique helped facilitate the removal of the nasal impression without tearing it. Models were poured from these impressions using yellow dental gypsum. All pre-ABG and post-ABG impressions were taken by the same investigator (J.D.).

Stereophotogrammetric Image Acquisition

Partial facial images were acquired with the 3dMD™ stereophotogrammetric system and analysis of the images were performed using 3dMDpatient™ v3.0 software

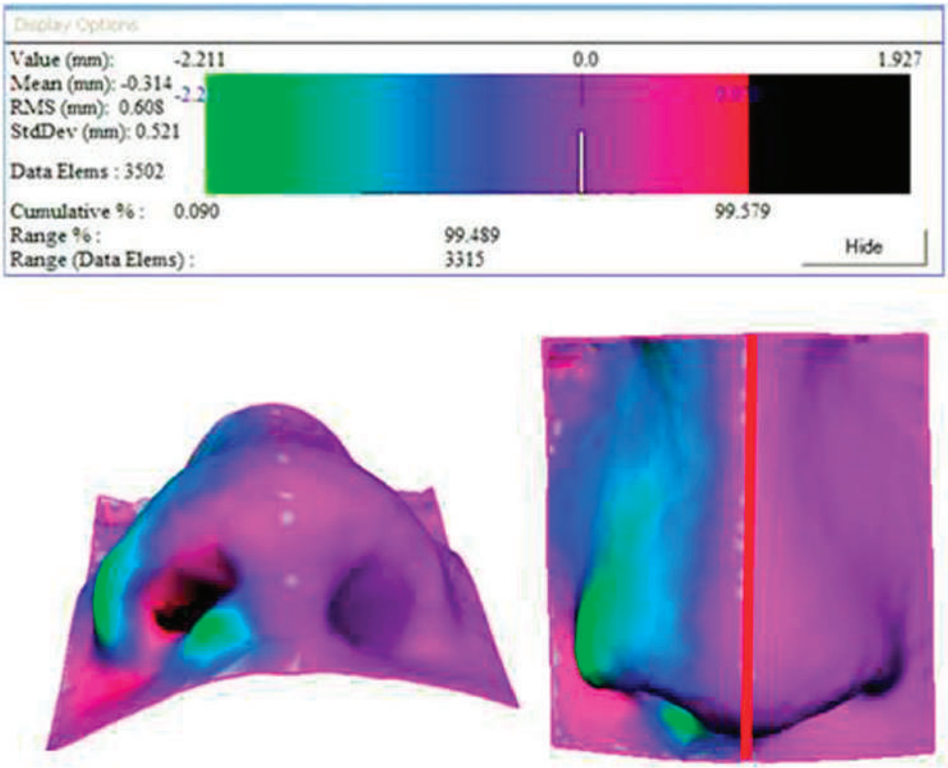

FIGURE 2 Asymmetry analysis for posttreatment mirrored image. Color histogram demonstrating differences in nasal morphology and symmetry. Best-fit superimposition of the noncleft-side nasal surface with the mirror image of the cleft-side nasal surface (patient's right). The asymmetry remained relatively the same following the alveolar bone graft.

(3dMD). All models were mounted on a surveyor affixed to a tripod at a standardized height and distance from the imaging machine. The system was calibrated before every imaging session.

Data Analysis

Asymmetry Analysis

A modified Procrustes technique was used to determine the symmetry of each UCLP nose by performing a best-fit superimposition of its surface with its mirror image (Maull et al., 1999). The vertical plane of the nose was established through soft tissue nasion (na) and subnasale (sn) perpendicular to the plane connecting the endocanthions (en). The cleft sides on the pre-ABG and post-ABG images were then selected and mirror images created (Fig. 2). In essence, an image was constructed of a nose with two cleft nostrils. The original unaltered image served as the reference image and was then superimposed on the constructed image or the difference surface to show the asymmetry between the cleft and noncleft nostrils (Fig. 2). Root mean squared distances (RMS) between the two surfaces were calculated and expressed as asymmetry scores for each 3D configuration before and after ABG. The RMS value quantified the degree of nasal asymmetry. Each patient served as his/her control, and qualitative and quantitative outputs were generated.

A two-tailed, paired *t* test was used to analyze the data and assess statistical significance between the pre-ABG and post-ABG asymmetry scores. Analysis of covariance (ANCOVA) was used to test for among-group differences and to investigate the influence of the following covariates: surgeon, gender, and time period between the pre-ABG and post-ABG impressions on the dependent variables and mean and RMS differences.

Registrations

Surface-based registrations of the pre-ABG and post-ABG nasal images were completed for each patient (Fig. 3). Manual registration followed surface-based registration when necessary to yield a more accurate final result, according to the manufacturer's instruction manual. A circular area of polygons in the area of the intercanthal line and long axis of the nose was selected on the post-ABG image to serve as a reference for the registration process. This region was selected because it was unlikely to be affected by the bone-grafting procedure. The two images were then registered using the pre-ABG image as the reference surface and the post-ABG image as the difference surface. ANCOVA was used to determine if any statisti-

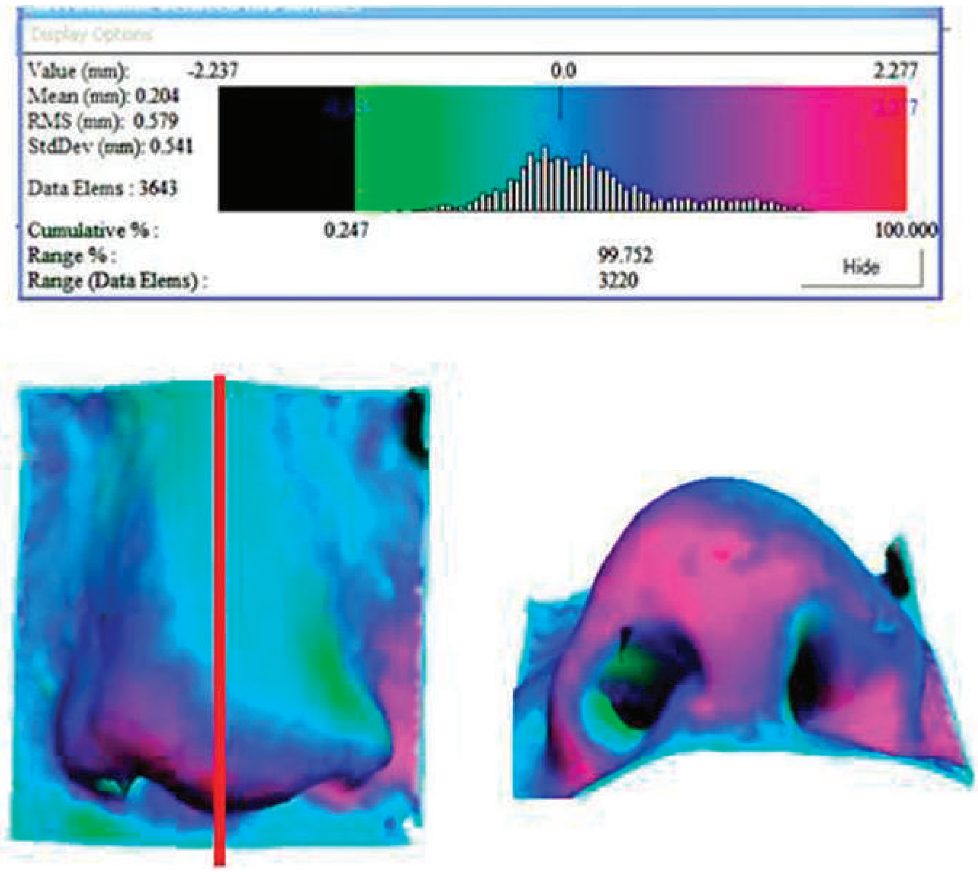

FIGURE 3 **Registration of pretreatment and posttreatment image. Histogram showing the distance between the two surfaces. The red end of the scale shows the most positive surfaces (i.e., those where the "post" surface is in front of the "pre" surface); green is the most negative (i.e., those where the "post" surface is behind the "pre" surface). Some improvement was noted at the inferior aspect of the cleft nostril (patient's left) where the alveolar graft was placed.**

cally significant differences were apparent between the cleft and noncleft registrations while controlling for time period between impressions, gender, and surgeon.

Linear Measurements

Linear height and width measurements were calculated by means of 3D coordinates on the pre-ABG and post-ABG images in order to quantify nasal morphology. The height of the nostril was determined by the linear distance between the highest and lowest point on the columella (c′) (Fig. 4). The width of the nostril was determined by the widest linear dimension, or more specifically, from the most medial point on the midportion of the alae (al′) to the midpoint of the columella crest (sn′). Repeated measures ANCOVA was used to determine whether differences existed between the cleft and noncleft nostrils before and after the bone-grafting procedure.

Pilot Study

A pilot study was done to validate the facial impression-taking technique that was used on the study subjects. Partial facial impressions were taken on nine noncleft individuals using the procedure outlined above. The plaster models produced from these impressions were scanned, and the acquired images were compared with real-time soft tissue images of the same noncleft individuals using the 3dMD^{TM} system (3dMD).

A surface-based registration was carried out with the images of the models and the images of the live subjects to determine the difference between the two surfaces. These registrations were completed in triplicate to ensure that the registration technique was reproducible. An intraclass correlation coefficient (ICC) was calculated from the collected data.

The pilot study indicated that the nasal models were highly representative of the real-time soft tissue images. The average mean difference was 0.084 mm and the average RMS value was 0.505 mm. All registrations were completed in triplicate, and the reliability of these measurements was excellent (ICC = .994).

The nostril height and width measurements also were calculated on the images of the nasal models and the live subjects. These measurements were very reliable, confirming the accuracy of the impression-taking technique (ICC > .992).

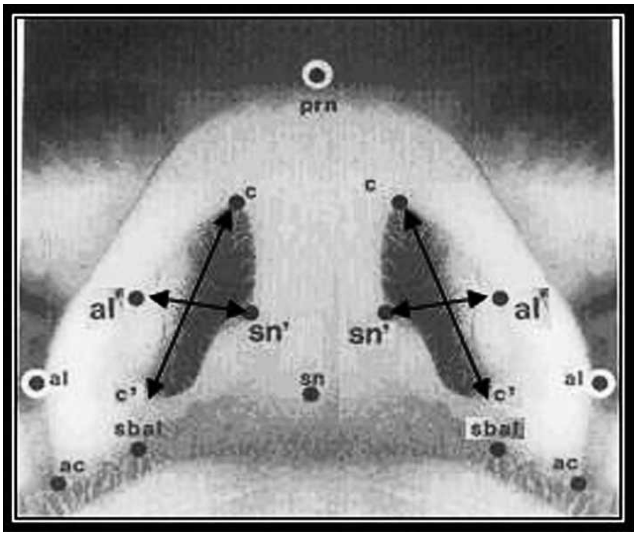

FIGURE 4 **Linear nasal height and width measurements (adapted from Farkas, 1994). Legend: Highest point of columella (c); lowest point of columella (c′); subnasale prime (sn′); subnasale (sn); pronasale (prn); alare prime (al′); subalare (sbal); alare (al); alar curvature (ac).**

Results

Asymmetry Analysis

The asymmetry analysis showed no significant differences between the pre-ABG and post-ABG mirrored images ($p = .074$). The amount of improvement in nasal symmetry appeared to decrease as the period of time between the pre-ABG and post-ABG increased. The greatest improvement was seen in patients who had their post-ABG impression fewer than 9 months after the procedure. Also, when each gender was considered as a group, the boys appeared to demonstrate greater improvements in the symmetry of the nose than the girls. Surgeon also appeared to have an impact on the overall improvement. None of these variables, however, was statistically significant. A two-tailed, paired t test revealed that there were no statistically significant differences between the pre-ABG and post-ABG asymmetry scores ($t = -1.838$; $p = .074$). The mean RMS difference between the pre-ABG and post-ABG scores was -0.118 ± 0.400 mm (range, -1.060 to 0.729 mm), indicating minimal improvement in the symmetry of the nostrils following the bone-grafting procedure. ANCOVA also demonstrated no significant differences between the pre-ABG and post-ABG images. Variables such as gender, surgeon, and time between the impressions did not influence the overall results ($p = .113$, $p = .249$, and $p = .583$, respectively).

Figure 5 illustrates the degree of asymmetry for the pretreatment and posttreatment images in terms of the RMS values. The presence of nasal asymmetry was established presurgically. The average amount of asymmetry was 0.938 ± 0.610 mm before the ABG compared with 0.820 ± 0.474 mm following ABG. The RMS values that decreased following the bone-grafting procedure indicated improvements in nasal symmetry. The largest improvement in symmetry, according to the RMS difference between the pretreatment and posttreatment images, was 1.060 mm. In contrast, the largest worsening of the asymmetry was 0.729 mm. Nasal symmetry improved in 61.5% (24/39) of the cases following ABG and marginally worsened in 38.5% (15/39) of the cases. However, the increments of change were clinically indiscernible. The average improvement in the degree of symmetry was 0.341 mm (range, 0.025 to 1.060 mm); whereas, the average worsening in the degree of asymmetry was 0.239 mm (range, 0.002 to 0.729 mm). The graph demonstrates that the change in symmetry was minimal, and the postoperative change only translated into a fraction of a millimeter. Some of the changes observed could be attributed to favorable or unfavorable growth patterns.

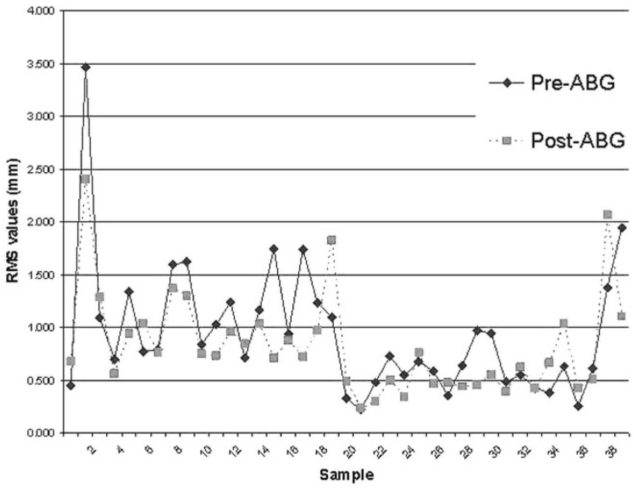

FIGURE 5 **Change in the degree of asymmetry between pre-ABG and post-ABG images for each of the subjects in the study (0 = perfect symmetry).**

Registrations

ANCOVA demonstrated that no statistically significant differences existed between the cleft and noncleft registrations in terms of RMS values. This finding suggests that the surgical procedure had a minimal effect on the nasal morphology. The time period between the pre-ABG and post-ABG impressions was the only significant covariate ($p = .004$). Qualitative assessment of the registered images was completed also. For the majority of cases, the nasal tip and columella were unaffected. Some differences were noted in the lateral and inferior margins of the alar base; however, these differences equated to a fraction of a millimeter.

The greater the mean and RMS values, the greater the distance between the pre-ABG and post-ABG surfaces, indicating more postoperative change. Higher values indicate a greater change in nasal morphology following the bone-grafting procedure; however, these values must be

TABLE 1 Comparison Between Cleft and Noncleft Registrations*

	RMS (SD)	*RMS Range*	*Mean (SD)*	*Mean Range*
Cleft side (n = 39)	0.402 (0.202)	0.143 to 1.051	0.133 (0.165)	0.002 to 0.653
Noncleft side (n = 39)	0.374 (0.193)	0.146 to 1.151	0.100 (0.141)	0.012 to 0.600

* Measurements in millimeters. RMS = root mean squared.

compared with the noncleft or control side to determine what changes can be attributed to growth. The larger the difference between the cleft and noncleft RMS and mean values, the greater the likelihood that the change is related to the surgical procedure rather than to growth. Table 1 summarizes the mean of the RMS values and the mean difference from the surface-based registrations for the cleft and noncleft sides, respectively.

The degree of change according to the RMS registration values between the cleft and noncleft side nose was not significant (p = .492). The average difference for the entire group between the cleft-side RMS value and the noncleft RMS value was only 0.028 mm. The cleft-side nose demonstrated a greater degree of change relative to the noncleft-side nose in 27 subjects; however, this only equated to an average of 0.063 mm (range, 0.005 to 0.234 mm). In 12 subjects, the noncleft-side nose demonstrated a greater RMS value than the cleft-side nose. The difference between the cleft and noncleft side was only 0.050 mm (range, 0.003 to 0.114 mm).

Qualitative assessments of all registrations were conducted also. For the most part, the changes following the surgical procedure were observed at the lateral margins of the alae and at the nostril margins. No consistent, repetitive pattern was seen between registrations.

Linear Measurements

Repeated measures ANCOVA showed that there were no significant differences in the shape of the nostrils after the ABG, as assessed by the height and width measurements on the cleft and noncleft sides, respectively. In addition, comparisons between the cleft and noncleft nostril height and width measurements following surgery showed no significant differences (p = .425 and p = .852, respectively). The factors gender, surgeon, and the time period between the pre-ABG and post-ABG impression did not significantly contribute to the variability.

The Sidak procedure was used to conduct *post hoc* comparisons of the cleft and noncleft height and width differences between the pre-ABG and post-ABG images. The mean difference in the height of the cleft nostril was 0.08 $\pm$ 0.09 mm compared with the difference in width of 0.05 $\pm$ 0.08 mm. The noncleft nostril showed slightly greater changes in height and width, which may be related to normal growth of the noncleft nostril. The cleft-side nostril for the group was slightly larger than the noncleft nostril before and after ABG, except in the posttreatment height dimension, which was the same between the cleft and noncleft nostrils. The width of the cleft nostril was greater than the height of the cleft nostril in both the pretreatment and posttreatment images. Conversely, the height of the noncleft nostril was greater than the width of the noncleft nostril before and after ABG.

Discussion

Distortion of nasal structures in patients with complete UCLP is common, with patients exhibiting more elliptical noncleft nostrils and more rounded cleft nostrils (Russell et al., 2001). Nasal revision surgery is an important part of their overall treatment and focuses on equalizing the shape of the nostrils. Such revisions are normally postponed until after secondary ABG is performed, based on the limited literature that suggests the procedure offers improved nasal symmetry and aesthetics. The present study attempted to quantify nasal morphology, symmetry, and nostril shape in patients with UCLP who received orthopedic treatment of the alveolar segments during infancy and secondary ABG during the mixed dentition. None of the patients in the study underwent nasoalveolar molding, which is claimed to improve nasal symmetry and aesthetics by decreasing the width of the base of the nose and by restoring the architecture of the nasal cartilage prior to the lip and nose repair (Grayson et al., 1999; Maull et al., 1999).

Stereophotogrammetry was used to acquire the nasal images, which were subsequently analyzed using three different methods. The 3dMD™ system (3dMD) uses a modification of the Procrustes technique to resize, reorient, and rescale the images to create accurate registrations. First, registrations of the pre-ABG and post-ABG images were used to identify differences in the morphology of each patient's nose following the surgical procedure. Second, the symmetry of the nose was assessed by superimposing the cleft-side nostril over the noncleft-side nostril before and after the ABG procedure to measure the degree of asymmetry. Finally, linear measurements were taken to detect differences in nostril shape.

Under the conditions of this study, the registered 3D pretreatment and posttreatment nasal images demonstrated no clinically appreciable differences both qualitatively and quantitatively. The nose was minimally affected by the bone-grafting procedure. Gender and surgeon did not appear to have any direct impact on the results. However, the time period between impressions was certainly a significant factor because the longer the period that had elapsed between the pre-ABG and post-ABG impressions, the smaller the difference between the registered nasal images. The same trend was observed from the measurements obtained during the asymmetry analysis; although statistical significance was not reached. This observation may be explained by the fact that some patients experience residual postoperative swelling. The residual swelling may create the illusion of an improvement in nasal morphology and symmetry, especially when the time between pre-ABG and post-ABG impressions is shorter. However, as the period of time is extended, the patients experience more nasal growth, which also could play an important role in the improvement or worsening of the nasal appearance.

Postoperative impressions in the study were taken a minimum of 6 months following the bone-grafting procedure. This period of time was chosen so the graft would have an opportunity to integrate and remodel. Perhaps a longer follow-up time or additional registrations over an extended period of time could be considered to ascertain the true differences that occur during the recovery process. Nevertheless, longer follow-up entails the risk of additional variability from growth of the nose, possibly camouflaging the treatment effect.

A modification of the Procrustes technique was used to investigate nasal symmetry by performing a best-fit superimposition of the noncleft-side nostril surface with the mirror image of the cleft-side nostril. These images were created by dividing the nose using the nasion as the soft tissue reference. This landmark has been used in previous studies and has been found to be reliable even in patients with CLP (Kyrkanides et al., 1996; Ras et al., 1996; Ferrario et al., 2003a, 2003b). The RMS distances between various points and their antimeres were calculated and expressed as asymmetry scores. No clinically significant changes were identified in the nasal region. Although statistical significance was not reached, it was apparent that certain surgeons demonstrated greater improvements in the asymmetry values. Investigators in the past have used similar techniques using asymmetry scores to characterize facial changes in patients with CLP (Maull et al., 1999; Hood et al., 2004). The same methodology that was employed in the current study to assess nasal symmetry has been reported in the plastic surgery literature to assess symmetry of the breasts (Losken et al., 2005).

Nostril height and width measurements showed no significant difference between the pre-ABG and post-ABG models on the cleft and noncleft sides. The changes that did occur could be attributed to growth. These measurements appeared to be unaffected by gender, surgeon, and time period between impressions. No significant differences were noted when the cleft-side nostril was compared with the noncleft-side nostril.

When analyzing the mean and RMS values obtained from the registration and symmetry analysis, care must be taken to evaluate their true meaning. Looking at the average of all the mean values of the sample could dilute or exaggerate the effect of the bone-grafting procedure on nasal morphology because these values carry positive or negative signs. The sign merely represents the location of the difference or posttreatment surface in relation to the reference or pretreatment surface, yielding positive or negative distances after registrations and superimpositions are performed. Positive values reflect that the difference surface is located in front of the reference surface; whereas, negative values indicate that the difference surface is located behind the reference surface. Nevertheless, mean values do provide important information individually and enable the investigator to quantify the difference between the pretreatment and posttreatment images.

The results described above contrast with the findings of Devlin et al. (2007), who, using similar instrumentation (3D stereophotogrammetry), reported an improvement in nasal symmetry in 18 patients with UCLP following augmentation of the alar base on the affected side with a block bone graft, secured in place with a positional screw. The discrepancy between the findings of the two studies may very well be a reflection of the difference in the surgical techniques used.

Examination of larger samples and real-time soft tissue imaging of subjects would be beneficial to confirm the findings of the present study. Because the 3dMD^{TM} system (3dMD) was not available at SickKids Hospital at the time the investigation was conducted, partial polyvinylsiloxane facial impressions of all the subjects were taken before and after ABG, and the models were subsequently imaged. The impression technique used was a modification of those outlined in previous studies, which have taken facial impressions using a variety of materials (Gregory et al., 1999; Maull et al., 1999; Russel et al., 2001; Krimmel et al., 2006). This procedure required full cooperation from the patient, and an effort was made to acquire the impression with facial tissues relaxed. Theoretically, some tissue distortion could occur during this process, which could influence the overall results (Spalding and Vig, 1990). However, the results of the pilot study were conclusive and indicated that the nasal models were highly representative of the real-time soft tissue images.

The current stereophotogrammetric study provides a benchmark for objective assessment of nasal morphology, symmetry, and nostril shape in patients with UCLP following secondary ABG. The reasons for ABG are primarily for the dental health of the patient, closure of oronasal fistulas, and consolidation of arch form. Perhaps ABG should not be expected to improve nasal symmetry and morphology to any significant degree.

Conclusions

Under the conditions of this study, the following conclusions were reached: (1) ABG, when performed as described above, has no significant effect on nasal morphology, symmetry, and nostril shape. (2) Factors such as gender and surgeon did not appear to have an influence on the impact of the surgical procedure on the nose.

References

Atherton JD. Morphology of facial bones in skulls with unoperated unilateral cleft palate. *Cleft Palate J*. 1967;4:18–30.

Bergland O, Semb G, Abyholm FE. Elimination of the residual cleft by secondary bone grafting and subsequent orthodontic treatment. *Cleft Palate J*. 1986;23:175–205.

Devlin MF, Ray A, Raine P, Bowman A, Ayoub AF. Facial symmetry in unilateral cleft lip and palate following alar base augmentation with bone graft: a three-dimensional assessment. *Cleft Palate Craniofac J*. 2007;44:391–395.

Farkas LG. *Anthropometry of the Head and Face.* 2nd ed. New York: Raven Press; 1994.

Ferrario VF, Sforza C, Dellavia C. A quantitative three-dimensional assessment of soft tissue facial asymmetry of cleft lip and palate patients. *J Craniofac Surg*. 2003a;12:739–746.

Ferrario VF, Sforza C, Dellavia C. Three-dimensional nasal morphology in cleft lip and palate operated adult patients. *Ann Plast Surg*. 2003b;51:390–397.

Grayson B, Santiago P, Brecht L, Cutting C. Presurgical naso-alveolar molding in patients with cleft lip and palate. *Cleft Palate Craniofac J*. 1999;5:139–169.

Gregory G, Das Gupta R, Morgan B, Bounds G. Polyvinylsiloxane dental bite registration material used to splint a composite graft of the nasal rim. *Br J Oral Maxillofac Surg*. 1999;37:139–141.

Heaston C. 3dMD^{TM} acquisition systems. Products. Available at www.3dmd.com/Products/3DSystems.asp/. Accessed January 1, 2006.

Honrado CP, Larrabee WF. Update in three-dimensional imaging in facial plastic surgery. *Curr Opin Otolaryngol Head Neck Surg*. 2004;12:327–331.

Hood CA, Hosey MT, Bock M, White J, Ray A, Ayoub AF. Facial characterization of infants with cleft lip and palate using a three-dimensional capture technique. *Cleft Palate Craniofac J*. 2004;41:27–35.

Kalaaji A, Lilja J, Friede H. Bone grafting at the stage of mixed and permanent dentition in patients with clefts of the lip and primary palate. *Plast Reconstr Surg*. 1994;93:690–696.

Kalaaji A, Lilja J, Friede H, Elander A. Bone grafting in the missed dentition in cleft lip and palate patients: long-term results and the role of the surgeon's experience. *J Craniomaxillofac Surg*. 1996;24:29–35.

Krimmel M, Kluba S, Bacher M, Dietz K, Reinert S. Digital surface photogrammetry for anthropometric analysis of the cleft infant face. *Cleft Palate Craniofac J*. 2006;43:350–366.

Kyrkanides S, Bellohusen R, Subtelny JD. Asymmetries of the upper lip and nose in non-cleft and post-surgical unilateral cleft lip and palate individuals. *Cleft Palate Craniofac J*. 1996;33:306–311.

Latham RA. The pathogenesis of the skeletal deformity associated with unilateral cleft lip and palate. *Cleft Palate J*. 1969;6:404–411.

Lilja J, Kalaaji A, Friede H, Elander A. Combined bone grafting and delayed closure of the hard palate in patients with unilateral cleft lip and palate: facilitation of lateral incisor eruption and evaluation of indicators for timing of the procedure. *Cleft Palate Craniofac J*. 2000;37:98–105.

Lilja J, Möller M, Friede H, Lauritzen C, Petterson LE, Johanson B. Bone grafting at the stage of mixed dentition in cleft lip and palate patients. *Scand J Plast Reconstr Surg Hand Surg*. 1987;21:73–79.

Losken A, Fishman I, Denson D, Moyer H, Carlson G. An objective evaluation of breast asymmetry and shape difference using 3-dimensional images. *Ann Plast Surg*. 2005;55:571–575.

Maull D, Grayson B, Cutting C, Brecht L, Bookstein F, Khorrambadi D, Webb JA, Hurwitz DJ. Long-term effects of nasoalveolar molding on three-dimensional nasal shape in unilateral clefts. *Cleft Palate Craniofac J*. 1999;36:391–397.

Millard DR. Earlier correction of the unilateral cleft lip nose. *Plast Reconstr Surg*. 1982;70:64–73.

Ras F, Habets LL, van Ginkel FC, Prahl-Andersen B. Quantification of facial morphology using stereophotogrammetry—demonstration of a new concept. *J Dent*. 1996;24:369–374.

Ross RB. Midfacial and mandibular dysmorphology and growth in facial clefting: clinical implications. In: Mooney M, Siegal M, eds. *Understanding Craniofacial Anomalies: The Etiopathogenesis of Craniosynostosis and Facial Clefting*. Toronto: Wiley-Liss; 2002:391–422.

Ross RB. Treatment variables affecting facial growth in complete unilateral cleft lip and palate. Parts 1–7. *Cleft Palate Craniofac J*. 1987;24:5–77.

Russell K, Waldman SD, Lee JM. Video-imaging assessment of nasal morphology in individuals with complete unilateral cleft lip and palate. *Cleft Palate Craniofac J*. 2000;37:542–550.

Russell KA, Waldman SD, Tompson B, Lee JM. Nasal morphology and shape parameters as predictors of nasal esthetics in individuals with complete unilateral cleft lip and palate. *Cleft Palate Craniofac J*. 2001;38:477–485.

Singh D, Levy-Bercowski D, Santiago P. Three-dimensional nasal changes following nasoalveolar molding in patients with unilateral cleft lip and palate: geometric morphometrics. *Cleft Palate Craniofac J*. 2005;42:403–409.

Spalding PM, Vig PS. External nasal morphology and respiratory function. *Am J Orthod*. 1990;97:207–212.

Tolman DE, Desjardins RP, Keller EE. Surgical-prosthodontic reconstruction of oronasal defects utilizing the tissue-integrated prosthesis. *Int J Oral Maxillofac Implants*. 1988;3:31–40.

Trotman C, Papillon F, Ross R, McNamara J, Johnston L. A retrospective comparison of frontal facial dimensions in alveolar-bone-grafted and nongrafted unilateral cleft lip and palate patients. *Angle Orthod*. 1997;67:389–394.

van der Wal K, van der Meulen D, van der Biezen J, Mulder JW. Bone grafting the piriform aperture deformity in isolated cleft lip patients: indication, technique and results. *J Oral Maxillofac Surg*. 1997;55:1089–1093.