Development of a Morphing Technique for Predicting the Position and Size of an Artificial Ear in Hemifacial Microsomia Patients

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Purpose: People with hemifacial microsomia may be missing an ear on the affected side of the face. The principal aim of the study was to develop a morphing technique and to determine whether it could be used to appropriately position an artificial ear, as well as to give an indication of prosthesis size in comparison with the natural ear. Comparisons also were made between the artificial ears being worn by the patients with their natural ears. ***Materials and Methods:*** Data from stereophotogrammetry images of the faces of 10 people were converted into stereolithographic format. Anthropometric points on the face and ear of the unaffected side were plotted. By a process of scaling, the distance between facial landmarks on the unaffected side was estimated for the affected side so as to identify where the morphed ear would be positioned once generated. ***Results:*** Generally, the morphed ears appeared to be in acceptable positions. There was a statistically significant difference between the position of the morphed and natural ears ($P = .011$), as well as the artificial and natural ears ($P = .001$), but this was unlikely to have any clinical implications. There were no significant differences among the sizes of the natural, morphed, and artificial ears ($P = .072$). ***Conclusions:*** Morphing appears to offer a more precise way of planning the positioning and construction of an artificial ear on patients with hemifacial microsomia than traditional methods. Differences in facial shape on either side of the face may impact on the process. This requires further study. *Int J Prosthodont 2014;27:451–457. doi: 10.11607/ijp.3990*

Patients with congenital deformities of the face (eg, hemifacial microsomia) may present with a missing ear on the affected side. In fabricating an artificial ear, the usual approach is to create a prosthesis freehand by direct measurement from the dimensions of the ear on the unaffected side and to position it in what is judged to be the best place for favorable esthetics based on the underlying form of the tissues. This might also be affected by how the ear is retained. When using implants to provide retention for an auricular prosthesis, these should ideally be placed below the thickest part of the ear (ie, the helix) to enable the most optimal esthetic outcome. However, this will, of course, depend upon adequate bone quality and depth.[1] Positioning and sizing an artificial ear is in many ways a fairly subjective procedure, because, not only is there a degree of uncertainty as to where the prosthesis might best be visually sited, but also the dimensions of the ear may have to be scaled to match the changes in facial form.

Techniques have been developed to produce an artificial ear by rapid prototyping. This involves using scanned data from the ear on the unaffected side of the face to produce an ear for the affected side that is, at least initially, similar in shape and dimensions.[2,3] In a recent study, three methods were evaluated by which the position of an artificial ear on the affected side of the face could be compared with the position of the natural ear.[4] It was found to be possible to mirror the position of the natural ear onto the affected

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side. The method of mirroring, using the outer canthi landmarks, resulted in the smallest dimensional differences between the anthropometric points on the ear and face on both sides. However, the surface anatomy of the soft tissues in patients with facial deformity can result in limitations in achieving a precise alignment of the ear to the facial tissues in order to create an esthetically favorable result. Furthermore, in previous studies, techniques have not dealt with the issue of the size (ie, length, width, etc) of the artificial ear for microtia patients. For patients with unaffected facial symmetry, the objective of current methods is to produce an ear that is dimensionally similar to the natural ear. However, in patients with more severe facial asymmetry (eg, microtia patients), it may well be the case that some degree of scaling is required to produce a slightly smaller ear dimensionally on the affected side. For these reasons, it was decided there was a need to explore whether a morphometry technique could be developed to address the two issues related both to location and size of an artificial ear.

Morphometry is a mathematical tool that can be used to compare biological shapes. It involves the placement of three-dimensional (3D) landmarks and their subsequent use to analyze shape.[5] In this instance, 3D landmarks are placed on biologically homologous points on both sides of the face in order to quantify the differences. In the context of producing an artificial ear, the first part of the technique involves the identification of landmarks on the face and unaffected ear that are then used to extrapolate new landmarks for locating the missing anatomy. The second part of this process, warping (morphing), is the process that modifies the 3D shape and position of one part of the anatomy to make it fit in a different region.[6] The warping process is used to deform (and to mirror-image) the unaffected anatomy in order to invent an interpolated shape between the new landmarks. This new shape can become the basis for fabricating a prosthetic ear.

The principal aim of this study was to develop a morphing technique and to determine whether it could be used to appropriately position an artificial ear and to give some indication of prosthesis size in comparison with the natural ear, given that the facial dimensions on either side of the face may well differ in patients with hemifacial microsomia. All patients were wearing an artificial ear at the time of the study that had been constructed and positioned using traditional freehand methods. The second aim of the study was to explore how such comparisons between the artificial ear and the natural ear related to similar comparisons between the morphed images and unaffected ears.

Materials and Methods

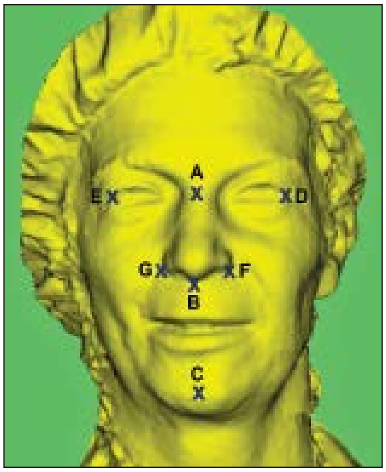
In the first part of the study, laser scans were obtained for five patients with balanced facial symmetry and five with hemifacial microsomia. The initial approach of using a morphing technique depended on a series of anthropometric landmarks to be identified on two separate images. The first image set into the viewing position was of the patient with hemifacial microsomia. The second image was of a patient with unaffected facial symmetry of approximately the same age and gender and with an ear shape of similar dimensions. A number of selected landmarks (inner canthi, outer canthi, nasion, subnasale, upper and lower insertion points of the unaffected ear, tragus of the unaffected ear, alae of the nose, tip of nose, gnathion, and cheilions) were plotted in the same sequence on each image. However, the morphing technique to obtain the position of the artificial ear was found to be unpredictable, with three of the five images showing distortion when viewed. It was concluded that the technique did not have a sufficient degree of reproducibility to take forward. This was principally because of a lack of identifiable landmarks on the affected side of the face, resulting in distortion of the morphed image, which would not offer a reasonable chance of predicting the ear position.

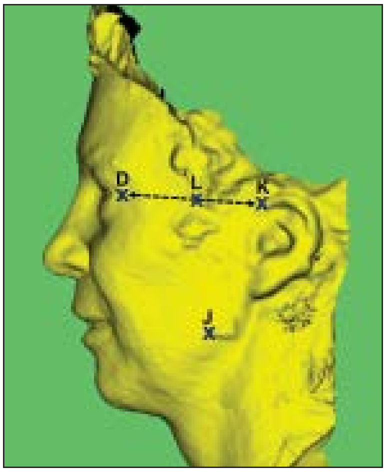
As a result of the difficulties, the computerized technique of morphing was refined over several years. At a later stage, data were obtained from 10 of the original group of 14 patients with hemifacial microsomia in order to compare three methods to evaluate the position of an artificial ear.[4] By this time, a more convenient digital technique of stereophotogrammetry (as opposed to laser scanning) was being routinely used for following up the clinical outcomes of the patients with hemifacial microsomia. In the definitive study, data were collected from 10 patients (3 men and 7 women) with an age range of 29 to 68 years. Six patients had an ear absent on the right side of the face and the remaining four on the left side.

The data from the stereophotogrammetry images were converted into a stereolithographic (.stl) format, and the images were viewed on a screen to allow a number of anthropometric points to be plotted on the face (Fig 1). In the first instance, nasion (point A), subnasale (point B), chin (point C), outer canthi (points D and E), and alae (points F and G) were identified. The angle of the mandible on the unaffected side was identified on the patient by means of a triangular marker, secured to the skin of the face by a skin contact adhesive, which was captured on the original stereophotogrammetry image and reproduced on the .stl image (Fig 2, point J). In addition, the corners of the lips (points H and I, Figs 3a and 3b) were identified.

Fig 1 *(left)* Frontal stereolithographic image of a patient with hemifacial microsomia with an absence of an ear on the right side of the face. The anthropometric points (X) are labeled points A to G.

Fig 2 *(right)* Left view of the patient showing the unaffected ear. A plane has been generated between the outer canthus (point D) and the upper insertion point of the ear (point K). The midpoint of this plane has been temporarily notated as point L, which becomes point K on all subsequent images. The angle of the mandible on the unaffected side is shown as point J, which is located at the anterior end of the triangular marker.





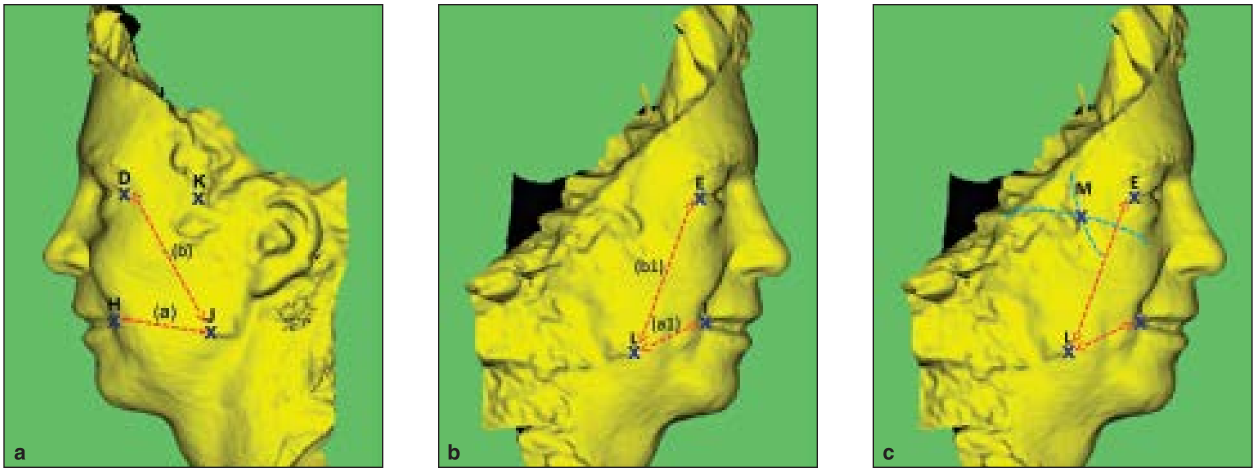


Fig 3 Generation of two reference planes on both sides. **(a)** The first (points H to J) and second (points D to J) planes on the unaffected side; **(b)** the similar first (points I to L) and second (points E to L) planes on the affected side; **(c)** the way in which a point of intersection is created on the affected side by using arcs from the scaling factors generated from the two planes on both sides is shown. The intersection of these arcs becomes point M, which represents the scaled midpoint of the dimension between the outer canthus and the upper insertion point of the natural ear.

Initially, the lack of landmark information on the affected side resulted in poor location of the morphed ear, which could be slightly hidden and needed to be moved in a lateral direction to allow its position to be seen. In order to address this issue, the following strategy was devised for placing an additional, interpolated landmark on both sides of the face. A reference plane was generated between the outer canthus (point D) and the upper insertion point of the natural ear (point K), and the midpoint (point L) of this reference line was identified (Fig 2). Subsequently, the upper insertion point was deleted, and the midpoint of the reference line (originally notated as point L, Fig 2) was then identified as point K (Fig 3a). This reference point was subsequently used to generate a pair of scaling measurements in two planes (an estimate of the magnitude of the gross hemifacial asymmetry). The first plane of measurement was based on the dimension (a) between the corner of the lip (point H) and the angle of the mandible (point J) on the unaffected side (Fig 3a). The second plane of measurement (b) was based on the dimension between the outer canthus (point D) and the angle of the mandible (point J) on the unaffected side (Fig 3a). These dimensions were then compared with similar dimensions on the affected side (Fig 3b). The angle of the mandible on the affected side also was identified with a triangular marker and notated as the new point L (Fig 3b). This allowed the first (a1; points I to L), and second (b1; points E to L) planes on the affected side to be measured with reference to the similar dimensions on the unaffected side (Fig 3b). The two planes of measurement on each side were compared, and scaling factors were generated to identify the most appropriate location for a similar point on the affected side (point M, Fig 3c) that compared with the midline point between outer canthus and the upper insertion point

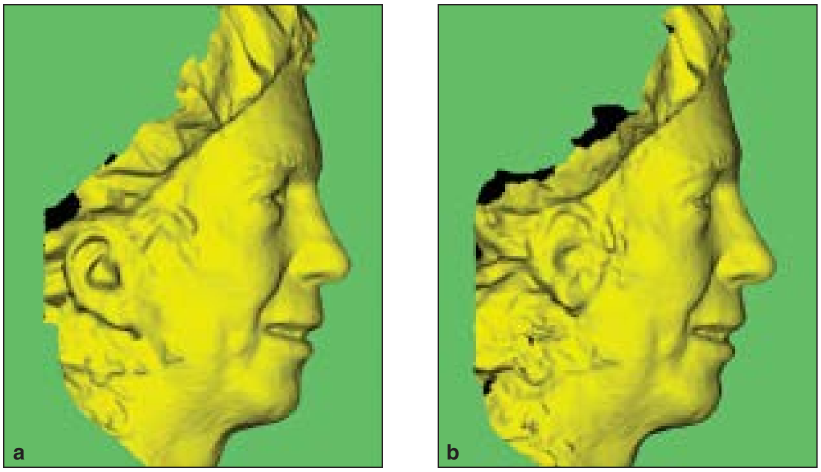


Fig 4 The affected side of the face. **(a)** The morphed ear that was generated; **(b)** the artificial ear that had been constructed by freehand conventional techniques.

Table 1 Dimensions Assessed on the Images of the Patients in Relation to Location and Size of the Natural, Morphed, and Artificial Ears*

	Anthropometric landmarks	Dimension from facial landmarks to ear landmarks on both sides of the face
Location	n–obs	Nasion to upper insertion point of ear
Location	n–obi	Nasion to lower insertion point of ear
Location	sn–obs	Subnasale to upper insertion point of ear
Location	sn–obi	Subnasale to lower insertion point of ear
Location	sa–horizontal plane	Superaurale to horizontal plane
Length	sa–sba	Highest point on free margin of auricle to lowest point on free margin of ear lobe
Width	pa–pra	Most posterior point on free margin of ear to most anterior point of ear located just in front of helix attachment to head
Insertion length	obs–obi	Superior point of attachment of the helix in the temporal region to point of attachment of the ear lobe to the cheek

*The dimensions were measured from the two facial points (nasion and subnasale) to the upper (obs) and lower (obi) insertion points. The length, width, and insertion length defined the size of the natural, morphed, and artificial ears.

of the natural ear (point K, Fig 3a). The process involved plotting a scaled point of intersection of these proportions on the affected side (point M, Fig 3c). The landmark file was saved, and a final series of steps was undertaken to morph[7] the unaffected ear to the affected side in an appropriate position (Fig 4a). Due to the discrepancy between each side of the face, at the end of the process a small modification to the lateral position of the ear was required to enable it to be dropped onto the skin surface.

Once the morphed image had been generated, a series of 21 landmarks[8–10] were plotted to identify anthropometric landmarks on the face, unaffected ear, and morphed ear. From these points, a series of dimensional measurements were generated in relation to the size of the unaffected and morphed ear and their location (Table 1).

Each patient in the study was wearing an artificial ear that had been constructed by conventional freehand techniques. The ears were neither produced by any kind of rapid-prototyping technique nor the morphing process outlined above. An .stl image was generated from the stereophotogrammetry full-face image to show the position and size of the prosthesis (Fig 4b) the patient was wearing alongside the natural ear on the unaffected side of the face. A similar set of anthropometric landmarks was plotted on the face, unaffected ear, and artificial ear. From these points, the same series of dimensional measurements, as produced for the morphed ear, were generated in relation to the location and size of the natural and artificial ears.

The location of the natural ear was compared with the morphed and artificial ears, respectively. Dimensional measurements of the natural ear also were compared with the morphed ear and the artificial ear, respectively. Differences were plotted as bar charts, and statistical analysis was carried out by means of an analysis of variance (ANOVA) and, if appropriate, a Bonferroni post hoc test.

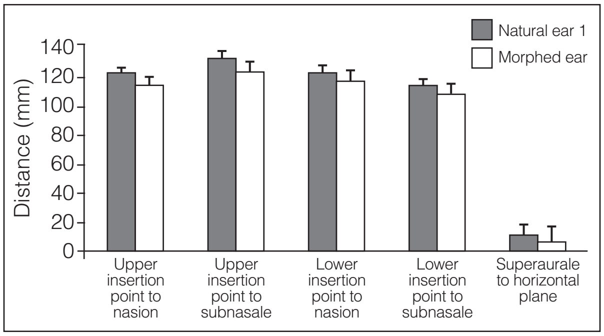


Fig 5 Mean and 95% confidence intervals of the natural and morphed ear position in relation to the midline anthropometric points of nasion, subnasale, and the horizontal plane.

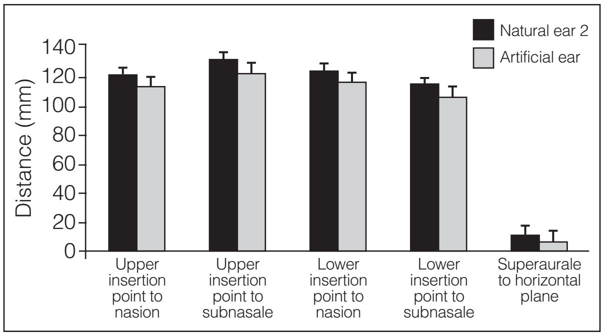


Fig 6 Mean and 95% confidence intervals of the natural and artificial ear position in relation to the midline anthropometric points of nasion, subnasale, and the horizontal plane.

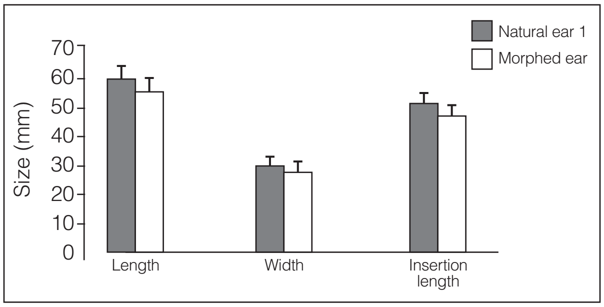


Fig 7 Mean and 95% confidence intervals of the natural and morphed ear size.

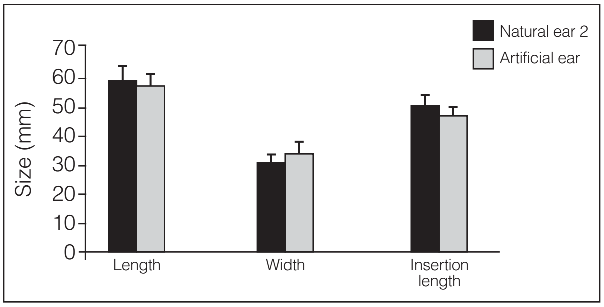


Fig 8 Mean and 95% confidence intervals of the natural and artificial ear size.

Results

Generally, it appeared that the morphing process was successful in producing an ear that was similar to the unaffected side in its dimensions and that appeared to be positioned acceptably, as shown in Fig 4a.

In relation to the anteroposterior position of the morphed ear, the upper and lower insertion points were used in conjunction with the midfacial points of nasion (point A, Fig 1) and subnasale (point B, Fig 1) to calculate and compare dimensions from the two sides. The bar chart showed that for each dimension, the morphed ear appeared to be positioned very closely in an anteroposterior direction to the existing natural ear (Fig 5). The generally smaller dimensional measurements on the morphed ears suggested that they were positioned slightly farther forward on the face than the natural ears in relation to nasion and subnasale. For both of the insertion points, the dimensions were slightly less for the morphed ear compared with the natural ear. In relation to the vertical position of the ear, the distance from the upper insertion point was calculated in relation to the horizontal plane. The derivation of the horizontal plane has been previously described[10] and corresponds with the level of the outer canthi. It was found that the level of the natural and morphed ears, in relation to the upper insertion point, were generally very similar.

For the anteroposterior position of the artificial ear produced by conventional freehand methods, the bar charts showed that for each dimension, the artificial ear was situated in a fairly similar position to the natural ear (Fig 6). Again, it was also slightly farther forward than the natural ear in relation to nasion and subnasale. In relation to level, with respect to the horizontal plane, the dimensions from the upper insertion points indicated that the two ears were generally in a similar vertical position.

Statistical analysis using ANOVA showed an overall significant difference in relation to position ($P < .0005$). Post hoc tests revealed a significant difference between the position of the natural ear compared with the morphed ear ($P = .011$) in relation to the anthropometric points and horizontal plane, as well as the natural ear compared with the artificial ears that the patients were wearing ($P = .001$).

In relation to size of the morphed ear, it was found that for length, width, and insertion length the morphed ear was slightly smaller than the natural ear (Fig 7). For the artificial ear, the width appeared slightly larger than the natural ear, but for the dimensions of length and insertion length, the artificial ear was slightly smaller than the natural ear (Fig 8). Statistical analysis using ANOVA showed no significant difference among the dimensions of the natural, morphed, and artificial ears ($P = .072$).

Discussion

This study has shown that it has been possible to develop a morphing technique that can be used to appropriately position an artificial ear on the affected side of the face. Whilst refinements might need to be made to locate the artificial ear in a position that is esthetically optimal, nevertheless, the sites at which the morphed ears appeared to be positioned on the images were generally favorable and showed little difference to the artificial ears that had been produced by more traditional techniques. Furthermore, size differences between the morphed ears and the natural ears appeared very similar to those between the artificial and natural ears.

Patients with hemifacial microsomia may present with a very different facial morphology on the affected side, compared with the side on which the natural ear is present. This means that if an artificial ear is positioned on the face at the same dimensions from the midline landmarks, it may well lie too far posterior for optimal esthetics to be achieved. When looking at the positions of the artificial ear that had been produced and located by freehand techniques, it was apparent that, generally, the dimensional measurements of the upper and lower insertion points from nasion and subnasale were slightly lower than similar dimensions in relation to the position of the natural ear, and these were confirmed to be statistically significant. This might suggest that the artificial ear had been positioned slightly farther forward in relation to facial dimensions than the natural ear. However, it is more likely to reflect the altered anatomical form on the affected side, meaning that it had to be put in this position for the most satisfactory result for the overall facial appearance. Similarly, when looking at the position of the morphed ears compared with the natural ears, the dimensional measurements of the upper and lower insertion points from nasion and subnasale were slightly lower than similar dimensions in relation to the position of the natural ear. Again, these were confirmed to be statistically significant. Morphing, therefore, produced a projected position of the artificial ear that reflected the changes to surface facial anatomy on the affected side. There was generally very little difference in the vertical level between the natural and morphed ears and the natural and artificial ears.

It was not possible to look at differences in the position of the ears laterally from the midline plane for two reasons. First, any artificial ear must be in contact with the skin of the face wherever it is positioned, and, therefore, differences in dimensions between natural and morphed ears, or natural and artificial ears, may simply be accounted for by the altered facial form on the affected side of patients with hemifacial microsomia. Second, as described in Methods and Materials, as part of the morphing process it was necessary to manipulate the ear laterally, using the software, to a position where it was visible. This would, therefore, account for differences between its location in relation to the natural ear.

In separate analyses, it was found that the length, width, and insertion lengths of the natural ears generally were very similar to the morphed and artificial ears, and no statistically significant differences were found. Although the sample size was fairly small, nevertheless, in the statistical analysis from the same sample for location of the ears, significant differences were found in relation to the positioning of artificial and morphed ears compared with natural ears. The absence of significance in relation to the dimensions of the ears themselves might, therefore, reflect the fact that the construction of artificial ears by freehand methods will ensure that they are produced to be a very similar size to the natural ears, and the process of morphing, which takes data from the natural ear in relation to scaled measurements on the face, will similarly produce an image of very similar dimensions.

The results suggest that the technique of morphing may allow for a more precise way of planning the construction and positioning of an artificial ear on patients with facial deformity. Traditional techniques for fabricating an ear rely on the operator constructing and positioning it to the best of his or her judgment. In a previous study, laser scanning was used to capture the shapes of the ear on the unaffected side, which was used to mirror the ear on to the affected side of the face using three different methods.[4] The results showed that the unaffected ear image could indeed be mirrored onto the affected side, with similar dimensional differences being found between landmarks of the ear and face on both sides. However, one serious limitation of the technique was that the contour of the face is usually different on the affected side compared with the unaffected side. This impacted on the positioning of the prosthesis and presented a significant challenge to produce an acceptable esthetic result. In the present study, these limitations have been largely overcome because the morphing technique involves using identified landmarks on the face and ear on the unaffected side, as well as appropriate landmarks on the affected side based on scaling factors as described, to produce an interpolated shape of ear that is positioned appropriately. It certainly appeared that the images produced by morphing would offer an acceptable starting point for the production of prosthetic ears and an appropriate template by which they might be positioned on the affected side. Nevertheless, as with any such technique, it may well be necessary for the clinician to make refinements to the overall shape and its position in order to create a harmonious esthetic result. The magnitude of the differences in facial shape on either side of the face of patients with hemifacial microsomia may impact on the process. This requires further study.

Acknowledgments

The authors reported no conflicts of interest related to this study.

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Literature Abstract

Topical xylitol administration by parents for the promotion of oral health in infants: A caries prevention experiment at a Finnish public health center

The authors shared the result of a topical xylitol program in infants at a Finnish public health center from 2002 to 2011. All mothers who gave birth between September 2002 and October 2004 in the municipality (n = 285) were invited to participate in the study when their children were approximately 6 to 8 months of age. A total of 271 children from 266 families participated; 133 and 138 infants were allocated to the treatment and comparison groups, respectively. The parent was taught to administer once or twice daily a 45% solution of xylitol (2.96 M) onto their children's primary dentition beginning at approximately 6 to 8 months and continuing until approximately 36 months of age. Xylitol was applied with a cotton swab or with a children's toothbrush. The approximate daily xylitol dosage was 13.5 mg per primary tooth. Children remaining in the study at 7 years of age were examined. The results showed that the 80 children who had xylitol treatment experienced a significant reduction ($P < .001$) in enamel and dentin caries on the primary dentition compared to untreated children (n = 90). Similar findings were obtained when the children were 5 or 6 years of age. The treatment reduced the relative risk of need for a tooth filling ($P < .001$). The oral counts of mutans streptococci were also reduced significantly in the treatment group ($P < .001$). The authors concluded that topical at-home xylitol administration improved the infants' caries resistance. Families were also receptive to the program, and no side effect was reported.

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