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# Identifying the position of an ear from a laser scan: The significance for planning rehabilitation

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*Abstract.* Laser scanning techniques are used to plan the construction of prosthetic ears as dimensional measurements between anthropometric points can be accurately measured on a screen image. The aim of this study was to determine if these techniques could be used to assess the position of ears on the face. Computer-generated images were created from laser scans of 20 subjects. Frames of reference were constructed by locating a series of anthropometric points on the face from which three orthogonal planes were constructed. A central reference point was identified at the intersection of the three orthogonal planes. Dimensional measurements were made between anthropometric points on the ear and the reference planes. The differences between anthropometric points and the reference planes on the left and right sides of the face were small. It was possible to describe the location of points three-dimensionally with respect to a central reference point. The development of frames of reference and a central reference point would appear to offer many advantages in the assessment and description of ear position for patients requiring reconstruction with prostheses.

Key words: ear; facial symmetry; laser scanning; three-dimensional position.

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Rehabilitation, either by surgical or prosthetic treatment, may be considered for a patient wishing to disguise the loss or absence of the whole or part of an external ear. This may arise because of trauma, surgical resection, or congenital malformation[19]. The development of laser scanning techniques has enabled a more quantitative approach to the assessment and planning of treatment for patients requiring facial rehabilitation[1,8–10,12,13,17,20]. Laser scanning used in conjunction with computer-aided design/computer-aided manufacturing (CAD/CAM) systems has been used to construct facial prostheses and in particular to develop the planning of shape and position of prosthetic ears[3–6].

An important aspect of successful rehabilitation is the positioning of any manufactured prosthesis on the face. In current practice, this aspect of positioning of the ear prostheses is largely empirical and is undertaken by direct measurements on the skin[18]. However there are limitations with the technique in that positioning can only be determined by visual assessment of the patient in conjunction with direct measurements from a number of facial points. Point-to-point location (e.g. superaurale to nasion) can only contribute limited information on ear position. Direct anthropometry is restricted to the measurement of linear distances between points and does not allow three-dimensional characterization and measurement[2]. Measurement with respect to established reference planes on the head and face is thought to be much more useful as it might result in a more predictable siting of the prosthesis. However this cannot be achieved by direct measurements from points on the face.

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Various methods of measuring soft tissue in three dimensions with respect to planes of reference have been reported[7,11,15,16]. These techniques are based on the spatial rectangular coordinate system and allow the position of a chosen point, and subsequent change in position to be expressed in three axes (i.e. x, y and z). A grid that is either uniformly spaced at pre-determined intervals or proportionally spaced (based on existing natural landmarks within the face and simple divisions of the distances between them) is superimposed onto the soft tissues and used in conjunction with skull radiographs.

In previous work on the development of laser scanning techniques for the assessment of normal ears, the issue of ear position (e.g antero-posterior, level, prominence) has not yet been examined[6]. This is critical because in the management of patients requiring rehabilitation, the siting of any prosthesis is as likely to be as important in achieving a harmonious appearance as achieving an optimal form.

There are two issues to consider in the assessment of the correct position of a normal ear from a laser scan. The first issue is that the head must be orientated correctly within the scanning gantry to enable the scanner to digitize the locations of the anthropometric points[4]. In previous work, we have been able to locate anthropometric points on the face and ear reliably[5]. The second issue arises from the orientation of the image of the face as viewed on the screen. If the image is not orientated correctly, it would be possible to make incorrect assessments of the position of the ear on the face with respect to planes of reference. Rotations of the image in this way could result in erroneous measurements and may result in an incorrect position being identified in which to site a prosthetic ear (Figs 1A, B, C). This might then lead to a poor outcome of treatment.

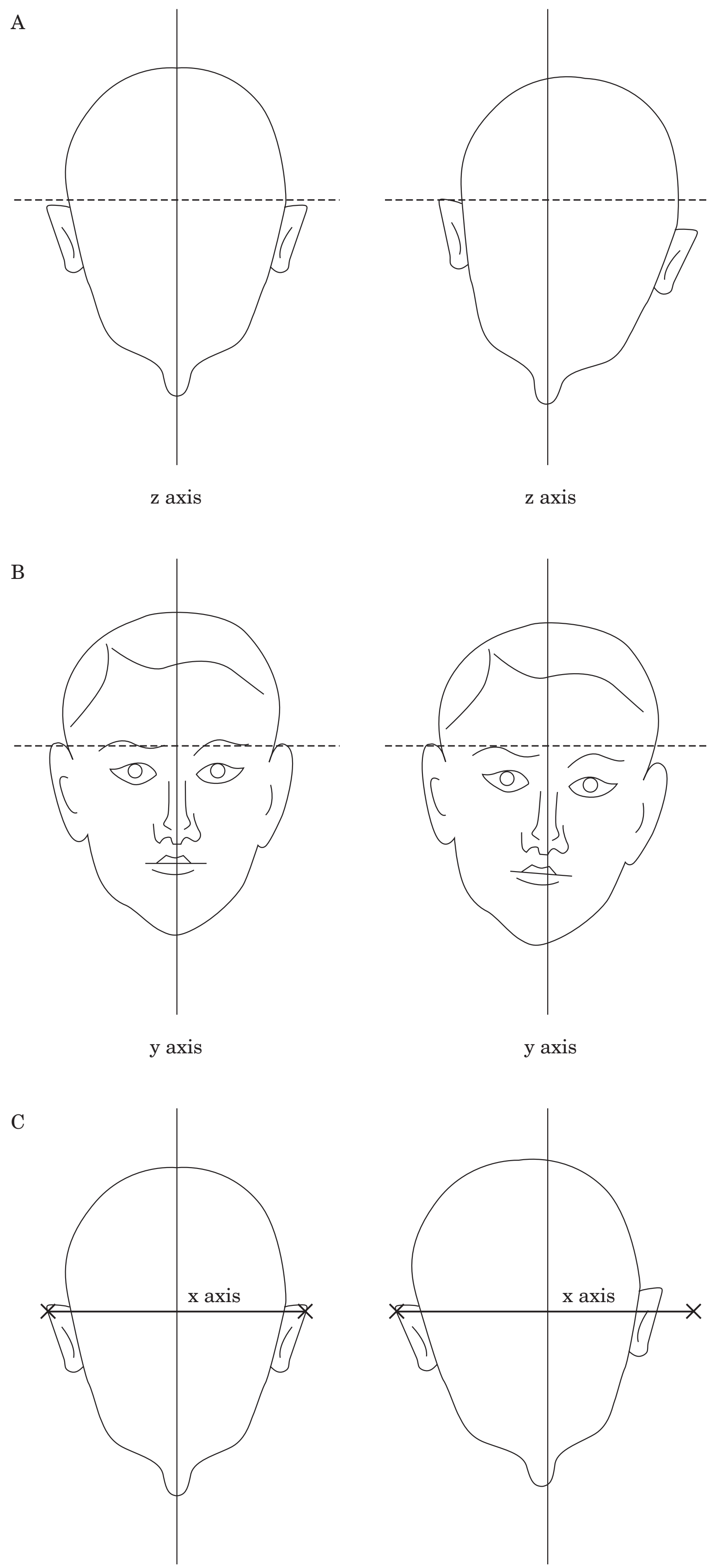


*Fig. 1.* Diagrams to show the effect of an error in failing to set up the image of a subject in the correct screen position on the possible location of an ear on the face. In each case the left diagram shows the correctly orientated image with respect to developed planes of reference. The right image shows the effect of a rotation of the image and its effect on assessment of ear position. (A) Effect on antero-posterior position (z axis). (B) Effect on level (y axis). (C) Effect on protrusion (x axis).

The aim of this study was to determine if laser scanning techniques could be used to assess the position of ears on the face. In the first instance, suitable reference planes (frames of reference) were constructed to which a small number of points on the ear could be related. In the subsequent part of the study, all anthropometric points of the ear and a number of facial points were related to a centre of origin developed from the intersection of the developed reference planes (frames of reference).

## Methods

This study was undertaken on a total of 20 subjects aged 16–24 years (mean age 21 years, 4 months [standard deviator (SD) 2 years, 6 months]) with normal facial symmetry and normal external ears (11 male, 9 female). The techniques for scanning the subject, viewing the image and identification of the landmarks have been fully described in a previous study[5].

### Construction of the frames of reference

A low power laser (Class iii) beam was projected on each subject's face as a vertical line. The position of the subject's head was adjusted so that the projection of the beam was coincident with the line joining the nasion and subnasale. The face was scanned as previously described[5]. The data for each subject were retrieved and displayed as a rendered surface by a custom-designed software package. The retrieved image was orientated to the frontal viewing position (i.e. face-on view) with the Frankfort plane of the skull set horizontally. The image was saved to a view file, enabling it to occupy identical spatial coordinates on the screen when retrieved. This was to permit consistent viewing and analysis of the image.

On the image, a frame of reference was defined by a set of three orthogonal planes. Before defining the planes, it was necessary to calculate the midpoint between the inner canthi (Points 1 and 2, Fig. 2), construct a line joining this midpoint (Point 3) with subnasale (Point 7, Fig. 3), and construct another line passing through both outer canthi (Points 4 and 5, Figs 2 & 3). The line from the midpoint between the inner canthi to subnasale is therefore vertical in the frame of reference (Fig. 3). The line drawn from outer canthus to outer canthus (Point 4 to Point 5) defines the face-on direction (Fig. 3).


*Fig. 2.* Laser scan of the face to show the location of a number of anthropometric landmarks. The description of the landmarks is given in Table 1. Point 3 was derived from calculating the midpoint between the inner canthi (Points 1 and 2). It should be noted that Point 3 is the midpoint of the line joining Points 1 and 2. In this view it appears more posterior because of the angulation of the viewing position.

The coronal reference plane was constructed first. This was made to pass through the previously defined vertical line (Point 3 to Point 7) and then made parallel to the outer canthus to outer canthus line (Point 4 to Point 5). The plane formed from these two lines was made parallel to the plane of the computer screen and defined the coronal reference plane (frontal view) (Fig. 4A). The sagittal reference plane (vertical) was constructed orthogonal to the coronal reference plane and passed through both the subnasale and midpoint between the inner canthi (Fig. 4B). The transaxial reference plane (horizontal) was constructed orthogonal to the other two planes, passing through the midpoint of the inner canthi (Point 3) (Fig. 4C). The outer canthus to outer canthus line (Point 4 to Point 5) is not necessarily parallel to the transaxial reference plane. The determination of the frames of reference does not rely on any ear measurements.

### Assessment of repeated dimensional measurements

In the first part of the study on 20 subjects, an assessment was made as to whether consistent dimensional measurements could be made from a small number of anthropometric points on the ear to the reference planes.

The scanned image for each subject was retrieved and displayed as a rendered surface by computer graphics. The image was orientated to the viewing position (e.g. full face/face on) as previously described[5]. Two assessors agreed the position of a selected sample of anthropometric landmarks on the ear (Fig. 5) which are defined in Table 1. The dimensional measurements between individual anthropometric points and either transaxial or sagittal reference planes were recorded. At the end of the recording session, the image was saved to a view file, so that when retrieved the image occupied the same spatial coordinates on the screen as the original, therefore permitting consistent viewing on the

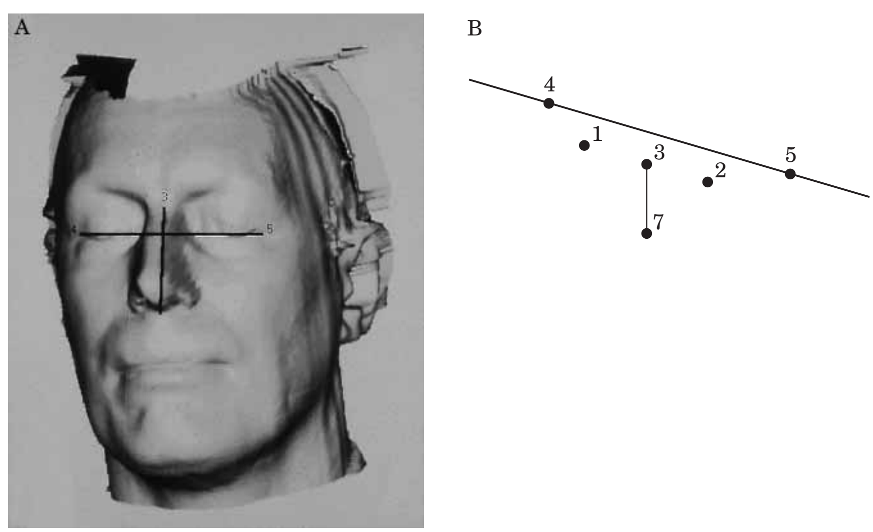


*Fig. 3.* Laser scan of the face (A) and line diagram (B) to show the construction of the frames of reference. To define the reference planes it was necessary to construct two lines. The first line joins the midpoint–subnasle (Point 3 to Point 7) and is vertical in the frame of reference. The second line joins outer canthus – outer canthus (Point 4 to Point 5), and determines the face-on direction of the image and so facilitates determination of the relative anterior/posterior location of the ears. It should be noted that the line joining Points 4 and 5, and the line joining Points 3 and 7 are *not* intersecting each other as they are lying separately in the third reference plane.

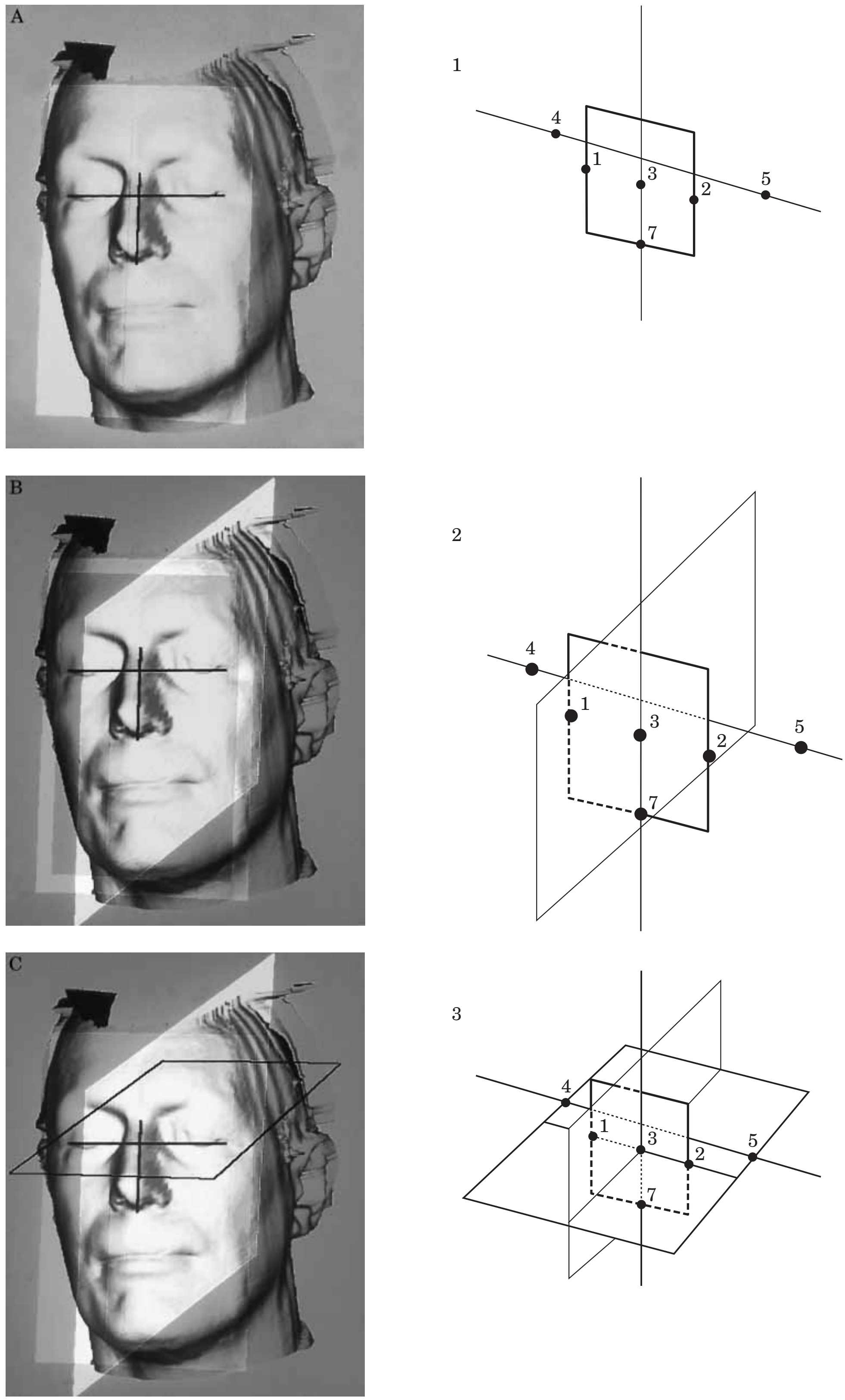


*Fig. 4.* Laser scan of the face pictures (A, B, C) and line diagrams (1, 2, 3) to show the construction of the frames of reference. The picture on the left side represents a scan of a subject and the line diagram on the right is for orientation. (A) The coronal reference plane was constructed by passing it through the vertical line (Point 3 – Point 7) and parallel to the outer canthus–outer canthus line (Point 4 to Point 5). (B) The sagittal reference plane was constructed orthogonal to the coronal reference plane and again passed through the vertical line (Point 3 to Point 7). (C) The transaxial reference plane was constructed orthogonal to the other two planes, passing through the midpoint of the inner canthi (Point 3).

*Table 1.* Anthropometric landmarks of the ear

| Point No. | Anthropometric landmark |
|---|---|
| 8 & 14 (sa) | sa (highest point on the free margin of the auricle) |
| 9 & 15 (sba) | sba (lowest point on the free margin of the ear lobe) |
| 10 & 16 (pra) | pra (most anterior point of the ear located just in front of the helix attachment to the head) |
| 11 & 17 (pa) | pa (most posterior point of the free margin of the ear) |
| 12 & 18 (obs) | obs (point of attachment of the helix in the temporal region, determining the upper border of the ear insertion) |
| 13 & 19 (obi) | obi (point of attachment of the ear lobe to the cheek, determining the lower border of the ear insertion) |
| 20 & 21 (new point) | Most prominent point on the ears |

obi: otobasion inferius; obs: otobasion superius; pa: postaurale; pra: preaurale; sa: superaurale; sba: subaurale.

*Table 2.* Dimensional measurements from selected anthropometric landmarks of the ear to selected reference planes used in the repeatability study

| Anthropometric landmark and plane | Dimension |
|---|---|
| sa–transaxial plane (Point 8 right ear and 14 left ear) | Top of right and left ear to transaxial plane |
| obs–sagittal midline plane (Point 12 right side and Point 18 left side) | Upper insertion point of right and left ear to the sagittal midline plane |
| Most prominent point on ear–sagittal midline plane (Point 20 right ear and Point 21 left ear) | Prominence of right and left ear from the sagittal midline plane |

obs: otobasion superius; sa: superaurale.

second assessment. At an interval of no less than 2 weeks, the image was retrieved and the same assessors re-plotted the landmarks and recorded a further set of the dimensional measurements between the same anthropometric points and either the transaxial or sagittal reference planes. The three-dimensional measurements determined the level and prominence of the ears on the face (Table 2).

A comparison was made between the dimensional measurements recorded on the two separate occasions and paired *t*-tests were used to determine if the differences were significant. The means of the repeated measurements were used to compare the dimensional measurements between the right and left ears and the reference planes. This indicated whether there were differences in position of the right and left ears.

### Three-dimensional location of landmarks from the zero reference point

In five subjects (from the original 20), a study was carried out to determine if landmarks of the ear could be described in three dimensions with respect to a zero reference point on the image. The position of the landmarks was expressed as x-, y-, and z-values that corresponded to the three orthogonal reference planes constructed as the frames of reference. The x-value related to the coronal reference plane, the y-value related to the sagittal reference plane, and the z-value related to the transaxial reference plane. The central point of origin (zero point) was defined by the intersection of the coronal, sagittal and transaxial reference planes that originated from Point 3 (the midpoint of the line joining the inner canthi).

All landmarks of the ear were expressed with respect to this zero point enabling the level, prominence, and anterior/posterior positions of the right and left ears on the face to be compared with each other.

## Results

### Repeatability of dimensional measurements

The differences between repeated dimensional measurements from a number of anthropometric points on the ear and the selected reference planes were determined (Table 3). For the two dimensions of prominence (upper insertion point to sagittal reference plane, most prominent point of ear to sagittal reference plane) the mean difference between the two repeated measurements ranged from 0–0.85 mm. No statistical significance was found between these repeated dimensional measurements. This difference represented less than 1% of the actual dimensional measurements. The repeated measurements for the level of the ears (superaurale–transaxial reference plane, Table 3) differed by a mean of 0.15 mm for the right ear and 0.25 mm for the left ear. Again this represented only a small proportion of the actual dimensional measurements and no significant differences were found.

The mean difference between the dimensions of the right and left ears were 1.4 mm (CI −3.83, 1.03) for the otobasion superius (upper insertion point) to the sagittal reference plane, and 0.5 mm for the most prominent point of the ear to the sagittal reference plane (CI −3.70,

*Table 3.* Repeated dimensional measurements from anthropometric landmarks of the ear to selected reference planes

| | Mean dimensional measurement (A) | Mean difference between repeated dimensional measurements (B) | B/A as % | 95% confidence intervals |
|---|---|---|---|---|
| Right ear | | | | |
| Perpendicular distance from top of ear to transaxial plane | 22.7 | −0.15 | 0.66 | −1.08, 0.78 |
| Upper insertion point to sagittal midline plane | 74.7 | 0.4 | 0.54 | −0.53, 1.33 |
| Most prominent point of ear to sagittal midline plane | 88.9 | 0.35 | 0.39 | −0.83, 1.53 |
| Left ear | | | | |
| Perpendicular distance from top of ear to transaxial plane | 21.0 | 0.25 | 1.19 | −0.48, 0.98 |
| Upper insertion point to sagittal midline plane | 76.1 | 0 | 0 | −0.83, 0.83 |
| Most prominent point of ear to sagittal midline plane | 89.3 | 0.85 | 0.95 | −0.23, 1.93 |

The mean difference between repeated measurements has been expressed as a percentage of the mean dimensional measurement (B/A as %). 95% confidence intervals are also shown. A negative value indicates that the second reading was larger than the first reading.

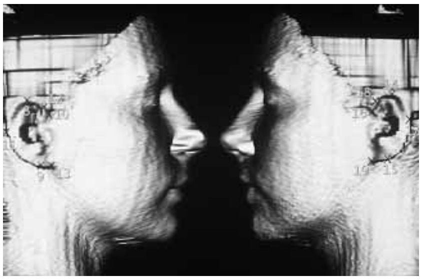

*Fig. 5.* Laser scan of the face in profile to show the location of anthropometric points of the ear in right and left lateral views. A description of the landmarks is given in Table 1.

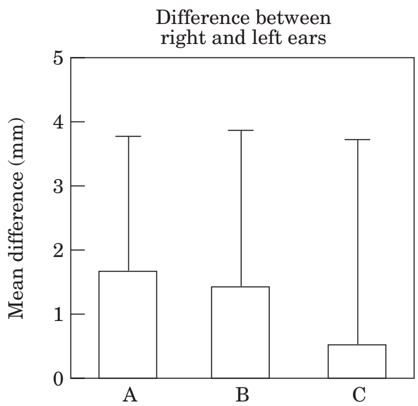


*Fig. 6.* Bar chart to show the mean differences and confidence intervals of the dimensions between landmarks of the ear on the right and left sides to the reference planes. (A) sa (ear) to transaxial reference plane. (B) obs (ear) to sagittal reference plane. (C) prominence of ear to sagittal reference plane.

2.70) (Fig. 6). There was a mean difference of 1.65 mm (CI −0.46, 3.76) between the level of the most superior point of the right and left ears (sa—transaxial reference plane) (Fig. 6).

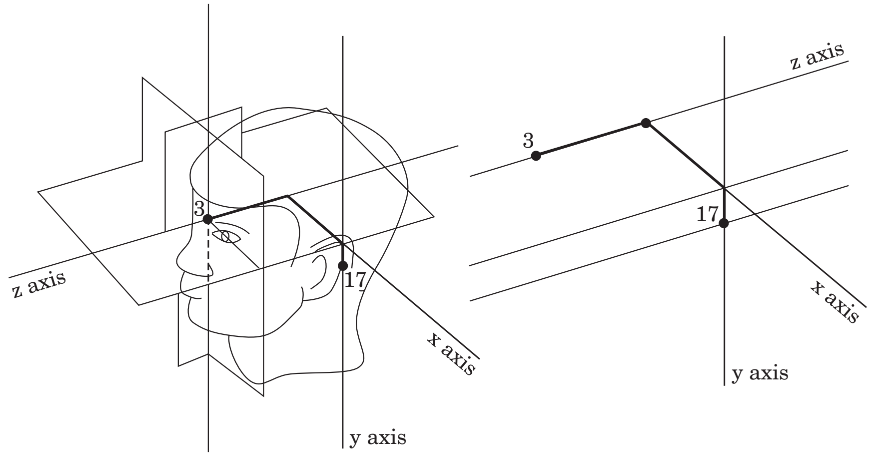


*Fig. 7.* Diagram to show the location of a landmark (Point 17) on the ear in relation to the central point of origin (zero point, Point 3) of the reference planes. Point 17 (most posterior point on the free margin of the ear) can be described three-dimensionally in the x, y, and z axes with reference to the central point of origin and the reference planes.

### Three-dimensional measurements

Data from five subjects were collected to show the locations of all points of the ear with respect to the central point of origin (zero reference point). An example of how a point is described three-dimensionally is shown in Fig. 7. The position of each individual landmark on each patient could be expressed by three numerical values defined in the x, y and z axes. For example, in one subject point 17, which is the most posterior point on the free margin of the left ear, has an x value of −88.03, y value of −3.70, and z value of −105.51, and the same point on right ear, Point 11, an x value of 86.09, y value of 3.36, and z value of −106.83. The readings from the five subjects were calculated as mean values for each anthropometric point from the central point of origin (zero reference point) and are shown in Table 4. As an example, the average position of the otobasion superius of the right ear (Point 12) was situated 72.81 mm lateral, 13.38 mm superior, and 79.34 mm posterior to the central point of origin.

The mean differences and confidence intervals between the positions of a number of critical landmarks on the left and right ears from the central reference point are shown for the x, y, and z axes in Table 5. The differences between left and right sides generally appear to be slightly greater on the z axes, e.g. for the superaurale and otobasion superius, but these differences are of a small magnitude.

### Discussion

Dimensional measurements between landmarks on the face and ear have traditionally been used for planning rehabilitation with prosthetic ears.

*Table 4.* The location of landmarks on the ear expressed in three dimensions from a central point of origin as a mean from five subjects

| | Right ear | | | | Left ear | | | |
|---|---|---|---|---|---|---|---|---|
| Anthropometric landmark | Point No. | x axis | y axis | z axis | Point No. | x axis | y axis | z axis |
| sa | 8 | 86.42 | 20.57 | −92.74 | 14 | −88.72 | 21.08 | −86.06 |
| sba | 9 | 73.91 | −36.36 | −86.75 | 15 | −77.11 | −33.81 | −85.13 |
| pra | 10 | 70.70 | 6.22 | −77.04 | 16 | −71.62 | 6.61 | −73.58 |
| pa | 11 | 86.65 | 4.77 | −107.78 | 17 | −90.64 | 5.46 | −103.70 |
| obs | 12 | 72.81 | 13.38 | −79.34 | 18 | −74.54 | 12.89 | −74.33 |
| obi | 13 | 66.79 | −35.43 | −81.19 | 19 | −68.52 | −32.12 | −78.14 |
| Prominence of ear (new point) | 20 | 88.75 | 11.20 | −101.48 | 21 | −90.95 | 12.87 | −96.78 |

obi: Otobasion inferius; obs: otobasion superius; pa: postaurale; pra: preaurale; sa: superaurale; sba: subaurale.
For the x axis, a positive reading represents a dimension on the right side of the face in respect to the central reference point, and a negative reading represents a dimension on the left side of the face in respect to the central reference point. For the y axis, a positive reading represents a dimension above the central reference point and a negative reading represents a dimension below the central reference point. For the z axis, a positive reading represents a dimension anterior to the central reference point and a negative reading represents a dimension posterior to the central reference point.

*Table 5.* The mean differences (mm) between right and left ears for the values in each dimension in five subjects

| Anthropometric landmark | Point No. | Mean difference x axis | 95% CI x axis | Mean difference y axis | 95% CI y axis | Mean difference z axis | 95% CI z axis |
|---|---|---|---|---|---|---|---|
| sa | 8 & 14 | − 2.30 | (− 7.04, 2.44) | − 0.50 | (− 6.15, 5.14) | − 6.67 | (− 12.81, − 0.53) |
| obs | 12 & 18 | − 1.72 | (− 6.15, 2.71) | 0.49 | (− 4.59, 5.57) | 5.01 | (0.37, 9.66) |
| obi | 13 & 19 | − 1.73 | (− 7.13, 3.66) | 3.32 | (− 1.31, 7.94) | 3.04 | (− 2.46, 8.55) |
| Prominence of ear (new point) | 20 & 21 | − 2.20 | (− 8.13, 3.74) | − 0.06 | (− 11.26, 11.15) | 4.70 | (− 0.22, 9.62) |

obi: Otobasion inferius; obs: Otobasion superius; sa: superaurale.
The 95% confidence intervals for differences in the x, y and z axes are shown. For the x axis, a positive value indicates that the mean distance of the anthropometric landmark from the central reference point is greater on the right side than the left, and a negative value indicates that the mean distance of the landmark from the central reference point is greater on the left side than the right. For the y axis, a positive value indicated that the mean level of the anthropometric landmark is higher on the right side than the left, and a negative value indicates that the mean level of the anthropometric landmark is lower on the right side than the left. For the z axis, a positive value indicates the mean position of the anthropometric landmark on the right side is more anterior to that of the anthropometric landmark on the left side, and a negative value indicates that the mean position of the anthropometric landmark on the left side is more anterior to that of the anthropometric landmark on the right side.

Measurement of the distance between anthropometric points on a normal ear and face gives some information necessary to the siting of the prosthesis, however, this type of information is limited. A distance measurement alone gives no information on the precise three-dimensional location of a landmark of the ear. This is regarded as critical information since in the construction of an artificial ear, the distances of anthropometric points of the ear from well-defined reference planes expressed as antero-posterior, lateral, and supero-inferior distances, would be expected to result in more precise positioning on the face than can be obtained with techniques currently used. There have been no previous studies in this area.

The first part of the study on the repeated measurements has shown that it is possible to reproducibly measure dimensions between anthropometric landmarks on the ear and selected reference planes of the face. A limited selection of anthropometric points and reference planes were used for this part of the study. These points are considered by the authors to be the most critical in the siting of prosthetic ears and it is known from previous work that they could be reproducibly located[5]. The anthropometric landmarks that were chosen in this study for subjects with normal facial symmetry were also considered to be reliably identifiable in subjects with facial asymmetry (e.g. hemifacial microsomia). This is in contrast to the use of a landmark such as the external auditory canal, which may be absent or displaced on the asymmetric side in patients with facial asymmetry. In the 20 subjects studied, there were only small differences between the left and right sides of the face, suggesting that the patient was correctly orientated in the scanner and the image correctly orientated on the viewing screen. There was no evidence of substantial asymmetry in the siting of left and right ears in the 20 subjects studied.

The development of reference planes is considered to be essential to position the subject image and set up the image in the correct on-screen orientation so as to analyze the face and plan the proper positioning of any prosthesis. However, in the first instance a correct positioning of the subject is essential for scanning the facial contours. In previous studies it was necessary to accurately position the subject's head so as to facilitate the superimposition of the coordinate grid prior to recording photographs of the subject[15,16]. This has meant that great importance is placed upon the need for the subject's head to be correctly aligned and orientated using proprietary cephalostats if rotational errors are to be avoided. However, it has been suggested that cephalostats, even if customised with ear and nose devices, do not overcome the problem[14]. The effect of head inclination on the capture of surface data on the image was considered[2]. It was found that a 10° change in inclination resulted in some landmarks becoming impossible to locate and assign coordinate values to. This problem varied with each landmark. Similar effects were noted when the head was moved from the centre of the image. It would seem likely that similar effects might occur for landmarks on the ear. It is therefore important to note that the orientation of the head is critical to the scanner being able to digitize the region of interest, and failure to do this correctly would mean that some anthropometric points may not be identified. However, in the present and earlier studies[5,6], a correct posture of the head was achieved, which allowed all anthropometric points to be clearly identified on a screen image from the laser scan.

In the present study, it proved possible to generate the set of orthogonal reference planes from the facial anthropometric points located on the image. The landmarks used for defining the frame of reference were chosen primarily for their reliability in terms of the accuracy with which they could be located. It should be noted that Point 3 is not on the surface of the face but lies within the confines of the image (Fig. 2). To define the central reference point, it was necessary to construct a line joining similar landmarks on each side of the face. It was judged that the inner canthi were the most appropriate points for construction of the line as they were located close to the midline of the face and would be least influenced by small amounts of facial asymmetry. The technique developed in this study allows the frames of reference to be constructed once the image has been captured and orientated to the desired position. The advantage of this technique is that if the frames of reference are incorrect, the image can be repositioned and viewed, and new frames of reference can be constructed without the need to scan the actual subject again.

The study on five subjects has shown that it is possible to define landmarks of the ear three-dimensionally with respect to a central reference point. Clearly these descriptions have most value in defining location of anthropometric points on a single subject. The mean differences for each dimension between the left and right sides were usually small and are to be expected. Although these differences might be related to fixed relations between features on the anterior part of the face[15,16], they may equally be explained by normal anatomical variation. The differences are regarded to be small and unlikely to have any clinical significance.

Points additional to those in the first part of the study were related to the central reference point and planes. These can all be used in the planning of the construction and the siting of prosthetic ears. The use of reference planes is considered to be critical in the planning for position of prosthetic ears and might also be useful in plastic surgical procedures of ear reconstruction. Nevertheless the anthropometric landmarks on the face also give useful information and should not be ignored in the planning process. As much relevant information as possible should be available to result in a more predictable prosthetic outcome in terms of position.

When a prosthetic ear is constructed and sited, it may require adjustment to make its position optimal for the patient. The optimal result may reflect a degree of artistry and aesthetic awareness by patient and operator. However the use of planning techniques to precisely position the ear would appear to offer significant advantages over simple visual assessment, even if minor correction of the prosthesis position is necessary. A potential problem with patients requiring prosthetic ears is that there may be irregular ear remnants remaining and the face and skull may be irregular.

However the ability to describe a series of landmarks three-dimensionally should offer the maxillofacial team considerable advantages in the planning and positioning of an artificial ear over a completely artistic approach. A patient who has lost an ear due to resection or trauma will usually be rehabilitated with a prosthetic ear. Laser scanning of the patient will produce an image that can be used to create the contralateral ear[4]. A knowledge of the precise location of the landmarks of the normal ear from the central reference point would allow a very accurate location of the artificial ear on the resected or trauma side by means of a template. A further use of this technique may be on patients who have congenitally absent ears (hemifacial microsomia). This aspect of treatment requires further study, since there may be more serious facial asymmetry.

Laser scanning techniques are of considerable value in the planning of ear position. The development of frames of reference and a central point of reference would appear to offer many advantages in the assessment and description of ear position over conventional techniques using measurements between anthropometric points.

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