The difference between registered natural head position and estimated natural head position in three dimensions


Abstract. This study determined the intra-rater and inter-rater reliability of re-orientating three-dimensional (3D) facial images into the estimated natural head position. Three-dimensional facial images of 15 pre-surgical class III orthognathic patients were obtained and automatically re-oriented into natural head position (RNHP) using a 3D stereophotogrammetry system and in-house software. Six clinicians were asked to estimate the NHP of these patients (ENHP); they re-estimated five randomly selected 3D images after a 2-week interval. The differences in yaw, roll, pitch, and chin position between RNHP and ENHP were measured. For intra-rater reliability, the intra-class correlation coefficient (ICC) values ranged from 0.55 to 0.77, representing moderate reliability for roll, yaw, pitch, and chin position, while for inter-rater reliability, the ICC values ranged from 0.38 to 0.58, indicating poor to moderate reliability. The median difference between ENHP and RNHP was small for roll and yaw, but larger for pitch. There was a tendency for the clinicians to estimate NHP with the chin tipped more posteriorly (6.3 ± 5.2 mm) compared to RNHP, reducing the severity of the skeletal deformity in the anterior–posterior direction.

Head orientation influences the anterior–posterior perception of the maxillomandibular complex and may result in incorrect diagnosis. Currently, intracranial reference lines such as the Frankfort horizontal (FH) and sella–nasion (SN) are widely used in standardizing lateral head film orientation. Natural head position (NHP) is more reproducible and is an alternative method of recording head orientation. As a consequence, NHP has gained popularity with both orthodontists and oral and maxillofacial surgeons. NHP is readily retrievable from a profile photograph or lateral cephalogram by using a true vertical reference line and is referred to as ‘registered natural head position’.

Three-dimensional (3D) surface imaging has become a routine method of capturing pre-treatment facial images. The
calibration of the device does not usually consider any physical reference lines or planes and only the patient’s surface topography, irrespective of orientation, is captured. Even though the patient’s facial image is captured in NHP, the resulting 3D facial image when re-loaded into viewing software will be displayed in an orientation dictated by the calibration and will no longer be in the correct orientation (Figs 1 and 2). To overcome this problem, the concept of registered natural head position (RNHP) was suggested. RNHP uses devices that record and transfer NHP. These include registration jigs, digital orientation sensors, and a laser level beam. However the devices themselves may influence the accuracy of RNHP and in some cases cause soft tissue distortion. Hsung et al. proposed the use of a physical reference system based on a secondary reference target to re-orientate the captured images to the pose in which the individual was originally captured, e.g. NHP. This technique was accurate and could be regarded as a method (gold standard) of re-orientating 3D facial images into NHP.

In situations where lateral cephalograms or lateral profile photographs are not taken in NHP, it is possible for clinicians to re-orientate the profile image (up and down) into the ‘estimated natural head position’ (ENHP). For 3D images, the complexity increases as the images can be manipulated with six degrees of freedom, three for changes in position (translation) along the x, y, and z axes, in addition to rotation around each of the three axes. The majority of 3D virtual orthognathic planning software packages require the user to load and re-orientate the 3D image into the correct pre-planning position, i.e. NHP. The assumption is that this can be performed correctly based on subjective clinical estimation or the use of some form of positioning device.

Given that 3D images are not always displayed in NHP and that positioning devices are not routinely available, the purpose of this study was to determine the intra-rater and inter-rater reliability of re-orientating 3D facial images of a group of class III patients into ENHP. The primary outcome measure was the difference in chin position between the ENHP and RNHP orientation using the technique suggested by Hsung et al. The null hypothesis was that the difference in anterior–posterior chin position (z direction) between the ENHP and RNHP orientation was not different to 6 mm, as this has been found to be clinically significant.

**Materials and methods**

**Sample size calculation**

Based on a standard deviation of 3.5° in the sella–nasion line to horizontal plane (SN/HOR) angle between RNHP and ENHP, an SN length of approximately 6.5 cm, SN–pogonion angle of approximately 80°, and total anterior facial height of 116 mm, the corresponding standard deviation at the chin (pogonion) would be expected to be approximately 5 mm. Using Minitab 17 (Minitab, State College, PA, USA) it was calculated that with 90% power, a significance level of 0.05, and a 6-mm clinical significance, a minimum sample size of 10 class III orthognathic surgical patients would be needed.

**Patient recruitment**

Following ethical approval by the Institutional Review Board (IRB) of Hong Kong...
University and Hospital Authority Hong Kong West Cluster, patients seeking treatment at the Department of Orthodontics or the Department of Oral Maxillofacial Surgery of the Prince Philip Dental Hospital were recruited. Based on the diagnosis of the orthognathic team, only pre-surgical class III orthognathic patients with no facial asymmetry were included. Individuals with craniofacial syndromes or anomalies were excluded. The average age of the 15 patients recruited was 21.9 years ± 8.5 months (range 17.2–26.9 years); 12 were female and three were male.

Clinicians
Six experienced clinicians (four male and two female, age range 27–34 years) from the Department of Orthodontics and the Department of Oral Maxillofacial Surgery, who were familiar with and routinely used NHP, were asked to estimate NHP by adjusting the pitch, roll, and yaw orientation of the images (Fig. 3).

3D imaging system calibration
A 3D stereophotogrammetry system (Di3D; Dimensional Imaging, Glasgow, UK) was adapted to record RNHP and to capture the 3D facial image of each of the subjects. This method involved three steps: first, the position of the mirror (25 cm × 21 cm) was recorded in three planes of space; second, the intrinsic properties of the Di3D system were calibrated using the Di3D calibration target; third, the physical external references were determined by aligning the reference board parallel to the mirror.

Obtaining registered natural head position (RNHP)
Subjects were asked to cover their hair with a headband and remove their glasses prior to 3D facial captures. They were then seated in front of the 3D capture system and instructed to obtain NHP as follows: sit upright, close their left eye and use their right eye to focus on a black point on the mirror and adjust the seating position if necessary, and tilt their head forward and backward with decreasing oscillations until a comfortable position of the head was obtained. They were then asked to look into their own eyes in the mirror and in relaxed lip position. When the subjects were in NHP, 3D facial captures were obtained using Di3D capture software (Dimensional Imaging, Glasgow, UK). All captures (at least five captures) were exported in Wavefront (OBJ) format, and using the appropriate in-house software, all subsequent 3D facial captures were automatically re-orientated into RNHP (TCH).

Obtaining estimated natural head position (ENHP)
The 3D images in RNHP were first imported into MeshLab software (STI-CNR, Rome, Italy; http://meshlab.sourceforge.net) and each image was prepared for standardized viewing by deleting the shoulders and hair but leaving the ears and neck region. The pitch, roll, and yaw of each cropped 3D image were then changed using MeshLab. The amount of change was a figure from 10° to 30° generated by a random number generator. The image was then saved as a new OBJ file. Each 3D image, in its new orientation, was imported into Di3Dview installed on a Dell PC computer (Dell Precision T5600; Dell Inc., Round Rock, TX, USA) with a 24" LED wide screen monitor. To familiarize the clinicians with the software, a demonstration was conducted prior to the main study. The clinicians were shown how to change the pitch, roll, and yaw of the image. For the main study, the clinicians were asked to re-orientate each 3D image into NHP based on their general experience, with no time limitation (T1). Each image was saved in the new position in OBJ format.

To assess the intra-rater reliability five randomly selected RNHP images were re-orientated into ENHP by six clinicians after a 2-week interval (T2). It has been reported that 2 weeks is an acceptable washout interval. For each patient, the RNHP and ENHP images were imported into Di3Dview. A single landmark was placed at pronasale on both images. The ENHP image was translated along the mediolateral direction (x-axis), inferosuperior direction (y-axis), and anteroposterior direction (z-axis) and aligned on pronasale, which then served as the centre of rotation and the local coordinate system. The aligned ENHP image was saved in OBJ format. Using in-house developed software, three soft tissue landmarks were selected on the RNHP, which displayed the vertex number associated with the landmark (Fig. 4). As the RNHP and the ENHP were the same image, the same vertices could be identified on the ENHP. It is more meaningful to consider the three landmarks as a triangle undergoing rigid body transformation (Fig. 5).

Determining the differences in yaw, roll, and pitch between ENHP and RNHP
To determine the differences in yaw, the angle between the lines joining the left exocanthion and the right exocanthion on both the ENHP and RNHP images of each participant was measured as if projected on the X−Z plane (Fig. 6). The error in roll was determined by projecting the same lines on the X−Y plane (Fig. 7). Finally the difference in pitch was calculated by measuring the angle between the lines joining pronasale and pogonion on both the ENHP and RNHP images as if they were projected on the Y−Z plane (Fig. 8). The angle θ between two

Fig. 3. The coordinate system used in this study and the pitch, yaw, and roll rotations around the x, y, and z axis, respectively.
lines was calculated using the equation \( \theta = \cos^{-1}\left( \frac{a \cdot b}{|a||b|}\right) \), where \( a \) and \( b \) are the vectors pointing in the direction of each line.

### Statistical analysis

The mean differences in \( x \), \( y \), and \( z \) coordinates of the three landmarks between RNHP and ENHP were measured and descriptive statistics determined. The data were checked for outliers and normality. No outliers were found and the differences between the \( x \), \( y \), and \( z \) coordinates for the RNHP and ENHP images were found to be normally distributed. Therefore a one-sample \( t \)-test was performed to detect whether the difference in chin position in the \( y \) direction was significantly different to 6 mm.

An intra-class correlation coefficient (ICC) analysis was used to assess the intra-rater reliability (one-way random) and inter-rater reliability (two-way mixed) for roll, yaw, pitch, and chin position for the six clinicians. ICC values of 0.75 and above represent good reliability, those between 0.50 and 0.74 represent moderate reliability, and those below 0.50 indicate poor reliability.

### Results

The mean differences in the \( x \) direction were \( 0.0 \pm 1.1 \) mm, \( -0.3 \pm 1.2 \) mm, and \( 0.4 \pm 1.7 \) mm for the right eye, left eye, and chin, respectively. The mean differences in the \( y \) direction were \( -2.9 \pm 2.6 \) mm, \( -2.3 \pm 2.7 \) mm, and \( -1.2 \pm 1.4 \) mm for the right eye, left eye, and chin, respectively. Finally the mean differences in the \( z \) direction were \( -4.0 \pm 3.5 \) mm, \( -2.7 \pm 2.9 \) mm, and \( 6.3 \pm 5.2 \) mm for the right eye, left eye, and chin, respectively (Table 1). The results of the one-sample \( t \)-test showed that the mean difference in chin position in the \( z \) direction between ENHP and RNHP was \( 6.3 \pm 5.2 \) mm and not significantly different to 6 mm (\( P = 0.645 \)), with a 95% confidence interval of 5.2 mm to 7.3 mm.

Figure 9 shows that there was a tendency for the clinicians to orientate the ENHP image so that the chin was rotated more posteriorly (\( 6.3 \pm 5.2 \) mm) in the \( z \) direction. As expected, with the chin more posteriorly placed, the right and left eyes (\( 4.0 \pm 3.5 \) mm and \( -2.7 \pm 2.9 \) mm) were more anteriorly positioned as the images were centred and rotated around pronasale.

### Intra-rater reliability

For intra-rater reliability, the ICC values ranged from 0.55 to 0.74, representing moderate reliability for roll, yaw, and pitch. Median differences between ENHP and RNHP for roll (\( -0.3^\circ \)) and yaw (\( 0.2^\circ \)) were small, but were larger for pitch (\( -1.3^\circ \)). The ICC value for chin position was 0.77, representing good reliability. Median difference between ENHP and RNHP was \( -1.2 \) mm (Table 2).

### Inter-rater reliability

For inter-rater reliability, the ICC values ranged from 0.39 to 0.58, representing poor to moderate reliability for roll, yaw, and pitch between clinicians. Median differences between ENHP and RNHP for roll (\( -0.7^\circ \)) and yaw (\( -0.2^\circ \)) were again small, but much larger for pitch (\( 5.5^\circ \)). The ICC value for chin position was 0.38, representing poor reliability. Median difference between ENHP and RNHP was \( 6.7 \) mm (Table 3).

### Discussion

The fundamental premise of assessment, diagnosis, and treatment planning for individuals with a dentofacial deformity relies on correct head positioning. Based on conventional two-dimensional (2D) facial photographs, natural head orientation (NHO) or estimated natural head position (ENHP) is an alternative to registered natural head position.
Fig. 6. Yaw angle calculated between right exocanthion (landmark 1) and left exocanthion (landmark 2), joined on both registered natural head position (RNHP, yellow) and estimated natural head position (ENHP, red) images and projected onto the axial plane (X–Z plane) looking down the y-axis (Gateno et al., 201124).

Fig. 7. Roll angle calculated between right exocanthion (landmark 1) and left exocanthion (landmark 2), joined on both registered natural head position (RNHP, yellow) and estimated natural head position (ENHP, red) images and projected onto the coronal plane (X–Y plane) looking down the z-axis (Gateno et al., 201124).

Fig. 8. Pitch angle calculated between pronasale (landmark 4) and pogonion (landmark 3), joined on both registered natural head position (RNHP, yellow) and estimated natural head position (ENHP, red) images and projected onto the sagittal plane (Y–Z plane) looking down the x-axis (Gateno et al., 201124). However, there appear to have been no equivalent studies using 3D facial images. The ability to correctly re-orientate a 3D facial image into the correct NHP is the starting point of virtual orthognathic surgical planning. This study was undertaken to determine the validity and reproducibility of undertaking this fundamental process based on subjective estimation only.

Ideally NHP should be recorded without any devices attached to the head, any markings on the face, or the use of subjective datum points9. Stereophotogrammetric NHP developed by Hsung et al. attains these requirements16. Even though the method may not be readily usable in a clinical setting, it did provide the ‘gold standard’ to obtain RNHP for the present study. The repeatability of the physical reference system was clinically acceptable, with standard deviations of less than 0.1° for pitch and yaw angles and 0.15° for roll angles.

The moderate level of intra-rater reliability for roll, yaw, and pitch indicates that individual clinicians could estimate NHP consistently in 3D space. The median differences between ENHP and RNHP for roll (−0.3°) and yaw (0.2°) were small, but were larger for pitch (−1.3°). It is worth noting that the 95% confidence interval for the difference in chin position in the z direction (5.2 mm to 7.3 mm) may have the potential to alter clinical assessment and outcome.

The poor to moderate inter-rater reliability indicated that 3D facial images could be reliably orientated into NHP with respect to roll and yaw only, but not pitch. The smaller differences in roll and yaw for both intra- and inter-rater reliability may be explained by clinicians using the eyes (pupils) to orientate the image horizontally and reducing roll error. The clinicians may also be using the ears and the amount of cheek show on the left and right halves of the facial image to adjust for rotational symmetry, therefore reducing yaw error. This hypothesis could be tested by repeating the study on a group of patients with hemifacial macrosomia. The orbital dystopia, differences in ear height and in asymmetric hemifacial projection may have a marked effect on the roll and yaw as well as the pitch; this was beyond the scope of the present study. Regarding pitch estimation, there are few visual cues to guide the clinician, which may explain the difficulties in reaching a consensus on the pitch orientation and so chin position. In the absence of such visual cues, clinicians may be using their own references for pitch, i.e. Frankfort plane. However,
similar to the cephalometric radiographs, difficulties in locating soft tissue landmarks accurately on a 3D image may result in the differences amongst clinicians.

The present study found that clinicians overwhelmingly orientated a 3D facial image so that the chin lies more posteriorly when estimating NHP, with a mean difference of 6.3 ± 5.2 mm (95% confidence interval of 5.2 mm to 7.3 mm). Interestingly this is in agreement with a previous study using 2D images to assess whether NHO is influenced by facial morphology. The study reported that the severity of both class II and class III skeletal patterns were underestimated.

The effect of chin position on the perceived need for orthognathic surgery has been reported previously. The study reported that when chin prominence reached approximately 6 mm beyond a class I acceptable profile, surgery was suggested by laypeople, orthognathic patients, and clinicians. Interestingly, in the present study, the difference between ENHP and NHP chin position in the z direction was not significantly different to 6.0 mm (P = 0.645); this would imply a clinically acceptable result. However, it should be noted that the chin prominence was compared starting from a class I profile, whilst the present study started with skeletal class III patients. This difference may exaggerate the severity of chin prominence and still has the possibility to change the desire for surgical correction amongst clinicians. Also the range of error for pitch was large, from −3.5° up to 13.2°, again highlighting the inconsistency in re-orientating the image correctly.

In conclusion, many current 3D imaging techniques do not maintain the recorded NHP. This study showed that subjective re-orientation of 3D images into NHP is reproducible with respect to roll and yaw, in the absence of facial asymmetry, but not in pitch. The subjective re-orientation of 3D images into NHP in class III patients may reduce the perceived severity of the skeletal deformity in the anterior–posterior direction, i.e. they will look less class III. Therefore when using 3D virtual planning, clinicians require an additional frame of reference to orientate the images prior to planning, as clinicians are unable to re-establish the correct NHP reliably.

Table 1. Descriptive statistics showing the mean differences in x, y, and z coordinates between registered natural head position (RNHP) and estimated natural head position (ENHP) for the three landmarks.

<table>
<thead>
<tr>
<th></th>
<th>MD (mm)&lt;sup&gt;a&lt;/sup&gt;</th>
<th>SD (mm)</th>
<th>95% CI for MD (mm)</th>
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<tr>
<td></td>
<td></td>
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<td>Lower</td>
</tr>
<tr>
<td>Right eye</td>
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<td></td>
</tr>
<tr>
<td>x</td>
<td>0.0</td>
<td>1.1</td>
<td>−0.2</td>
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<tr>
<td>y</td>
<td>−2.9</td>
<td>2.6</td>
<td>−3.5</td>
</tr>
<tr>
<td>z</td>
<td>−4.0</td>
<td>3.5</td>
<td>−4.8</td>
</tr>
<tr>
<td>Left eye</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>x</td>
<td>−0.3</td>
<td>1.2</td>
<td>−0.3</td>
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<tr>
<td>y</td>
<td>−2.3</td>
<td>2.7</td>
<td>−2.9</td>
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<tr>
<td>z</td>
<td>−2.7</td>
<td>2.9</td>
<td>−3.3</td>
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<tr>
<td>Chin</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>x</td>
<td>0.4</td>
<td>1.7</td>
<td>0.1</td>
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<tr>
<td>y</td>
<td>−1.2</td>
<td>1.4</td>
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</tr>
<tr>
<td>z</td>
<td>6.3</td>
<td>5.2</td>
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</table>

MD, mean difference; SD, standard deviation; CI, confidence interval.

<sup>a</sup> Positive (+) values in the x, y, and z directions indicate that the ENHP image is to the left, lower, and more posterior, respectively, than the RNHP image.

<sup>b</sup> Mean difference = RNHP − ENHP.

Fig. 9. Distribution of the frequency of ENHP 3D facial image orientated so that the chin lies more posteriorly (negative) or anteriorly (positive) than the RNHP. (RNHP, registered natural head position; ENHP, estimated natural head position.)

Table 2. Intra-rater reliability for roll, yaw, pitch, and chin position. Also shown are the median differences between registered natural head position (RNHP) and estimated natural head position (ENHP) for roll, yaw, and pitch, along with the range and IQR.

<table>
<thead>
<tr>
<th></th>
<th>ICC</th>
<th>95% CI for ICC</th>
<th>Median difference (degrees)</th>
<th>Minimum (degrees)</th>
<th>Maximum (degrees)</th>
<th>IQR (degrees)</th>
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<tbody>
<tr>
<td>Angular</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roll</td>
<td>0.55</td>
<td>0.24 to 0.75</td>
<td>−0.3</td>
<td>−2.9</td>
<td>1.4</td>
<td>1.5</td>
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<tr>
<td>Yaw</td>
<td>0.64</td>
<td>0.37 to 0.81</td>
<td>0.2</td>
<td>−5.9</td>
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<td>1.3</td>
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<tr>
<td>Pitch</td>
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<td>0.53 to 0.87</td>
<td>−1.3</td>
<td>−6.2</td>
<td>7.9</td>
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<table>
<thead>
<tr>
<th></th>
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<th>Minimum (mm)</th>
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<th>IQR (mm)</th>
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<tr>
<td>Chin position</td>
<td>0.77</td>
<td>0.58 to 0.88</td>
<td>−1.2</td>
<td>−8.9</td>
</tr>
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</table>

CI, confidence interval; ICC, intra-class correlation coefficient; IQR, interquartile range.
Table 3. Inter-rater reliability for roll, yaw, pitch, and chin position. Also shown are the median differences between registered natural head position (RNHP) and estimated natural head position (ENHP), along with the range and IQR.

<table>
<thead>
<tr>
<th></th>
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<th>95% CI for ICC</th>
<th>Median difference (degrees)</th>
<th>Minimum (degrees)</th>
<th>Maximum (degrees)</th>
<th>IQR (degrees)</th>
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<tbody>
<tr>
<td>Angular</td>
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<td></td>
</tr>
<tr>
<td>Roll</td>
<td>0.39</td>
<td>0.18 to 0.66</td>
<td>−0.7</td>
<td>−3.1</td>
<td>3.2</td>
<td>1.8</td>
</tr>
<tr>
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<td>0.58</td>
<td>0.31 to 0.76</td>
<td>−0.2</td>
<td>−3.9</td>
<td>5.3</td>
<td>3.0</td>
</tr>
<tr>
<td>Pitch</td>
<td>0.39</td>
<td>0.19 to 0.66</td>
<td>5.5</td>
<td>−3.5</td>
<td>13.2</td>
<td>7.3</td>
</tr>
</tbody>
</table>

| Linear   |       |                |                            |                  |                  |               |
| Chin position | 0.38 | 0.16 to 0.66 | 6.7                       | −3.8             | 16.9             | 9.0           |

CI, confidence interval; ICC, intra-class correlation coefficient; IQR, interquartile range.

Funding
None.

Competing interests
None.

Ethical approval
Ethical approval was granted by the Institutional Review Board (IRB) of Hong Kong University and Hospital Authority Hong Kong West Cluster (protocol reference number UW 14-355).

Patient consent
Written patient consent was obtained to publish the clinical photographs.

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References

Address: Balvinder S. Khambay
Institute of Clinical Sciences
College of Medical and Dental Sciences
The School of Dentistry
University of Birmingham
5 Mill Pool Way
Edgbaston
Birmingham B5 7EG
UK
E-mail: b.s.khambay.2@bham.ac.uk