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A skull-holding device for experimental cephalometric research

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SUMMARY This paper describes and illustrates an innovative versatile skull-holding device for experimental research in cephalometrics. Repositioning of the skulls was evaluated and found to be highly reproducible.

Introduction

Dry human skulls have frequently been used in lateral cephalometric studies and have the advantage of accurate orientation of the reference planes. Markers can be placed in the skulls in order to locate the true skeletal and dental landmarks. Examples of markers include lead bits, calibrated rods, radio-paque paste, lead shot indicators, and spherical lead markers.

During any series of lateral radiographs, the position of the skulls in the cephalostat needs to be reproducible. Typically, the skulls are removed and then replaced following the placement of landmark markers. Any shifting or rotation of the skulls during the repositioning would distort the radiographic images and affect the landmark locations on the cephalograms.

In reviewing the literature, no suitable design of skull holder has been described. Mattila and Haataja (1968) used a specially designed skull holder to support the skulls in the cephalostat, but no details of that skull holder were given. In a recent study on medieval skulls, Luther (1993) did not describe how the skulls were mounted in the cephalostat.

The aims of this study were to design a versatile skull holder for cephalometric research and also to evaluate the error arising from skull repositioning.

Construction of the skull holder

Design of the holder

A skull holder (Fig. 1) has to hold and support the skulls in the cephalostat while the radiographs are taken. It should not interfere with the X-ray beam and 'block out' the landmarks of interest. In addition, the skull holder should allow the skulls to be replaced in an exact orientation and location within the skull holder and cephalostat. Moreover, for studies investigating the effect of head posture on cephalometric landmark identification (Tng *et al.*, 1993), the skull holder should allow the skulls to rotate in the cephalostat along the sagittal plane (i.e. upward and downward tipping).

Aluminium was selected as it is light yet has the strength and rigidity to hold the skulls, and allow manipulation. Also, screw threads can be easily incorporated into the frame to allow the placement of screw pins. The skull holder should be designed to be 'away' from the skull so that it will not interfere with the radiation or with the radiographic film images (Fig. 1).

The skull holder comprised five main parts (Fig. 1A–C).

Clamps. Four clamps with adjustable universal joints clamp the skull. Two are in front, and two at the back, of the skull. There is a screw hole in each clamp which allows the screw pins to fit into it and to support the skulls in the skull holder.

Screw pins. Four screw pins, two in the front and two behind, are inserted into the screw hole of the clamps to support the skulls. These screw pins are connected to the main framework by universal ball joints on the connectors. The skull holder can hold a skull with the calvarium removed by means of the clamps or, if the calvarium is intact, the screw pins can hold the skull surfaces directly.

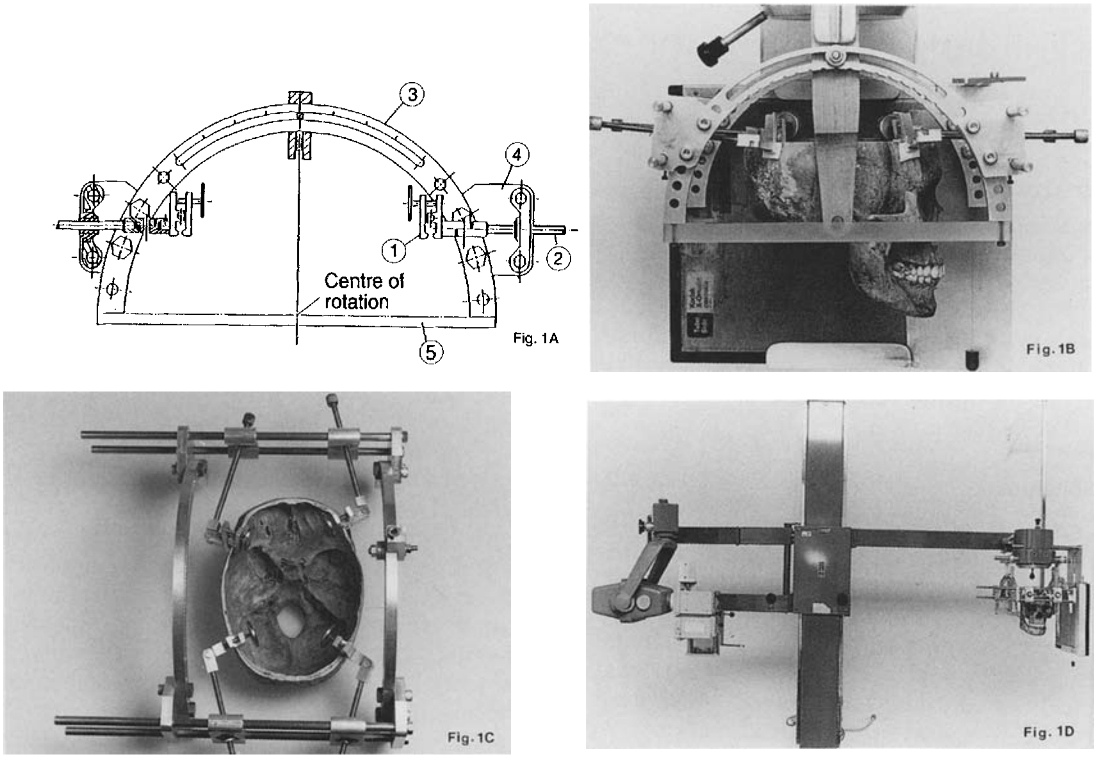

Figure 1 (A) Technical drawing of the skull holder. (1) Clamps—clamped to the skulls and with a screw hole to allow the screw pin to be inserted to support the skulls onto the skull holder. (2) Screw pins—inserted into the screw hole in the clamps and connected with the connectors by universal ball joints. (3) Frames—semi-circular frames with 5-degree intervals. The left frame is fixed on the connectors and the right frame can slide along the connectors to accommodate different sizes of skulls. (4) Connectors—connects the semi-circular frames and the screw pins. (5) Alignment jig—for the alignment of the skulls with the Frankfort plane parallel to the floor. (B) The skull holder (lateral view). The two semi-circular frames have markings at five degree intervals (from −40 to +40 degrees). (C) A skull attached to the skull holder (top view). Four clamps with adjustable universal joints are clamped on the skulls. There is a screw hole in each clamp which allows the screw pins to support the skulls in the holder. Four screw pins are inserted into the screw hole of the clamps to support the skulls. These screw pins are connected to the main framework by universal ball joints on the connectors. (D) The holder with a skull in a firm and reproducible position in the cephalostat.

Frame. Two semi-circular frames with markings at five degree intervals, one on the left side and one on the right, which allow the skull holder to rotate from −40 to +40 degrees. The frame on the left side is fixed on the connectors. The frame on the right side can slide along the connectors to accommodate different sizes of skulls.

Connectors. These connect the two semi-circular frames and allow the frame on the right side to slide along in order to accommodate the different sizes of skulls.

Alignment jig. This is made of plastic material and is attached with screws at the two ends of the semi-circular frame. It lies along the diameter of the semi-circular frame. When the skull holder is mounted on the cephalostat with the marking on the semi-circular frames at 0 degrees, the alignment jig lies parallel to the floor. The skulls mount on the skull holder with the Frankfort plane parallel to the alignment jig and parallel to the floor.

The skull holder is attached to the cephalostat ear posts in such a way that the centre of the diameter of the semi-circular frame is at the ear rod (Fig. 1D). This centre is also the centre of rotation of the skull holder. The skull holder can rotate around the centre of rotation at intervals of 5 degrees as marked on the frames. The width of the skull holder can be adjusted for different sizes of skulls by sliding the frame

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on the right side along the connectors (Fig. 1C). The skull holder is first mounted on the cephalostat with the marking at the semi-circular frames at 0 degree. The skull is then attached to the skull mount with the Frankfort Plane parallel to the alignment jig. The assembly is then secured by tightening the screw pins to the clamps.

Skull repositioning error

Materials and methods

This part of the study investigated the error of repositioning the skulls into the cephalostat. The material consisted of 30 skulls with full dentition, aged between 20 and 40 years of age. The skulls were mounted into the cephalostat and orientated with the Frankfort Plane horizontal, with the aid of a skull mount. Steel ball markers were glued onto the skulls to represent 15 'true' skeletal and dental landmarks (Fig. 2A). A series of cephalograms was obtained (Series 1). The skulls were removed from the cephalostat and skull mount by a single investigator and repositioned back into the cephalostat. A second series of cephalograms was obtained within the same session (Series 2).

The cephalograms were orientated by the computer along a reference line (R1–R2) constructed from two arbitary fiducial reference points, R1 and R2 (Fig. 2A and 2B). R1 and R2 were predetermined radio-opaque fiducial points marked on the inner skull surface away from the other areas of study. The X-axis was defined as the line joining R1 and R2. The Y-axis was defined as a line from the anterior reference fiducial mark (R1) perpendicular to the X-axis.

The two series (Series 1 and 2) of cephalograms were digitized once by one observer. The contact points between the steel ball markers and the bone/tooth surfaces were digitized as the true landmarks except for sella, where the centre of the steel ball was digitized. The distances along the X- and Y-axes of the landmarks were measured by the computer (Fig. 2B). The computer calculated the mean differences and standard deviations between the two series of assessments. The differences in the assessments between Series 1 and Series 2 was tested by Student's two-tailed t-test at $P<0.05$.

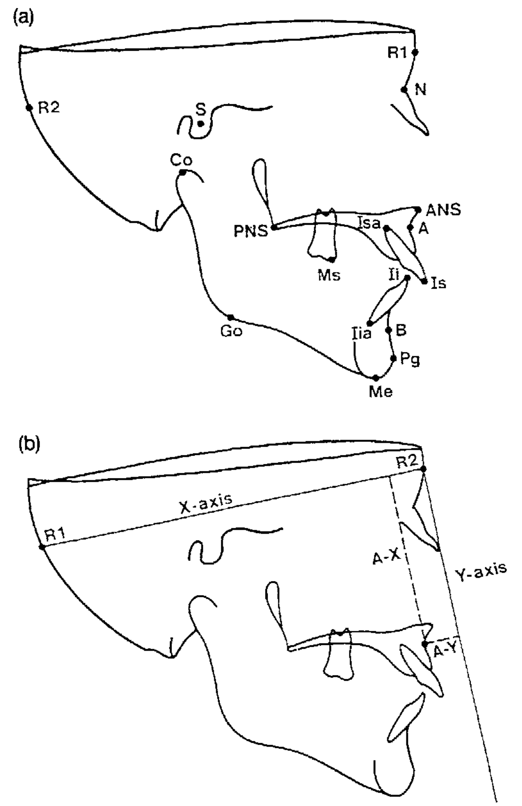

Figure 2 (A) The 15 skeletal and dental landmarks (Björk, 1947) used in this study. (B) The co-ordinate reference system based on the reference points R1 and R2. These points are arbitrary radio-paque fiducial points marked onto the inside of the calvarium. The X-axis is defined as the line R1–R2 and the Y-axis as the perpendicular from R1. All the landmarks were measured with respect to the X- and Y-axes (Tng, 1991; Tng *et al.*, 1994).

Results (Tables 1 and 2)

The mean differences between the assessments were small (NS) along both the X- and Y-axes (−0.05–0.06 mm). The standard deviations for all landmarks except condylion were also small, being less than 0.21 mm along the X- and Y-axes. For condylion, the standard deviation along the X-axis was four times higher than those of the other landmarks (Table 1).

The mean differences for the cephalometric angles and distances (Table 2) were all small and not statistically significant except for the SN to mandibular plane angle (NSL–ML) ($P<0.05$). The standard deviations of the angles and distances were also small, being 0.1–0.4 degrees and 0.1–0.2 mm, respectively. However,

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Table 1 Repositioning error. The linear differences (mm) between the initial and repeat recordings along the X- and Y-axes ($n=30$). No statistically significant differences were found at $P<0.05$.

Landmark	Mean	Standard deviation
Sella–X	−0.01	0.11
Sella–Y	0.01	0.09
Nasion–X	−0.02	0.11
Nasion–Y	0.03	0.10
ANS–X	0.03	0.16
ANS–Y	0.02	0.14
PNS–X	0.00	0.12
PNS–Y	0.01	0.12
A-point–X	0.02	0.13
A-point–Y	0.01	0.13
B-point–X	−0.05	0.15
B-point–Y	0.01	0.20
Pogonion–X	−0.03	0.16
Pogonion–Y	0.00	0.18
Menton–X	−0.05	0.19
Menton–Y	−0.00	0.21
Gonion–X	0.00	0.15
Gonion–Y	0.02	0.19
Condylion–X	0.05	0.44
Condylion–Y	0.03	0.74
Apex superior–X	−0.00	0.14
Apex superior–Y	0.03	0.14
Incision superior–X	−0.03	0.18
Incision superior–Y	0.05	0.19
Incision inferior–X	−0.02	0.18
Incision inferior–Y	0.03	0.19
Apex inferior–X	−0.02	0.16
Apex inferior–Y	0.06	0.17
Molare superior–X	−0.01	0.12
Molare superior–Y	0.02	0.13

the mean difference (0.1 degrees) and standard deviation (0.12 degrees) of NSL/ML were no higher than those of the other measurements.

Discussion

In measuring the error of positioning the skulls, the total error measured could be broken down into digitizer error and actual error incurred in the positioning of the skulls.

The standard deviation of the digitizer error had been tested previously and was small (Tng, 1991). The standard deviations of positioning the skulls for all landmarks except condylion were 0.11–0.18 mm along the X-axis and 0.09–0.21 mm along the Y-axis (Table 1). In general, the standard deviation of the digitizer error was quite similar to that of the positioning of the skulls which indicated that the error in positioning the skulls alone contributed very little to the total error. The only exception was condylion. The standard deviation was 0.44 mm along the X-axis and 0.74 mm along the Y-axis. However, the high standard deviations were due to the difficulty in locating the steel ball indicators in this area.

Table 2 Repositioning error. Differences of cephalometric angles (degrees) and distances (mm) between the initial and repeat recordings ($n=30$)

Landmark	Mean	Standard deviation
Angles (degrees)		
SNA	−0.01	0.13
SNB	−0.04	0.10
SNPg	−0.03	0.09
ANB	0.03	0.10
NSL–NL	0.00	0.17
NSL–ML	0.06*	0.12
NL–ML	0.06	0.16
ILs–NSL	0.07	0.23
ILs–NL	0.08	0.26
ILs–NA	0.08	0.24
ILs–ML	0.01	0.38
ILi–NB	0.02	0.36
Ils–ILi	0.02	0.44
Distances (mm)		
N–Me	0.05	0.16
N–Sp	0.01	0.11
Sp–Me	0.04	0.12
Ii–Apg	−0.02	0.14

*$P<0.01$.

The mean differences of cephalometric angles and distances were not statistically significant ($P<0.05$) except NSL/ML (0.06 degree) (Table 2). However, the standard deviation for NSL/ML (0.12 degree) was small. The statistically significant systematic error was due to the small value in the standard deviation rather than a large mean difference. Therefore, although statistically significant, it was not considered to be of significance.

There was no systematic error found in the positioning of the skulls and, on average, it was only slightly higher than that for digitizing alone. Accordingly, the positioning of the skulls seemed to have been completed with high accuracy.

This skull holder supported and held the skulls steadily while taking the radiographs, and did not interfere with the images of the landmarks of interest on the cephalograms. The versatility of the design allowed skulls of all sizes to be mounted in the skull holder and allowed rotation along the sagittal plane.

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As the contour of the cranium was not the same in every skull, the clamps could not fit closely to the surface of the skulls. Moreover, as the clamps were made of aluminium, it was found that the clamps would slip on the surface of the skull. Plastic foam which deformed under pressure was therefore placed in between the clamps and the surface of the skulls. This provided a surface contact between the clamp and the skulls.

This device has been used to investigate the validity of cephalometric landmarks, angles and distances (Chan *et al.*, 1994; Tng *et al.*, 1994) and the effects of head posture on cephalometric sagittal angular measurements (Tng *et al.*, 1993). It should have wide application to a range of studies involving accurate holding and repositioning of dry skulls.

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