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Development of Equipment for the Standardization of Skull Photographs in Personal Identifications by Photographic Superimposition

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ABSTRACT: The technique of photographic superimposition of postmortem specimens (dried skull or head) positioned identically to the orientation in an antemortem smiling photograph is now a recognized method for personal identification of human remains. Previous methods used to produce the postmortem photographs were problematic as orientation of the specimen could not be easily adjusted and positions were not reproducible. The objective of this paper is to describe the design and method of use of purpose-constructed equipment intended to alleviate these problems.

The equipment comprises a skull-holding jig based conceptually on the Royal Berkshire Hospital halo frame. This is mounted on a pan-and-tilt device, incorporating calibrated measurement scales, enabling independent movements in each of the Cartesian coordinates. A camera is attached to an adjustable mount running on twin parallel rails allowing the camera-to-specimen distance to be varied.

The equipment has proven to be straightforward in use and offers considerable advantages over previously described methods for producing postmortem photographs.

KEYWORDS: odontology, dentition, superimposition, photography, human identification, photographic superimposition, cranium, skull

Identification of human remains is necessary to satisfy legal, insurance, and social requirements [*1*], and for this purpose the use of dental records to achieve a positive identification, on the basis of corresponding antemortem and postmortem records, has been widely accepted [*2*]. There are, however, cases in which such a conventional identification system is not possible due to either a lack of dental treatment or a lack of dental records. Where this situation exists and the identity of the decedent is suspected, use can be made of antemortem photographs to carry out superimposition with postmortem photographs of the skull of the decedent; the individuality of the dentition and facial skeleton provides multiple reference points for such identification [*3,4*].

In recent years a number of methods of photographic superimposition have been published accompanied by case reports. A detailed review of those methods using still photogra-

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phy has been published by McKenna et al. [*4*]. An often encountered problem is the postioning of the skull in the identical orientation relative to the camera as depicted in the antemortem photograph [*5*]. The recent introduction of video techniques to this field [*5–8*] has reduced the magnitude of this problem as it is now possible, using special video mixing units, to readily obtain a visual "match." A conventional photograph of the skull in the selected orientation is, however, generally required for substantive evidence in court and can usually be made by substituting the video camera for a still camera. A method of holding the skull is essential regardless of whether video or still photography is used; the majority of such skull holders as used by previous authors have been rather elementary in design and have not enabled a record of the skull position to be made for the purpose of standardization or reproducibility.

The desirability of being able to record the actual position of the skull in the holder and its exact orientation to the camera becomes obvious when considering a situation involving multiple victims in which it may be necessary to return to individual skulls for reexamination, or to examine one skull against a number of possible antemortem matches. With this need in mind, we have designed equipment for supporting and photographing a skull, or fragments of a skull, in a standardized and reproducible manner.

The objectives of this report are to describe: (1) the design features and (2) the method by which this equipment is used in personal identifications.

Description of the Equipment

The equipment that has been developed is depicted in Fig. 1. It has been specifically designed to be strong, lightweight, and portable; this has been achieved by using aviation grade aluminum for the construction of the majority of the components.

The four basic components of the equipment will be described in turn.

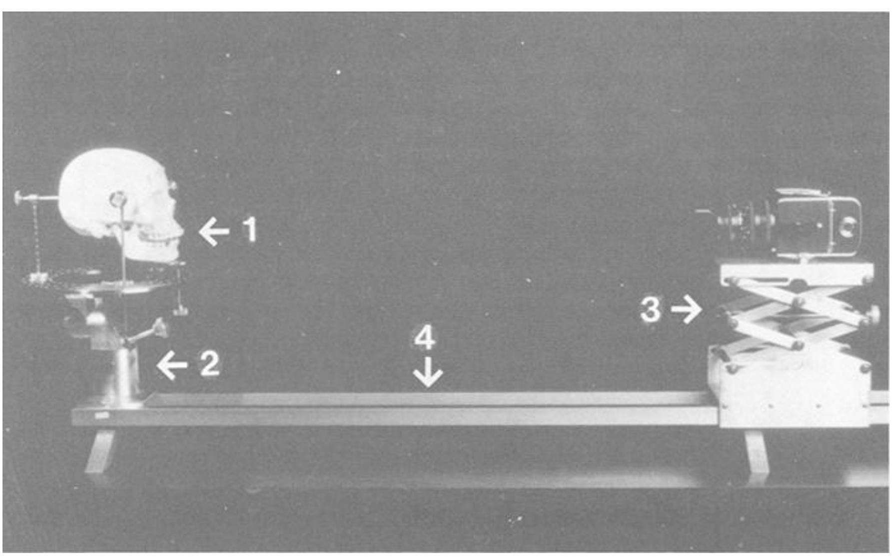

FIG. 1—*Basic components of the equipment comprising* (1) *a skull-holding jig,* (2) *a pan-and-tilt device,* (3) *a camera mount, and* (4) *supporting rails.*

1. The Skull-holding Jig

This component of the apparatus (Fig. 2) is based on the design of the Royal Berkshire Hospital (RBH) halo frame, which was originally developed by MacKenzie and Ray [*9*], to be used in the field of maxillofacial trauma for stabilization of fractures involving the middle third of the facial skeleton.

The halo frame illustrated here comprises a circular disk of aluminum drilled with three rows of concentric holes. A mounting plate positioned central to the halo enables the skull jig to be attached of the pan-and-tilt device described in (2) below; the need to mount the jig on top of this pan-and-tilt device made it necessary to design the apparatus with the skull suspended above the halo, and in this respect the design differs from the original RBH halo where the facial skeleton is suspended beneath the halo.

The skull to be photographed is positioned in the jig by a number of horizontal, threaded fixing pins made of stainless steel which provide point contact with the outer table of the skull. These horizontal fixing pins screw into vertical, threaded connecting rods, likewise made of stainless steel, which pass through selected holes in the halo. The three rows of concentric holes in the halo enable the position of the vertical connecting rods and respective horizontal fixing pins relative to the skull to be altered. Locking nuts on both horizontal pins and vertical connectors enable individual adjustments to be effected enabling skulls of different size, shape, and condition to be accommodated.

Three-point fixation has proven to be more than adequate for the majority of identification cases in which this equipment has been used. Additional horizontal fixing pins and vertical supporting rods of different lengths are available for those instances in which supplemental fixation is required.

The mandible is supported at its lower border in the region of the chin by a circular aluminum platform adjustable in height by means of a vertical threaded rod passing through one

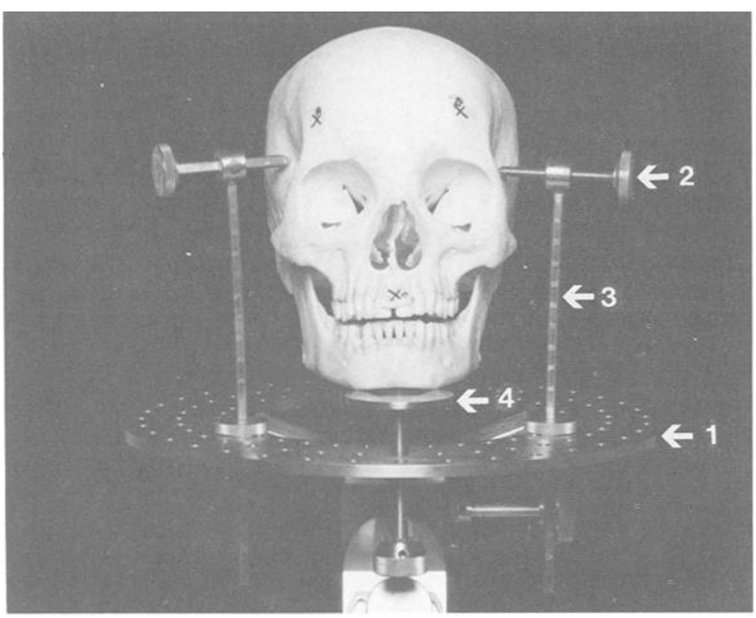

FIG. 2—*The skull-holding jig comprising* (1) *halo frame,* (2) *horizontal, threaded fixing pins,* (3) *vertical, threaded connecting rods, and* (4) *adjustable platform to support the mandible.*

of the holes in the halo. This enables the degree of opening to be modified to correspond to the antemortem photograph.

2. *The Pan-and-tilt Device*

The pan-and-tilt device (Fig. 3) enables the skull to be tilted in either or both of the two vertical planes while also permitting rotation in the horizontal plane.

The degree of tilt in each of the two vertical planes can be independently adjusted by means of two worm-gearing mechanisms positioned at right angles to each other. Each worm gear comprises an adjustment shaft that is threaded at one end (the worm), which in turn mates with a gear (wormwheel). The worm gears are subject to wear and have therefore been constructed of brass. Rotation of the adjustment shaft results in rotation of the gear thereby producing tilt of the skull in one plane. This gearing mechanism permits very fine adjustment of the degree of tilt.

Rotational movement in the horizontal plane is possible through 360°. The two tilting devices described above are attached to a collar which rotates round a central spindle. A locking device located on the collar enables the rotation position to be fixed. The central spindle forms part of a mounting plate which is attached to the two supporting rails by thumb screws.

3. *The Camera Mount*

The camera mount is designed to fulfill three requirements which are to provide: (1) stable mounting for either a still or video camera, (2) adjustment of the camera height to center the skull within the camera viewfinder, and (3) adjustment of the camera-skull distance to accommodate lenses of different focal lengths.

The camera is fixed to the mount by means of an attachment plate and a thumb screw

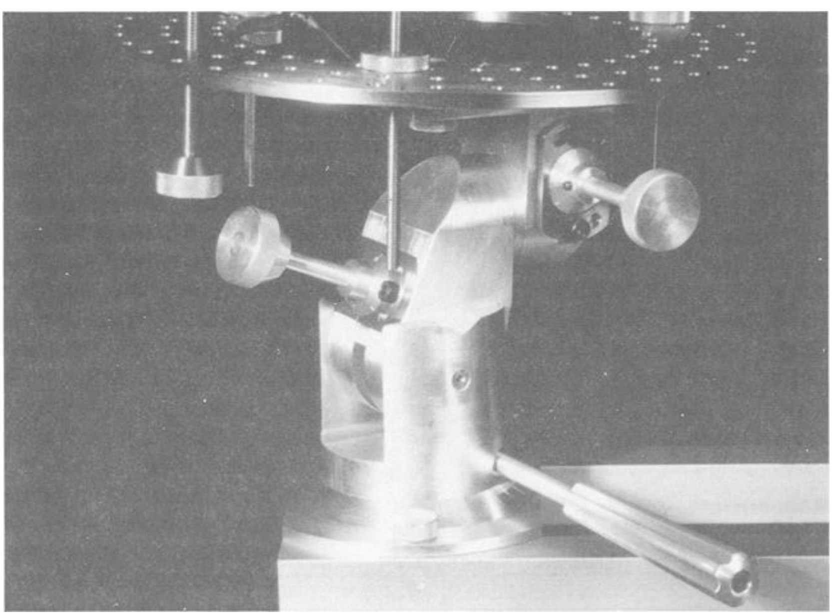

FIG. 3—*The pan-and-tilt device allowing tilting and rotation of the specimen.*

which fits the standard tripod mounting hole found on most cameras; the plate routinely used by the authors has been machined to maintain the focal axis of the camera parallel to the supporting rails. This method of fixation of the camera enables the camera type to be rapidly changed when both video and still cameras are being used. A rack-and-pinion mechanism incorporated in the camera mount provides height adjustment to compensate for variations of camera sizes and different skull positions; adjustment is possible through 28 cm. The base of the camera mount incorporates roller bearings that ride on the supporting rails, thereby facilitating adjustment of the camera-to-skull distance.

4. The Supporting Rails

The skull-holding jig with pan-and-tilt device and the camera mount are supported on two parallel rails constructed of square section aluminum. The parallel rails are fixed in position by supporting brackets which incorporate feet to stabilize the whole assembly. The length of the rails is adjustable by addition of supplementary rails in those instances in which cameras with long focal lengths need to be accommodated.

Replication of the skull position

A skull position can be replicated for further photography by virtue of specifically calibrated scales and markings provided on the apparatus. These are as follows:

1. Each horizontal fixing pin is engraved with a millimetre scale.
2. Each vertical connecting rod is similarly engraved with a millimetre scale.
3. The position of each of the concentric holes in the disk of the halo frame is identified by means of an engraved number adjacent to each hole.
4. The adjustment shafts on the two-tilting mechanism of the pan-and-tilt device have scales incorporated with markings every 2°. Each half turn of the adjustment shaft is equivalent to 1° of arc.
5. The collar surrounding the central spindle on the pan-and-tilt device is engraved with a scale with markings every 2°.

Method of Use of the Equipment

To date the equipment has been principally used for photographic superimposition with still photography, and its use for that purpose will be described. The antemortem photograph that is to be used for the comparison is selected on the basis of being in sharp focus and showing as many anterior teeth as possible. From this photography, a low density positive transparency of the head is made on Ortholith film (Kodak) with a maximum dimension of 5 by 5 cm which is slightly smaller than that of the viewing screen of the Hasselblad 500C/M (Victor Hasselblad Aktiebolag) camera which we use. This camera produces a6-by 6-cm format negative and meets our requirements as this format size is a satisfactory compromise between the convenience but small format size of a 35-mm single lens reflex camera and the unwieldy handling characteristics but large format size of a view camera. The design of the Hasselblad is ideal in that the antemortem transparency can be easily placed on the fresnel viewing screen to act as a direct guide in positioning the skull.

The skull is mounted securely in the jig using three horizontal fixing pins positioned to oppose each other, thereby providing evenly distributed forces on the skull. The condylar joint spaces are simulated by "artificial" condylar disks make of a thin layer of BLU-TACK (Bostik Ltd., Leicester LE4 6BW England); the elasticity and cohesive properties of this material enable the degree of opening between the upper and lower teeth to be adjusted by the threaded rod of the circular platform supporting the mandible so as to correspond with that depicted in the antemortem photograph. A record is made of the position of the vertical supports and the readings on the scales of both horizontal and vertical pins and rods, as detailed above. Should it be necessary to remove the skull and later replace it, this record and marks on the skull at the point of contact of the pins enable replacement in the identical position. To enable accurate enlarging to life-size, a millimetre scale is incorporated in the photographs positioned in the same plane as that of the maxillary incisor teeth and inferior to the skull.

While viewing the skull through the transparency, the tilt and rotation of the skull are altered by a second person until the position closely approximates that of the antemortem inclination. At this stage it is important to match the size of the skull image on the screen with that of the transparency positioned on the camera viewing screen before making the final adjustments. This is achieved by adjusting the camera-to-skull distance by moving the camera on the parallel rails. On achieving the "correct" position, a record is made of the skull-to-camera distance and the angular rotation and tilt of the skull from the scales incorporated in the pan-and-tilt device. A series of exposures is made using 120 size black-and-white negative film. In some cases in which there is a complicated tilting of the head a Polaroid picture using the Hasselblad Polaroid film back allows an immediate comparison of permanent images; Polaroid 668 black-and-white film is particularly useful for this purpose as this film yields both a black-and-white print and a permanent negative.

Where more than one antemortem photograph is being used for comparison with the skull the procedure is repeated, ensuring that an accurate record is kept of each individual skull position. Incorporation of the case number and exposure/position number in each negative is effected by use of adhesive labels on the millimetre scale. The film is processed and the selected negative then enlarged to life-size onto Ortholith film using the millimetre scale incorporated in the photograph of the skull to achieve the correct size. The Ortholith film, being inherently very high in contrast, is developed in very dilute print developer (Kodak Dektol 1:3) to achieve a continuous tone positive. Enlargement of the antemortem picture is carried out using measurements made on the skull or of a visible feature shared by both the skull and the life-size enlargement of the skull. The ideal feature is part of the anterior dentition, and when the dentition is intact this can be measured directly on the specimen.

The antemortem and postmortem enlargements are now subjected to further analysis to assess the degree of positive superimposition. Tracings are made on tracing film of outlines of all relevant features of both antemortem and postmortem transparencies to enable an objective assessment of the degree of superimposition without bias from personal judgement. Suitable hard and soft tissue features include: all dental features visible in the antemortem photograph and the corresponding features in the skull; outlines of bone margins and corresponding soft tissue features; midline of the face and the skull; and the interpupillary line and midorbital line.

Superimposition of the antemortem and postmortem positive transparencies and the tracings can then be carried out to determine whether there is a positive match or not and the level of confidence in the resultant identification.

Discussion

The skull holders described by previous authors for use in personal identification investigations have generally been rather elementary in design, an example being the "phantom head" support used by McKenna et al. [*4*]. None have permitted rapid and accurate replication on the position of the skull relative to the camera should further photographs be required at a subsequent stage in an investigation.

The availability for over 40 years of devices permitting rigid connection of the skull to the chest in the treatment of cervical spine injuries and muscle weakness secondary to poliomyelitis, and similarly of the skull to the facial bones in trauma cases, provides a solid basis on which to develop a purpose-built system for use in the field of photographic superimposition.

The apparatus described in this paper is conceptually similar to the RBH halo frame, but it is noteworthy that this was developed to supersede earlier halos with similar characteristics to Crawford's original tiara. The first halos to be described were based on a flat vertical band [*10-13*]. Mackenzie and Ray [*9*] in designing the RBH frame moved away from this concept and used a horizontal section halo and we have continued to apply this principle in our design.

Most investigators have used some method of controlled tilting and rotation of the skull in all three Cartesian planes [*4,7,8,14-16*], but none of the systems previously described have incorporated a method for quantification of the degree of tilt or rotation with the sole exception of the system used by Bastiaan where simple protractors were used. An alternative approach to this problem of quantification has been the "goniometer" developed by McKenna [*17*] where the position of the camera is moved relative of the skull which is held in a fixed position. The camera position is recordable but the potential problem of replicating the position of the skull within the "goniometer" has not been addressed as this equipment uses only rather crude supporting rods which fit into the external auditory meati of the skull. The apparatus presented by the authors not only provides reproducible repositioning of the skull within the skull jig but also allows quantification of all movements to an accuracy in the current model of 2° and enables independent movement in each direction.

Considerable variation has existed in respect of the method of viewing the antemortem photograph for the purpose of positioning the skull and production of the final superimposed images. The advent of video has brought a degree of standardization as the antemortem photograph may be viewed continuously through one camera while the skull is viewed through a second; the "superimposition" is judged using a video mixing/special effects unit [*5-8*]. Before this, and for those workers who still require still photography for providing evidence in court, two distinct methods have been reported with minor variations. In the first a camera with a ground glass viewing screen is used. On this Bruch [*15*] advocates marking key features from the antemortem photograph with black ink, and Sekharan [*14*] advocates viewing the skull directly through a transparency of the antemortem photograph. An alternative method proposed by Dorion [*16*] is to use a beam-splitting device such that the camera can focus on both the skull and the antemortem photograph at the same time, thus producing a similar effect to the video mixing unit; half-silvered mirrors are used between the photograph and the camera to equate the distance between the skull and the camera. However, the ability to look through the antemortem photograph while adjusting the position of the skull will reduce the time spent on adjusting and checking the position, and this has become the favored method. The control of the orientation of the skull has been carried out using visual objective assessment by all workers except Iten [*8*] who proposed a system for adjusting both the orientation and inclination of the skull according to distances measured from the antemortem photograph; these necessitate first achieving images of comparable size and rely on the ability to locate the auditory canal axes in both the photograph and the skeletal specimen, which will not always be feasible. His method has not been taken up by other workers.

The equipment described in this paper offers a number of advantages over previously published systems and has for the most part fulfilled all the original requirements of this equipment. These were to be portable, rapidly assembled and disassembled, noncorrosive and readily disinfected, able to accommodate whole or fragmented skulls, straightforward to use, and to permit accurate recording of adjustments thereby making positions reproducible. This was achieved at a material cost of approximately US$ 250 (in 1987), excluding the cost of labor.

The success of this design can be measured both in the practical applications for which it has been used to date and by the acceptance of evidence resulting from its use in courts of law. Progress has been made such that empirical evaluation is no longer necessary, and all adjustments can be permanently recorded.

Future modifications of the equipment are envisaged to enable standardized cephalometric or intraoral radiographs to be made of the skull using external and internal bone features in those instances where antemortem radiographs may be available.

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