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Comparative radiologic identification with standardized single CT images of the paranasal sinuses—Evaluation of inter-rater reliability

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ABSTRACT

The aim of this study was to assess the reproducibility of a standardized image for personal identification (SIPI), used in the comparative analysis of paranasal sinuses, and test the effect of inaccurate reformation of the SIPI on suitability for comparative identification.

Five raters with different professional backgrounds independently reformatted SIPIs from ten post-mortem head CTs. Inter-rater, intra-rater agreement as well angular deviations between reformatted SIPI images and reference SIPI images were calculated. Second, raters assessed the suitability of 70 accurately and inaccurately reformatted SIPIs for identification with a 4-point Likert scale. Inter-rater agreement as well as levels of significance regarding image suitability were calculated.

Inter-rater agreement regarding reproducibility of SIPI reformation was excellent (inter-rater correlation coefficient (ICC) 0.9995, intra-rater ICC 0.9983). Deviation between the angular dimensions of the reformatted SIPIs and the reference SIPIs was $\leq 1^{\circ}$ in 94% of all 300 measurements. Inter-rater agreement regarding the effect of inaccurate SIPI reformation on suitability for comparative identification was fair (ICC 0.6809). There was no statistically significant difference between raters' evaluation of image suitability ($p = 0.9755$).

This study shows that the standardized image for personal identification can be accurately reformatted by different raters with varying professional backgrounds. In addition, raters agree that inaccurately reformatted SIPIs are still suitable for comparative identification in the majority of cases.

1. Introduction

There are several established and reliable methods to identify the dead, including DNA samples, fingerprints or radiologic images [1]. The process of identification depends on the scenario or circumstances of death, the availability of experts [2], and the availability and quality of antemortem records for comparison. Technological developments in medical imaging and the subsequent ascent of cross-sectional imaging in forensic sciences uncovered an enormous potential of radiologic images, especially computed tomography (CT) for personal identification [2–4]. Irrespective of the medical imaging modality used for identification, an identification is performed through careful comparison of ante-mortem (AM) images to post-mortem (PM) images, which may include both macroscopic (visual) assessment as well as the use of population frequency data for traits being compared [5]. Radiologic images of osseous structures are well suited for this purpose because of their durability [6].

The first published report on a positive identification with radiologic images of the paranasal sinuses was published as early

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as 1927 [7]. The paranasal sinuses are fully developed by the age of 20 and their morphology remains unchanged throughout adult life unless affected by pathologies [8–11]. In the late 1980s, Harris et al. observed that the morphology of the frontal sinus features a high inter-individual variability and hence offered a reliable means of radiologic identification [12]. This conclusion was affirmed in studies by Kullmann et al. and later by Christensen who used Elliptical Fourier Analysis to demonstrate that the outline of the frontal sinus is highly variable between individuals [13–15]. A significant step towards modern radiologic identification was taken in the early 1990s by forensic anthropologist Kathleen Reichs who successfully identified a decedent based on her comparison of ante-mortem CT (AMCT) and post-mortem CT (PMCT) of the paranasal sinuses [16]. Since then, a number of publications have demonstrated the utility and reliability of radiologic identification based on CT images of the paranasal sinuses [2,6,17].

Today, there is general agreement that CT offers two fundamental advantages over conventional radiographs: First, CT images are cross-sectional images and thus allow for a more detailed comparison of the morphology of the paranasal sinuses than conventional radiographs. Second, the use of multi-planar reformation (MPR) tools enables investigators to reformat PMCT images to match nearly any radiographic ante-mortem image [2]. Typically, alignment between PMCT and AMCT is achieved through individual reformation of PMCT images to the axial AMCT images. A recent publication proposed the use of a single standardized image of the paranasal sinuses and orbit for identification [18]. The use of standards in forensic sciences, particularly in comparative identification can increase the accuracy of identifications both in individual cases as in mass disasters (quantitative identification instead of qualitative visual comparison), decrease the time needed to perform individual identifications, and also improve the evidentiary value of an identification in court (e.g. Daubert Standard) [19,20].

In their article, Ruder et al. detail the method to create the standardized image for personal identification (SIPI) from both AMCT and PMCT data [18]. The SIPI is reconstructed parallel to the orbito-meatal plane, using the inner ear and inferior margin of the left frontal bone as anatomical landmarks [18]. A detailed description of the anatomical landmarks is provided in Fig. 1. They propose that this image plane is well suited for the purpose of radiologic identification for the following reasons: (1) the selected anatomical landmarks are covered in the scan volume of standard head-CTs, which means that any existing clinical head-CT should be suitable for comparison with a corresponding PMCT; (2) clinical head-CT (i.e. potential AM reference material) is traditionally acquired in the orbito-meatal plane, which means that the in-plane resolution of an old non-isotropic CT image of the head will be highest in the orbito-meatal plane and thus image quality should be sufficient for comparative identification regardless of the scan date of the AMCT; (3) all elements used for anatomical orientation, reformation and identification are osseous, which means that they should remain unchanged even after a long postmortem interval; and (4) the selected anatomical landmarks are thought to be unambiguous and easy to recognize, which means that the reformation of the SIPI should be a straightforward and simple task [18]. There is an abundance of published evidence to support the authors' first three reasons for selecting the SIPI for radiologic identification [2,17,21–23]. However, the publication by Ruder et al. does not provide any evidence to confirm the supposedly straightforward and simple task of creating the SIPI.

The aim of this study is to (1) assess the reproducibility of the SIPI by multiple raters with different professional backgrounds, and (2) test the effect of inaccurate reformation of the SIPI on suitability for comparative identification.

2. Methods

Ethical approval for this study was waived by the responsible Ethics Committee of the Canton of Zurich, Switzerland (Waiver Number: KEK Zurich 22-2015). PMCT images used in this study were scanned between March 1 and March 4, 2016 as part of the judicial investigation into the manner and cause of death of the deceased.

2.1. Study population

In this study, 10 postmortem head CT datasets were analyzed. The population consisted of 7 males and 3 female with a mean age

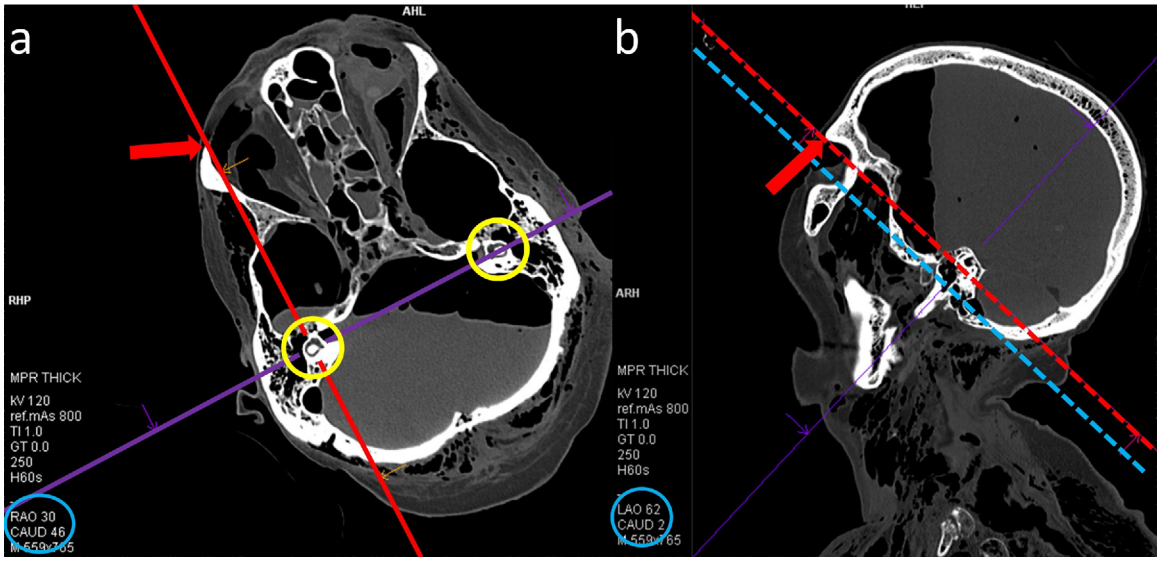

Fig. 1. Axial and sagittal CT images of a skull. Fig. 1a corresponds to the standard image for personal identification (SIPI). The image plane of the SIPI (red dotted line in b) is parallel to the orbito-meatal plane (blue dotted line in b) using the inner ear (yellow circles in a) and the inferior orbital margin of the left frontal bone (red arrows in b and a) as anatomical landmarks. The center of cross-hairs on the axial image (Fig. 1a) is positioned over the small bone between the lateral semilunar canal and the vestibule The anterio-posterior cross-hair line (red dotted line in b) is positioned just below the inferior left orbital margin of the frontal bone (red arrow in b). Note the numbers in the lower left corner of the images (blue circles in a and b) which are used to document the angular position of the images within the x-, y-, and z-axis of the CT coordinate system. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)