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Application of Digital Radiography for Examination of the Calvarial Diploic Venous Channels in Intact Dry Skulls

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The diploic venous channels (DVCs) are tunnels in the *diploë*, between the outer and inner tables of the cranial bones. Because of its enclosed location, the diploic venous system is challenging to study. It has been claimed that the radiological examination provides a non-destructive, simple and accurate method to inspect DVCs. In this study, we tested the application of the digital radiography for investigation of the DVCs in intact dry skulls. A series of 345 intact skulls of contemporary adult males were radiographed using an industrial computed tomography. The digital radiography was applicable for visualization of the main DVCs in intact dry skulls, but showed some limitations due to the overlaying and difficult differentiation from the grooves for the middle meningeal vessels. The main shortcoming resulted from the superimposition of structures beyond the plain of interest and the impossibility to trace the complete pattern of DVCs throughout the cranial bones.

Key words: diploic veins, diploic venous channels, digital radiography, visualization

Introduction

The diploic venous channels (DVCs) are tunnels in the *diploë*, between the outer and inner tables of the flat cranial bones, which house the diploic veins (DVs). The protected location preserves the channels from taphonomic processes and gives an opportunity for an indirect examination of this portion of the vascular tree on dry specimens. Due to their variable anatomy, the diploic venous imprints have been compared to fingerprints by their individuality and been considered “skull glyphics” [2]. Furthermore, the topographic localization of the DVs is important to prevent implications during routine neurosurgical procedures such as placement of pins, bur holes, bone drilling and craniotomies [1].

The diploic venous system (DVS) is challenging to study because of its enclosed location between two layers of hard compact bone. By this reason, studies on the DVS are scarce and the DVs are still poorly understood from anatomical, physiological, and surgical perspectives. A dissection-based direct examination of the DVs is difficult and requires an external lamina removal [1]. According to Hershkovitz et al. [2], the radiological examination provides a non-destructive, simple and accurate method to study these vascular channels. In this study, we tested the application of the digital radiography for visualization of the DVCs in intact dry skulls for examination of their distribution and branching pattern through the calvarial bones.

Materials and Methods

A series of 345 intact dry skulls of contemporary adult males from Bulgaria were investigated. The skulls belonged to soldiers who died in the wars at the beginning of the 20^{th} century and were kept in the Military Mausoleum with Ossuary at the National Museum of Military History of Bulgaria. The skulls were digitally radiographed using an industrial computed tomography system Nikon XT H 225, developed by Nikon Metrology. The Inspect-X software was used to adjust the parameters and manage the capture of the projections. The settings ranged dependent on the density of the specimens: voltage 85-126 kV, 80-140 µA tube current and exposure time of 500-708 ms.

The skulls were oriented in lateral and posteroanterior (PA) views (**Fig. 1a, b**). Most of the PA radiographs were captured within the range considered a "Caldwell view", i.e. the skulls were angled in the interval of 15-20° towards the Frankfurt plane (FH). Using the tilt function of the manipulator, selected skulls in the PA view (n=10) were inclined from Frankfurt plane (FH) up to +45° (Waters' view) at an interval of 5 degrees (**Fig. 2**). Trying to avoid the superimposition, selected skulls were also inclined under various degrees in different positions, and the oblique projections were captured. Moreover, we injected a radiographic contrast agent (urografin) into DVCs of a sec-

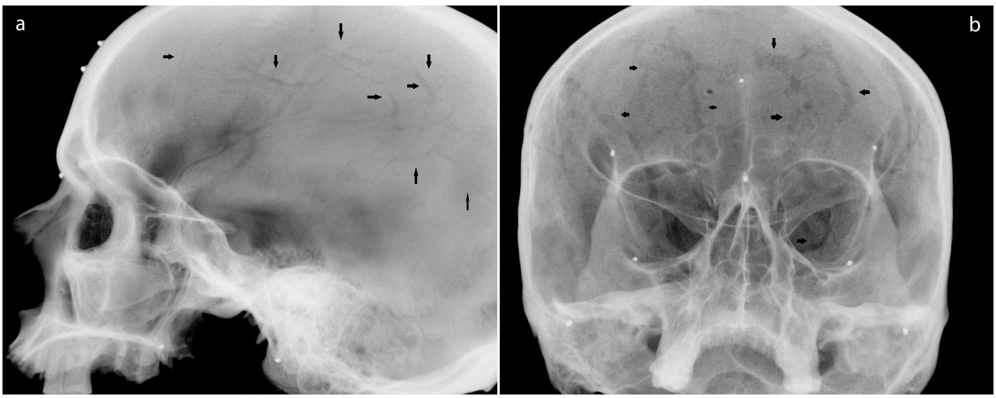

Fig. 1. Skull projections: a) lateral view; b) posteroanterior view. The diploic venous channels were indicated with arrows

Fig. 2. Posteroanterior views: a) at the Frankfurt plane (0°); b) inclined to +10°; c) inclined to +25°; d) inclined to +40°. The diploic venous channels were indicated with asterisk

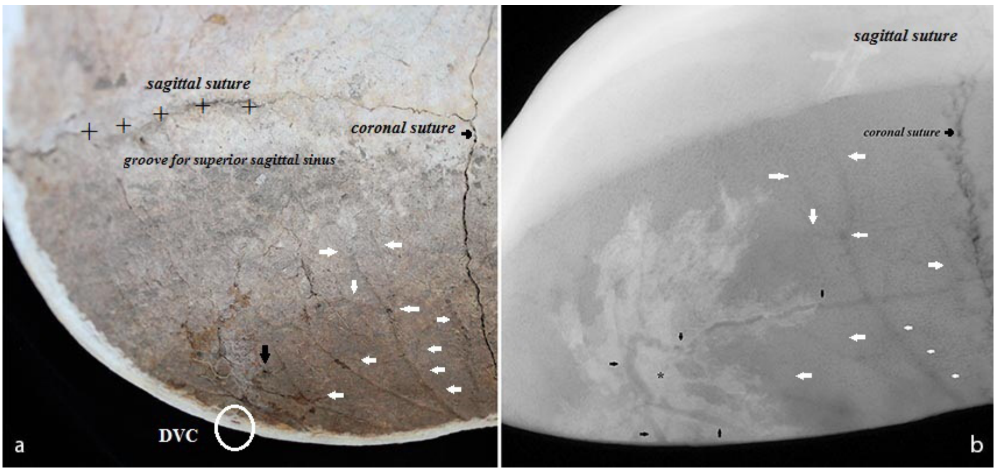

Fig. 3. A sectioned calvaria: a) an image of the internal aspect; b) a radiograph after injection with a radiocontrast agent. Indications: diploic venous channels (DVCs, black arrows); grooves for middle meningeal vessels (white arrows); radiocontrast agent (asterisk); groove for superior sagittal sinus (plus signs)

tioned calvaria which was subsequently radiographed (**Fig. 3a, b**). The sectioning level lied at the parietal bones above *lambda* and both temporal squamas and trough the frontal eminences. All of the generated projections were saved in TIFF format.

Results and Discussion

The digital radiography has many advantages compared to the conventional one like rapidity, effectiveness, inexpensiveness, short expositions, immediate inspection, transfer, processing and storage of the generated images. The digital radiography also allows rapid and accurate radiographic documentation of large samples.

Generally, the 2D radiography of an intact dry skull causes a superimposition of the shadows beyond the plain of interest on the obtained image. The plain radiography could be of benefit in cases of sectioned skulls in the sagittal or transversal plain, as in such manner the superimposition would be avoided (Jefferson and Stewart, 1928; Hershkovitz et al., 1999).

In a lateral projection of an intact skull, the main DVCs were visible and distinguishable from the grooves for the middle meningeal vessels (**Fig. 1a**). The finer ones, however, could be easily confused with the grooves even following the recommendations of Jefferson and Stewart [3] for their demarcation. Furthermore, the right and left DVCs superimposed and their delimitation was difficult as well (**Fig. 1a**). In a PA projection, the frontal DVCs were visible, but the superimposition impeded visualization of the occipital ones (**Fig. 1b**). Furthermore, the inclination of the skull at an interval of 5° showed that the optimal visualization of the DVCs was between FH (0°) and +25° (**Fig. 2**). The oblique projections were useful for distinguishing of the DVCs. However, the overall distribution, places of anastomoses and branching pattern of the DVCs in the cranial bones could not be clearly traced and determined.

For better visualization of the DVCs, we injected a radiocontrast agent into a sectioned skull as it was suggested by Hershkovitz et al. [2]. A subsequent radiography revealed that the substance soaked up into the surrounding diploic space instead to accumulate in the channel itself. In this way, the contrast outlines the DVCs, but does not differentiate them from the grooves for middle meningeal vessels on the inner table (**Fig. 3b**). Our observations showed that this approach was not easily applicable to a sectioned skull part and entirely impracticable for an intact skull.

Illumination of the skull from within has also been used for DVCs inspection [5]. A superior non-destructive method for visualization of the DVS is the volumetric imaging obtained by patients undergoing magnetic resonance (MR) and computed tomography (CT) scanning with radiocontrast agents [1, 4]. Besides the advantages of the 3D imaging, the low resolution appears to be the main shortcoming. However, scanning of dry skulls using micro-computed tomography (μCT) could generate high resolution 3D images. Segmentation of the DVS from such models is a challenge and an objective of further examinations.

Based on our experience, we could conclude that the digital radiography was applicable for visualization of the main DVCs in intact dry skulls, but showed some limitations due to the overlaying and difficult differentiation from the grooves for middle meningeal vessels. The main shortcoming to examine the DVCs resulted from the superimposition of structures beyond the plain of interest and the impossibility to trace the complete pattern of distribution throughout the cranial bones.

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