Legal Medicine 17 (2015) 60–64

Contents lists available at ScienceDirect

Legal Medicine

journal homepage: www.elsevier.com/locate/legalmed

Brief Communication

Application of high resolution pQCT analysis for the assessment of a bone lesion: A technical note

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ARTICLE INFO

Article history:
Received 9 May 2014
Received in revised form 3 September 2014
Accepted 4 September 2014
Available online 16 September 2014

Keywords:
Forensic anthropology
pQCT
Bone lesion
Sharp force

ABSTRACT

Peripheral quantitative computed tomography (pQCT) has found new fields of application in bone medicine, but none of them concerns the forensic practice. This study exposes the potential of pQCT applied to a penetrating lesion in a vertebral body. A pQCT scanner was used for the measurements (XCT Research SA+; Stratec Medizintechnik GmbH, Pforzheim, Germany). A more precise reconstruction of the path of the lesion within the trabecular bone was reached, with more details concerning the morphological characteristics of the lesion inside the vertebral body, and the elaboration of a 3D model was created, which allowed the operator to define the volume of the lack of tissues related to the lesion. The application of pQCT scan proved to be a potentially useful tool for the assessment of bone lesions, although further studies are needed in order to verify its applicability to forensic context.

1. Introduction

Analytical evaluation of the bone lesions is critical in forensic anthropology and pathology for determining cause and manner of death. The correct interpretation of the morphological characteristics of bone damages is essential for identifying the location of impact sites, establishing multiple impact sites, sequence of blows and the characteristics of the weapon [1]. From this point of view the study of bone lesions is one of the main topics in forensic anthropology and pathology. In particular the analysis of sharp force wounds, and especially stab wounds, is as crucial as problematic: the correct interpretation of the morphology of lesions on bone tissue may be fundamental in order to recognize the tool used, the energy of the impact and reconstructing the way of inflicting trauma. However the small size of the lesions, their sites and structure of the wounded bone compartments, i.e. cortical vs trabecular, often do not allow an exhaustive interpretation of the weapon.

To overcome this challenging task, advanced technologies such as scanning electron microscopy coupled with X-ray energy dispersive spectrometry (SEM–EDS) [2,3] and traditional CT scan (computerized tomography) and NMR (nuclear magnetic resonance) technologies [4–7] have been applied. Recently, micro-CT technology has allowed researchers to reach a higher resolution with isometric voxel ranging from 10 to 100 μm, although imposing adequate preparation for bones larger than the gantry size (2 cm). Cone beam technology (used in odontological field) does not reach the same resolution but can be applied to larger bone without causing their destruction. The first studies concerning the employment of this technology for the documentation of sharp wounds on spongy bones seem to lead to promising results based upon a balanced equilibrium between size of the sample and spatial resolution of the data acquisition [8,9]. However, all these techniques suffer from two major limits: they do not allow a quantitative evaluation of the bone structure surrounding the lesion path and are confined to highly specialized institutions. There is therefore a need for an easily accessible analyzing tool able to provide the missing quantitative parameters.

The natural history of forensic sciences is characterized by the progressive implementation in the forensic practice of the most advanced technologies, usually previously developed with clinical purposes, with a consequent improvement of morphological and metrical details of bone structures. This evolution led in some cases to the "blind" application of such techniques to the forensic cases, without a preliminary evaluation concerning the specific issues which can be adequately and specifically evaluated by the new

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http://dx.doi.org/10.1016/j.legalmed.2014.09.002
1344-6223/

technologies, usually determined by the idea that technology (especially if novel and advanced) means more information. This point of view was challenged in the last years by different authors who underlined the existence of specific factors of variability which affect the analysis of corpses and define the complementary nature of the new techniques with regards to the classical morphological autoptical and forensic anthropological approaches [10].

On the other hand, some methods may bring about relevant improvements in the field of bone assessment, since they may meet specific limits which cannot be faced by other methodologies or the traditional morphological analysis. This is the case of the morphological evaluation of signs of trauma on trabecular bone, which is usually difficult to assess by the macroscopic, microscopic (SEM–EDS) and radiological methods because of the most irregular disposition of bone trabeculae and the absence of the compact structure of the cortical bone (moreover the traditional casting techniques are problematic on cancellous bone). The introduction of Peripheral Quantitative Computerized Tomography (pQCT), may give some help in this field of research: it is a tomographic technique, easily accessible and user friendly, that quantitatively assesses the densitometric and morphometric properties of bone as a result of a very accurate calibration procedure. Research pQCT scanners, developed for the measurement of bone size and density in small laboratory animals like mice or rats, have a sufficient voxel size ($\geqslant$70 μm) to visualize the trabecular network of human bone in the three spatial dimensions [11], and therefore allow the operator to reconstruct an accurate geometrical and densitometric model of bone which takes into account both macro- and microstructural components [12]. Since the forensic scenario does not require an in vivo application, the expensive High Resolution (HR)-pQCT, designed for the clinical setting, is not cost-effective. On the contrary, the pQCT developed for research in small animals might represent a reasonable cost-effective solution for in vitro acquisition having a comparable voxel size: $\geqslant$70 μm vs 61–82 μm of the HRpQCT. Furthermore, the use of specific developed software can provide a 3D model of the bone specimen, based on the information obtained by the scanner. In this way, this technology allows the observer to obtain a virtual model of the bone sample which can be analyzed in three dimensions; in addition, the specific properties of the research pQCT render easier the analysis of the trabecular bone, which is traditionally difficult to assess by the classic radiological methods.

At the moment, pQCT has been applied to different fields of research, especially for the evaluation of osteoporosis, thanks to its accuracy in the analysis of trabecular and cortical bone compartments [13–15]. In addition, it has been applied for evaluating the anatomy of dental root canals and canal volumes changes after instrumentation [16]. However, at the moment no study has been yet performed concerning the possible application of such technology to the forensic scenario. This study aims at providing the first example of application of pQCT to a forensic case and at highlighting its advantages.

2. Materials and methods

The bone lesion assessed belonged to a mummified and partly skeletonised body of a woman was found almost 20 years after she went missing. A violent death was determined because of cut marks still visible in her clothes. The autopsy also revealed several traumatic lesions at the chest with regular edges. The lesions were diagnosed as sharp force wounds, according to their morphological characteristics and the existing literature concerning the differential diagnosis of traumatic injuries [17], and was confirmed by two forensic pathologists.

Ribs, cervical and thoracic vertebrae and the scapulae were affected by sharp force injuries; these were all analyzed in order to try to answer the judge's question on type of stabbing or cutting instrument, since the weapon was never found. Among the others, a specific penetrating lesion affected the body of the first thoracic vertebra (Fig. 1); this lesion seemed like the most suitable for extrapolating the shape of the instrument used. Since its apparent morphology and position in the trabecular bone segment was considered suitable for the pQCT evaluation, it was decided to verify how much detail this method would provide on the morphology of the lesion.

A research pQCT scanner was therefore applied for the data acquisition (XCT Research SA+; Stratec Medizintechnik GmbH, Pforzheim, Germany). The technical data and images of the instruments are provided by the manufacturer (http://www.galileo-training.com/de-english/products/p26/xct-research-sa.html).

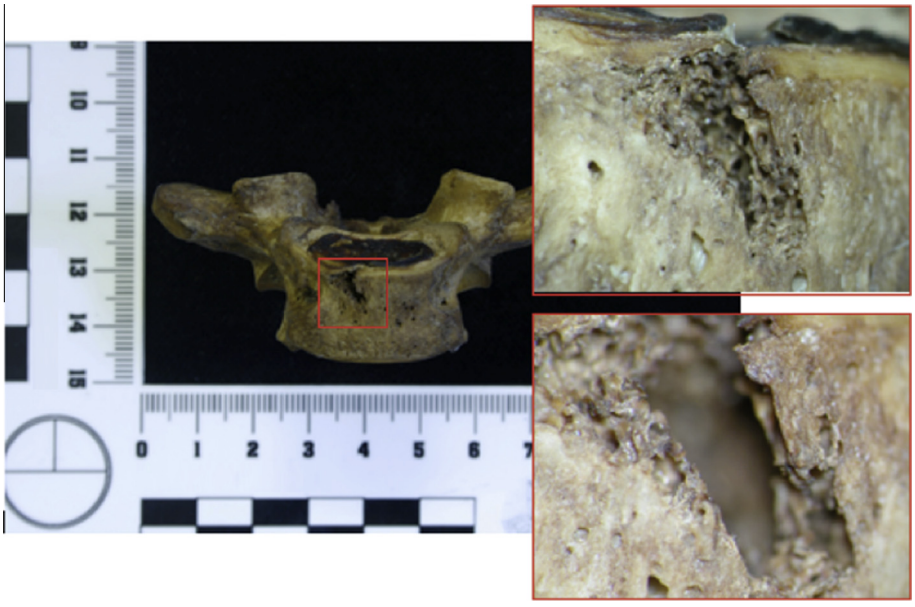

Fig. 1. On the left, position of the sharp force lesion on the first thoracic vertebra (in the red square); on the right, details of the same lesion analyzed by stereomicroscopy (10× and 40×). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)