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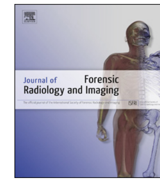

Review article

The use of cone beam computed tomography in forensic radiology

David P. Sarment [a], Angi M. Christensen [b,*]

[a] Private Practice, 4660 Kenmore Avenue, Ste 312, Alexandria, VA 22304, USA
[b] Federal Bureau of Investigation Laboratory, 2501 Investigation Parkway, Quantico, VA 22135, USA

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ABSTRACT

Cone beam computed tomography (CBCT) is a relatively recently-developed CT technology that is currently used primarily in maxillofacial applications. CBCT may also be very useful in some forensic contexts, offering several advantages for postmortem forensic imaging including good resolution for skeletal imaging, relatively low cost, portability, and simplicity. Here we present an overview of CBCT technology, comparing and contrasting to conventional CT in regards to various forensic applications, and conclude that CBCT may be an advantageous and accessible alternative in many cases.

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1. Introduction

Radiologic analyses using computed tomography (CT) have become an increasingly routine method of postmortem imaging in forensic investigations [1], especially in the areas of radiologic identification [2], assessing biological characteristics such as sex and age [3,4], performing non-invasive postmortem examinations such as Virtopsy [5], as well as determining whether fragmentary remains are human or non-human in origin [6] and detecting and locating foreign materials such as projectiles and their wound paths [7]. The benefit of CT compared to projected imaging has become obvious because of the ability to depict the anatomy, objects and trajectories in great details without depending upon projection angles. Many of these analyses are carried out in the morgue or laboratory setting, but are also increasingly used in field analyses, particularly in cases involving mass fatalities [8]. The use of CT in postmortem investigations has especially increased in recent years with decreasing cost of acquiring CT technology [9]. Conventional medical CT, however, may not always be accessible or the most practical option in all cases. Here we suggest that cone beam computed tomography (CBCT), a variant of conventional medical CT that is commonly used in maxillofacial applications [10], is in many applications comparable to conventional CT, offers several technical and practical advantages, and suggest that forensic practitioners may consider its use more frequently for postmortem imaging, in particular for certain skeletal applications.

* Corresponding author.
E-mail addresses: ds@sarmentperio.com (D.P. Sarment), angi.christensen@ic.fbi.gov (A.M. Christensen).

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2. Overview of compact cone beam computed tomography technology

Computed tomography utilizes a rotating X-ray source and opposing detectors such that object attenuation is obtained for each position. This acquisition phase is followed by an image reconstruction process whereby software algorithms are utilized to form an image of the object being analyzed. Since CT was invented in the late 1970s, various technologies have been utilized to improve image quality and expand its applications. CT imaging has benefited from enhancements in computer processing power [11]. Faster rotation, spiral/helical movement and arrays of detectors together with narrow X-ray beams have been the general trend.

Cone beam computed tomography (CBCT), a more recently-developed CT technology, utilizes large detectors and non-collimated simpler radiographic sources, emitting a cone-shape X-ray beam towards the field of view (Fig. 1). The gantry rotates in a simple circular motion and the X-ray beam illuminates a relatively large flat panel detector. While conventional CT utilizes small detectors to construct an image in the long axis of the patient, CBCT images are obtained with one rotation on high quality panels. The result of CBCT scanning is a series of two-dimensional projections which are reconstructed into a three-dimensional image.

First invented in the early 1980s, the primary purpose of CBCT was the detection of lung cancer and heart disease [12]. It has since been utilized for various applications such as c-arms for intervention radiology [13], or treatment planning and positioning device for radiation therapy. Until the early 2000s, image intensifiers commonly used in fluoroscopy and two-dimensional radiology were adapted to CBCT. More recently, significant improvements such as less distortion, larger flat panel detectors and better dynamic range have been implemented. Over the past ten years, CBCT units have been utilized for in-office head and neck applications, but the technology is now being developed for intra-operative use and for imaging extremities [14].

CBCT technology is commonly incorporated into compact and mechanically simple devices (Fig. 2), and machines are typically adapted to specific anatomy and clinical applications. For example, only a very small detector is necessary for endodontics, and therefore a small, inexpensive X-ray source is sufficient. Slow scanning speed is a reasonable compromise because motion can be mitigated by patient positioning and software. In turn, this allows for simple mechanical components which also contribute to relatively low costs and few maintenance issues. Because most machines are dedicated to a specific application, software tools have been maximized to simplify training and daily use (Fig. 3). The intra-operative unit shown in Fig. 2 weighs about 500 pounds and is constructed on a wheeled mobile platform which is easily manipulated by hospital staff such as nurses and physicians. It can be moved into operating suites and other areas of the building on demand because it is self-shielded and therefore does not require dedicated lead walls.

CBCT is now present in thousands of clinics and is well on its way to becoming the standard of care for specific maxillofacial applications such as implantology because of the significant benefit compared to traditional projected radiography (Figs. 4–6) [15]. CBCT is also increasingly present in otolaryngology practices for imaging of sinuses and ethmoids (Figs. 7–9). It is also used in allergy clinics to diagnose sinus diseases, and is being introduced for operating room applications such as functional endoscopic sinus (Fig. 10) and skull base surgeries [16], this last application being representative of the more recent developments in CBCT. These examples highlight the expanding scope of applications of clinical CBCT, indicating that antemortem CBCT images will be increasingly accessible, and suggesting that the range of applications may soon more commonly include postmortem imaging and forensic applications.

Anatomy such as that present in Figs. 6 and 7 might be captured during the course of routine maxillofacial or otolaryngology investigation and may later be useful for forensic identification purposes. While it is not suggested that the CBCT images are superior to those of conventional CT for this purpose, image quality is comparable to conventional CT. Soft tissue contrast and attenuation measurements are noted to be more limited in CBCT versus CT (Fig. 8), but resolution for skeletal applications is similar using flat panel and multidetector CT [17]. Furthermore, conventional two-dimensional radiography such as cephalometric (Fig. 9 left) or frontal (Fig. 9 right) views can also be extracted to compare features to antemortem images. These methods are available using conventional CT, and CBCT datasets can be similarly manipulated.

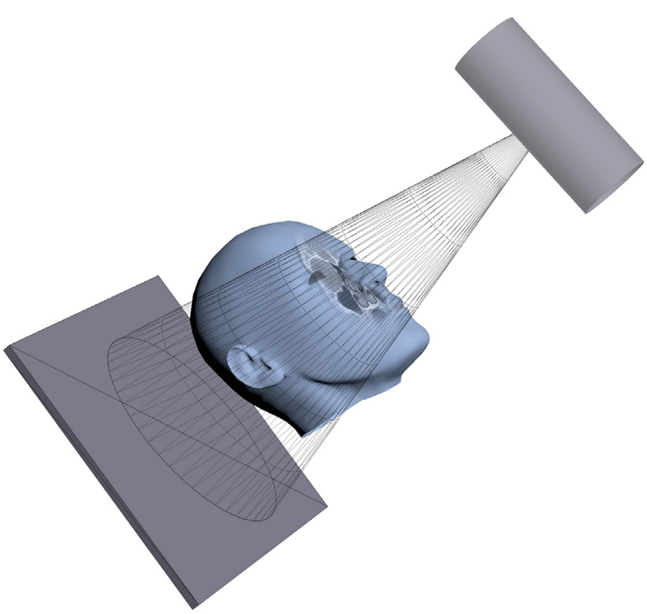

Fig. 1. Depiction of CBCT radiologic source, cone-shaped X-ray, and flat panel detector.

3. Cone beam and conventional computed tomography in forensic investigations

Conventional CT continues to be the technology of choice for many imaging applications including postmortem radiology. The fan beam geometry of conventional CT acquires one cross section at a time, resulting in relatively small size and low cost detectors as well as the option of very fast rotation. This advantage, however, is offset by the need for multiple detectors. The narrow beam of fan beam CT irradiates a small area at one time, causing less scattered X-rays and resulting in a higher quality image. CBCT has to compensate for this limitation using complex algorithms. Moreover, patient motion is less significant with conventional CT because only a small portion of the anatomy is imaged at any given time. In contrast, movement on a CBCT affects an entire series of projections.

Fan beam geometry, however, also has limitations, some of which are resolved with CBCT. X-ray use in conventional CT is relatively inefficient because of the need for collimators. A large amount of radiation is therefore wasted and results in significant