ANTROPOLOJİ
ÖZEL SAYI / *SPECIAL ISSUE*
Antropoloji, (46), OZ90-OZ101 (2023)
ARAŞTIRMA MAKALESİ / *RESEARCH ARTICLE*

Evaluation of the reliability and accuracy of femur measurements acquired from computed tomography images

Öznur Gülhan[1*]

[1] Asst. Prof. Dr. | Ankara University, Faculty of Humanities (DTCF), Department of Anthropology, Ankara - Turkey

* Sorumlu Yazar / *Corresponding Author*:
Öznur Gülhan
Ankara University, Faculty of Humanities (DTCF)
Department of Anthropology
06100 Sıhhiye, Ankara - Turkey
E-posta/*E-mail*: oznurgulhan@gmail.com

Alındı/*Received*: 31 Temmuz / *July* 2023
Düzeltildi/*Revised:* 22 Ekim / *October* 2023
Kabul/*Accepted*: 22 Ekim / *October* 2023
Yayımlandı/*Published:* 29 Ekim / *October* 2023

Abstract

The biological profile holds notable significance within forensic assessments, as it plays a crucial role in determining biological identity. Moreover, it possesses substantial potential for applications in fields such as medical legal cases and forensic anthropology. Recent advancements in technology, specifically in the field of computed tomography, have enabled the accurate acquisition of detailed anatomical data from CT scans present in extensive medical repositories. The validity of new methods developed through the application of these techniques should therefore be analyzed. The primary intent of this research was to investigate the measurement accuracy obtained from CT-generated 3D femur models. To investigate the accuracy and reliability of measurements obtained from CT-generated 3D femur models, 3 different studies were conducted. A dataset comprising fifteen femurs was employed for analysis and measurement purposes. The obtained images were subsequently compared to twelve measurements acquired from the dry femora, enabling an assessment of the reliability and accuracy of both measurement protocols. To investigate the effect of CT parameters and soft tissue, 4 femurs were used. The analysis of twelve femur measurements obtained from the CT images processed with OsiriX software was carried out using Excel software packages and SPSS 24.0. From the results of this study, it can be observed that there is no discernible pattern regarding the reliability of image acquisition in any particular way. This implies that both dry femur bone and 3D virtual femur models can be used interchangeably for the 12 metric measurements used in this study, and at the same time, different scanning parameters or soft tissue influence for these measurements do not make a statistically significant difference.

Key Words: 3D imaging, CT parameters, metric measurements, femur, forensic anthropology

Bilgisayarlı tomografi görüntülerinden elde edilen femur ölçümlerinin doğruluk ve güvenilirliğinin değerlendirilmesi

Öz

Biyolojik profil, biyolojik kimliğin tespitinde kritik bir rol oynadığı için adli değerlendirmelerde önemli bir konuma sahiptir. Mevcut güncel iskelet materyallerinin sınırlı olması nedeniyle, bilimsel araştırmalar çağdaş popülasyonları incelemeye yönelmiştir. Özellikle bilgisayarlı tomografi alanındaki son gelişmeler sayesinde, tıbbi arşivlerde bulunan BT taramalarından detaylı anatomik veriler doğru bir şekilde elde edilebilmektedir. Bu araştırmaların zamanla artan kullanımıyla birlikte, bu tekniklerle geliştirilen yeni yöntemlerin uygulanabilirliğini analiz etmek önemlidir. Bu çalışmanın temel amacı, BT ile oluşturulan 3B femur modellerinden elde edilen metrik ölçümlerin doğruluğunu değerlendirmektir. Bu doğruluk değerlendirmesi için 3 farklı çalışma yapılmıştır. Bu çalışmaların ilki, BT görüntülerinden elde edilen ölçümleri referans olarak kullanılan kuru femur örneklerinden elde edilen ölçümlerle karşılaştırmayı amaçlamaktadır. Ayrıca çalışma, BT parametrelerinin ve yumuşak dokunun femurların üç boyutlu BT görüntülerinden elde edilen 12 ölçümün doğruluğu üzerindeki etkisini incelemeyi hedeflemiştir. Analiz ve ölçüm için on beş femurdan oluşan bir veri seti kullanılmıştır. Elde edilen görüntüler daha sonra kuru femurlardan elde edilen 12 ölçümle karşılaştırılarak her iki ölçüm protokolünün güvenilirliği ve doğruluğu değerlendirilmiştir. CT parametlerinin ve yumuşak dokunun etkisini araştırmak için ise 4 femur kullanılmıştır. OsiriX yazılımı kullanılarak işlenen femur görüntülerinden elde edilen on iki ölçüm, Excel yazılım paketi ve SPSS 24.0 kullanılarak analiz edilmiştir. Bu çalışmanın sonuçlarına göre, BT ile görüntü alımının güvenilirliği açısından belirgin bir standart olmadığı gözlemlenebilir. Sonuçlar hem kuru femur kemiği hem de 3B sanal femur modellerinin bu çalışmada kullanılan 12 metrik ölçüm için birbirlerinin yerine kullanılabileceğini ve aynı zamanda bu ölçümler için farklı tarama parametrelerinin veya yumuşak doku etkisinin istatistiksel olarak anlamlı bir fark yaratmadığını göstermektedir.

Anahtar Kelimeler: *3B görüntüleme, BT parametreleri, metrik ölçüm, femur, adli antropoloji*

Introduction

Numerous investigations have provided evidence that sex assessments based on long bones are influenced by population-specific variations attributed to differences in size among distinct population groups (Srivastava *et al.,* 2012). Consequently, the demand for standards specific to the population in the area of forensic anthropology has intensified, as highlighted by İşcan (2005). In response to this, numerous scholars have directed their attention towards population-specific investigations, aiming to provide more precise insights for the application of current techniques or data in

Atıf için / *Cite as*:
Gülhan, Ö. (2023). Evaluation of the reliability and accuracy of femur measurements acquired from computed tomography images. *Antropoloji,* (46), OZ90-OZ101.
https://doi.org/10.33613/antropolojidergisi.1335356

medico-legal practice. As forensic anthropologists increasingly contribute their expertise to a growing number of medico-legal cases, there arises a heightened necessity to acquire knowledge regarding modern human populations. Consequently, researchers have initiated efforts to obtain contemporary population data that can facilitate accurate examinations of unidentified individuals in contemporary forensic cases. However, the availability of information concerning differences among existing populations is commonly utilized in forensic anthropology, due to the limited availability of modern skeletal collections on a global scale (Dirkmaat, 2014). Consequently, an increasing emphasis has been placed on anthropological investigations employing radiographic methodologies, as they offer the advantage of working with living individuals. In recent years, computed tomography has gained popularity as a prominent method for the identification of human remains. Additionally, the scarcity of collections representing contemporary populations and ethical concerns associated with the utilization of maceration techniques have prompted researchers to adopt current technology as a means to compile modern population data, facilitating the creation of virtual databases comprising modern human skeletal information.

Consequently, virtual anthropology, particularly through the use of computed tomography (CT), has gained significant traction in forensic anthropological research and has found widespread application in biological profiling. Additionally, several investigations have demonstrated the comparable accuracy of measurements acquired from CT reconstructed images with physical measurements (Hildebolt *et al.,* 1990; Kranioti *et al.,* 2009; Lopes *et al.,* 2008; Ramsthaler *et al.,* 2010; Uslu *et al.,* 2005; Vandenbussche *et al.,* 2010). Nevertheless, the establishment and validation of standardized measurement protocols specifically for CT-derived images remain an area that requires further development (Robinson *et al.,* 2008).

Preceding investigations have emphasized the essentiality of adhering to detailed criteria for three-dimensional (3D) reconstructed data employed in research to ensure the reliability and accuracy of metric measurements emanating from such data. The reproducibility of measurements acquired from 3D reconstructed images can be influenced by the reconstruction and acquisition parameters employed (Goo *et al.,* 2005). Previous experimental research has provided evidence that, with the application of appropriate scanning and measurement techniques, metric measurements derived from CT scans exhibit a commendable level of accuracy (Spoor & Zonneveld, 1995; Uslu *et al.,* 2005).

Nevertheless, there exists a contentious discussion surrounding the accuracy and reliability of osteometric measurements acquired from 3D reconstructed bone images derived from CT scans. While certain research has demonstrated the high accuracy of 3D reconstructions derived from CT datasets, others have highlighted significant disparities between physical and virtual measurements. Numerous investigations have provided substantiation for the accuracy of osteometric measurements acquired from CT-reconstructed images. For instance, Christiansen et al. (1986) performed a study demonstrating that the linear measurements conducted on axial CT images demonstrated acceptable adherence to standards when compared to physical measurements taken on mandibles. Whyms et al. (2013) examined the impact of different scanning parameters on volumetric, linear, and surface area measurements taken over 3 mandibles. As a result of the examination, they discovered that while no differences were observed in linear measurements, volume measurements were not precise for 2.5 mm slice thicknesses, and measurements from surface area differed for different scanning parameters. The measurements taken from the surface area did not create an adequate degree of accuracy for the mandibles and were significantly inflated in comparison with volume and linear measurements.

Furthermore, Matteson et al. (1989) conducted a comparative analysis by directly measuring dry skulls and obtaining measurements from CT images, revealing that the accuracy of CT measurements amounted to 0.28%. Rawal et al. (2012) observed that measurements derived from 3D images obtained through CT scans exhibited greater accuracy and ease compared to direct measurements obtained from cadaveric bones and 2D radiographs. Moreover, Waitzman et al. (1992) carried out an examination on 5 skulls, utilizing both direct and indirect CT methods, and revealed a remarkable level of concurrence between the two techniques.

Multiple investigations have explored the impact of CT acquisition parameters on the quality of bone images, particularly regarding various scanning and acquisition parameters (Oka *et al.,* 2009; Shirley *et al.,* 2009; Whyms *et al.,* 2013). Acquisition parameters employed for original data hold great significance as they possess the potential to impact image quality (Conlogue & Wade, 2011). Additionally, the accuracy of segmentation can be influenced by the chosen CT reconstruction and acquisition parameters (Waarsing *et al.,* 2004).

Among the factors affecting the 3D image accuracy obtained from CT scans, slice thickness emerges as the most crucial factor (Whyms *et al.,* 2013). Opting for thinner slices results in improved image quality, as it minimizes the averaging effect of partial volume (Joo *et al.,* 2011). Furthermore, factors such as different field of view (FOV) settings and various reconstruction algorithms can also exert an influence on the quality of images. These considerations collectively contribute to potential discrepancies in measurements. An increase in field of view (FOV) values is associated with larger pixel sizes in the axial plane, which subsequently impacts the interpolated voxel size utilized for segmentation (Ted & Way 2008; Whyms *et al.,* 2013). Pixel size generally corresponds to spatial resolution, where smaller pixels enhance spatial resolution and overall image quality. Therefore, a smaller FOV results in more detailed images. Algorithms employing edge enhancement techniques tend to yield better outcomes in distinguishing between bone and soft tissues, but they can introduce additional image noise. Smoothing algorithms effectively reduce image noise, but they can also induce blurring in bone images. The choice of convolution filters (FC) also affects image quality. Smaller numbers of FCs lead to image softening and reduced noise but at the expense of poorer edge definition. Conversely, higher numbers of FCs increase noise levels, yet they improve spatial resolution and edge definition (Conlogue & Wade, 2011). Scholarly research suggests that CT imaging of soft tissue bones and dry bones may exhibit different image qualities. Dry bone images might appear smaller compared to those of soft-tissue bones, as the CT scanner may face challenges in distinguishing structures with varying Hounsfield units (Stull *et al.,* 2014).

The initial objective of this research is to analyze the usability of the metric techniques used when working with three-dimensional images. Therefore, this research endeavors to produce a comprehensive examination and understanding of the following aspects. One of the points of this article is to evaluate the accuracy of measurements acquired from dry femur specimens in comparison to their corresponding 3D images. Another intention of this analysis is to investigate the effects of multiple factors, including slice thickness, convolution kernel, reconstruction algorithms, and field of view on the accuracy of 12 measurements acquired from femur images generated through CT scans. Moreover, a comparative analysis is conducted, on the impact of soft tissue on the accuracy of 3D reconstructed femora.

Materials and Methods

The source of data

This research utilized two distinct datasets for analysis. The selection of sample sizes (n=15 and n=4) was determined based on the availability of the CT modality and time limitations. CT scans were performed at the John Radcliffe Hospital in Oxfordshire, UK, utilizing a Toshiba Aquilion 64 CT scanner.

The primary dataset consisted of fifteen femora sourced from the dry femur collection at Cranfield University's Institute of Forensic Science. This particular sample, consisting of 15 specimens was employed to evaluate the measurement accuracy when comparing 12 measurements derived from the dry femur specimens to their respective 3D images.

The second subset of the data comprised four femora chosen from the aforementioned fifteen femora. This specific sample was utilized to evaluate the impact of CT parameters, such as FC, FOV, slice thicknesses, and reconstruction algorithms on the measurement accuracy conducted on CT-rendered femur images. Additionally, it provided an opportunity to examine the attenuation characteristics of soft tissue equivalents and assess the potential impact of soft tissue on the accuracy of measurements.

Data acquisition and image creation

Utilizing a Toshiba Aquilion 64 CT scanner, data from both sets were obtained, with a tube current of 200 mA and a 120 kV tube voltage employed. A matrix size of 512x512 mm was employed for all femur CT scans. Various acquisition parameters were employed during the scanning process, encompassing FOV, reconstruction algorithm, slice thickness, and FC. During the scanning process, the femur bones were scanned, progressing from the proximal region of the bone to the distal part, and axial slices were obtained. Each femur specimen was positioned perpendicularly on the CT table, aligned with the direction of table motion.

The image acquisition process was carried out in two separate sessions. In the first session, 15 femur bones were used to compare measurements taken directly from the bones with measurements taken from CT images. For the second part, four out of the 15 samples were specifically selected to examine the attenuation characteristics of soft tissue. To simulate an environment more akin to living human femora, where water density closely approximates the density of soft tissues, the 4 femora were immersed in a plastic container filled with water (Damstra *et al.,* 2010; Gaia *et al.,* 2011; Periago *et al.,* 2008; Whyms *et al.,* 2013). This arrangement ensured soft tissue equivalent attenuation. Within the second part of the experiment, 4 distinct sets of CT acquisition parameters were acquired for all femur imaging. Further details regarding the various variables and CT parameters employed for all data sets can be found in Table 1.

All four femora underwent 3D rendering using various combinations of experimental parameters, including two FCs, two slice thicknesses,

Table 1. *Details pertaining to the CT data used in the research*

Images	Samples	Field of View (FOV)	Reconstruction Algorithm	Convolution Filter (FC)	Slice Thickness
2	Dry Femur	350	Soft or Bone	30	1,3,5
3	Dry Femur	350	Soft or Bone	30	1,3,5
4	Dry Femur	350	Soft or Bone	30	1,3,5
6	Dry Femur	350	Soft or Bone	30	1,3,5
7	Dry Femur	350	Soft or Bone	30	1,3,5
8	Dry Femur	350	Soft or Bone	30	1,3,5
9	Dry Femur	350	Soft or Bone	30	1,3,5
10	Dry Femur	350	Soft or Bone	30	1,3,5
11	Dry Femur	350	Soft or Bone	30	1,3,5
13	Dry Femur	350	Soft or Bone	30	1,3,5
14	Dry Femur	350	Soft or Bone	30	1,3,5
15	Dry Femur	350	Soft or Bone	30	1,3,5
16	Dry Femur	350	Soft or Bone	30	1,3,5
17	Dry Femur	350	Soft or Bone	30	1,3,5
26	Dry Femur	350	Soft or Bone	30	1,3,5
4	Femur model with simulated soft tissue	247.5,140	Soft or Bone	30,81	3,5
15	Femur model with simulated soft tissue	247.5,140	Soft or Bone	30,81	3,5
26	Femur model with simulated soft tissue	247.5,140	Soft or Bone	30,81	3,5
17	Femur model with simulated soft tissue	247.5,140	Soft or Bone	30,81	3,5

FOVs, and two reconstruction algorithms. Furthermore, 15 femora were processed utilizing only two slice thicknesses and two reconstruction algorithms. As a result, a total of 92 femur models were generated, encompassing four CT scan series for each set of 15 dry femur bones and 8 CT sequences for each set of 4 femur models with simulated soft tissue.

The observer conducted measurements three times, with each measurement recorded with a precision of 1.0 millimeters (mm). At the outset, each femur underwent three measurements, and the mean value was utilized for subsequent statistical analyses. Length measurements, including Femur Trochanteric Length (FTL), Femur Maximum Length (FML), and Femur Bicondylar Length (FBL) were obtained using an osteometric board, while other measurements were calculated utilizing sliding calipers. The equipment utilized for obtaining physical measurements and related abbreviations is outlined in Table 2.

Furthermore, an additional accuracy assessment was conducted by comparing 3D volumetric images of 4 femora. This assessment aimed to analyze the impact of soft tissue on the accuracy of 3D reconstructed femora.

Following that, an estimation of the variation in linear measurements was conducted for the 4 femora that were scanned using distinct scan parameters. Throughout this evaluation, the remaining reconstruction parameters were kept constant. This analysis aimed to investigate how CT parameters influenced femur measurement accuracy. The acquired images were stored in DICOM to facilitate their easy utilization in the following step. This involved importing the various image series into specialized computer software for further analysis and processing. OsiriX software was employed for the imaging and analysis of the CT images. The creation of 3D models was

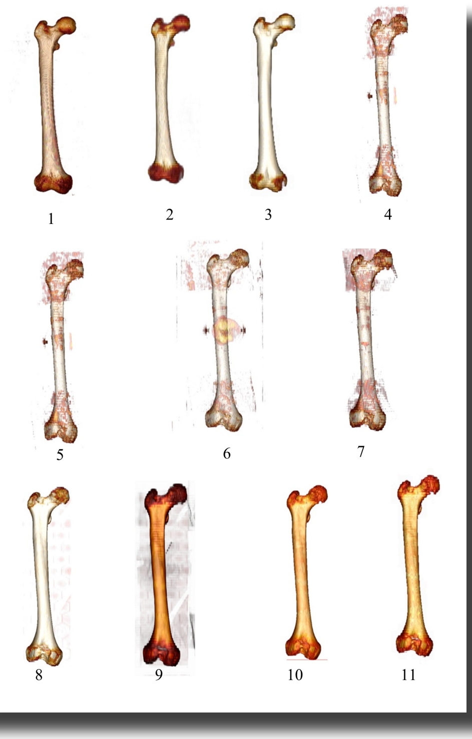

Figure 1. *Comparative evaluation of three-dimensional (3D) images derived from CT scans utilizing different acquisition parameters. 1(Bone 1.0); 2(Bone 5.0); 3 (Soft 5.0); 4 (FOV140, FC81,Bone3.0); 5(FOV 140, Bone 5.0, FC81); 6 (FOV 247.5, Bone 3.0, FC30); 7 (Bone 5.0, FOV247.5, FC 30,); 8 (Bone 3.0, FOV140, FC30,); 9 (Bone 5.0, FOV140, FC30,); 10 (FOV247.5, Bone 3.0, FC81,); 11 (FOV 247.5, Bone 5.0, FC81,).*

Table 2. *Information regarding femur measurements obtained from the literatureresearch*

Abbreviations	Measurements	Reference	Equipment
APDMC	Antero-Posterior Diameter of Medial Condyle	(Moore-Jansen et al., 1994)	Sliding Caliper
APDLC	Antero-Posterior Diameter of Lateral Condyle	(Moore-Jansen et al., 1994)	Sliding Caliper
FBCB	Femoral Bicondylar Breadth	(Terzidis et al., 2012)	Sliding Caliper
MLD	Medial- Lateral (Transverse) Subtrochanteric	(Buikstra and Ubelaker, 1994; Moore-Jansen et al., 1994)	Sliding Caliper
FBP	Femur Proximal Breadth	(Moore-Jansen et al., 1994)	Sliding Caliper
FVDN	Femur Vertical Diameter of Neck	(Gregory and Aspden, 2008)	Sliding Caliper
FNAL	Femur Neck Axis Length	(Moore-Jansen et al., 1994)	Sliding Caliper
VHD	Vertical Head Diameter	(Buikstra and Ubelaker, 1994; Moore-Jansen et al., 1994)	Sliding Caliper
MTD	Medial-Lateral (Transverse)	(Moore-Jansen et al., 1994)	Sliding Caliper
FTL	Femur Trochanteric Length	(Moore-Jansen et al., 1994)	Osteometric board
FBL	Femur Bicondylar Length	(Moore-Jansen et al., 1994)	Osteometric board
FML	Femur Maximum Length	(Buikstra and Ubelaker, 1994)	Osteometric board

accomplished utilizing the volume rendering algorithm. A visual representation of the 3D reconstructed view of the segmented femur from various CT settings in the OsiriX application is presented in Figure 1.

Statistical methods

The statistical examination was performed utilizing the SPSS software version 21.0 designed for the Windows operating system and Microsoft Office 2010's Excel software. Initially, the mean discrepancies between linear measurements acquired from the dry femur and their corresponding 3D volumetric models were compared using paired t-tests. Subsequently, a reliability analysis was conducted, incorporating the computation of the intra-class correlation coefficient (ICC), to evaluate the concordance between direct measurements derived from visual measurements obtained from 3D reconstructed femoral images and dry femora. Furthermore, paired t-tests were employed to investigate the dissimilarities in linear measurements among different CT reconstruction parameters in four femur samples, as well as to examine the impact of soft tissue on linear measurements.

Results

This research encompassed two distinct datasets derived from separate studies. The initial dataset, consisting of 15 samples, was employed to examine the dissimilarities between linear metric measurements acquired from the dry femur and their respective 3D reconstructed images. Table 3 provides a concise summary of standard deviations and the average values for both CT measurements and the reference values. In relation to the twelve measurements under examination, it was observed that, in seven instances, the direct measurement from the bone exhibited higher mean values in comparison to the measurements derived from the 3D reconstructed images.

The normality of all twelve measurements was assessed using the Shapiro-Wilk test. This test was employed to analyze the normal distribution of the fifteen measurement sets across the 12 different measurement categories. No major differences were noted in any of the measured values. Subsequently, a Student's t-test was performed (Table 4) to ascertain if there was a statistically meaningful distinction existed between CT and physical measurements. A two-tailed p-value lower than 0.05 was taken indicative as of statistical significance.

Table 4 reveals that no statistically meaningful discrepancies were noticed between the physical and CT values for each measurement. This suggests that there were no substantial size variations between the CT and direct measurements.

A precise analysis has been performed in order to check the reliability of repeat measurements. The Intra Correlation Coefficient (ICC) was estimated to evaluate the intra-examiner error, wherein each femur measurement was repeated three times and the examinations were carried out at monthly intervals. The ICC values for each measurement approached unity (see Table 5), indicating a high level of consistency in the results across each examination. The ICC values between 12 measurements obtained from dry bones and CT femur images were all greater than 0.84. This signifies excellent intraobserver reliability between measurements derived from CT images and direct measurements. The analyses conducted indicate that the accuracy of measurements acquired from reconstructed CT images is comparable to that of measurements acquired from direct measurements of dry femora.

Four femora chosen from the original fifteen femora were employed to investigate the impact of specific CT acquisition parameters (such as reconstruction algorithm (bone/soft), FC, FOV, and slice thickness) on the accuracy of detecting 12 measurements in the femur. To

Table 3. *Summary statistics of measurements obtained from 3D reconstructed femora and dry femora are shown as the standard deviation and mean (in millimeters)*

Variables	3D femur (n=15)		Dry femur (n=15)	
	Mean	SD	Mean	SD
APDMC	54.24	5.72	57.28	5.47
APDLC	55.41	5.65	58.59	4.88
FEB	73.25	6.34	73.46	6.18
FBCB	62.58	4.68	67.99	5.67
FBP	83.38	7.30	82.64	6.65
FVDN	29.24	4.35	30.18	4.18
MLD	28.96	3.95	30.88	3.04
FTL	400.76	29.62	386.11	26.72
FBL	411.97	30.80	408.01	33.92
MTD	25.17	2.36	26.21	2.39
FML	410.68	30.09	416.18	29.24
VHD	41.61	5.28	42.47	4.30

Table 4. *The result of the* t-*test for mean values between CT and direct femur measurements*

Measurements	*t*	*P* value
APDMC	2.138	.051
APDLC	2.723	.061
FEB	.137	.893
FBCB	3.166	.070
FBP	-.743	.470
FVDN	1.719	.108
FML	.665	.517
MLD	3..900	.054
FTL	-2.427	.059
FBL	-,898	.384
MTD	1.972	.069
VHD	.917	.374

Table 5. *Results of the Intra-class correlation coefficient (ICC) analysis conducted with three repetitions.*

Variables	CT images (n=15)		Dry femur (n=15)	
	ICC	Cronbach's Alpha	ICC	Cronbach's Alpha
APDMC	.985	.985	.984	.986
APDLC	.984	.983	.985	.987
FEB	.974	.972	.965	.994
FBCB	.841	.857	.959	.957
FBP	.993	.994	.962	.964
FVDN	.989	.990	.936	.945
MLD	.971	.971	.935	.947
FTL	1.000	1.000	.980	.979
FBL	.997	.999	.968	.970
MTD	.978	.980	.901	.924
FML	.999	.999	.969	.971
VHD	.991	.993	.967	.967

assess the existence of significant discrepancies in linear measurements, four distinct CT scans were obtained for each femur bone and a set of 16 images derived from the 4 femora was created.

Additionally, the examination of the impact of soft tissue on the accuracy of 3D images of the femur was explored through a comparative analysis. CT images obtained directly from the dry femur were compared by placing the same dry femur in a water-filled plastic container. Paired t-tests were performed for statistical comparisons, and comprehensive outcomes can be found in (Table 6 to Table 11), which provides detailed results of the analysis.

Based on the results obtained from the paired t-tests (Table 6 to Table 11), no statistically significant differences were detected for the different reconstruction parameters (p <0.05). Moreover, the statistical analysis conducted on the dry and water-soaked (simulated soft tissue) femur images revealed that the presence of simulated soft tissue did not exert any discernible effect on the assessment.

Overall, the findings from these analyses suggest that the measurements acquired using various reconstruction parameters are similar. This enables meaningful comparisons of datasets from diverse sources, regardless of the specific CT parameters employed.

Discussion

Population-specific standards have garnered increasing attention in the context of medico-legal applications (İşcan, 2005). Skeletal collections associated with ancient populations have traditionally been the primary source for deriving these standards. Nevertheless, population standards derived using these skeletal collections may not yield equivalent accuracy when applied to contemporary populations, owing to recent demographic shifts subsequent to the era when the archaeological populations existed. As a result, no longer sufficient for forensic criteria is rely solely on collections from previous centuries (Spradley & Jantz, 2011). Consequently, numerous research studies have been conducted to gather unique data for contemporary populations, with recent researchers focusing on population-specific investigations aimed at providing more accurate information using updated techniques and data relevant to medico-legal applications. As forensic anthropologists increasingly contribute to a growing number of medico-legal cases, there is a pressing need for knowledge about modern human populations. Consequently, scholars have shifted their focus towards acquiring modern population data, which can provide precise interpretations of unidentified individuals in current forensic anthropological cases.

The comprehension of existing population variations in forensic anthropology remains relatively

Table 6. *A paired* t*-test was conducted to compare the 12 measurements taken from CT reconstructed images utilizing different parameters and dry bone specimens*

Samples		APDMC	APDLC	FBP	FVDN	FBCB	MLD	FEB	VHD	FTL	MTD	FBL	FML
VM11-PM	Sig. (2-tailed)	0.99	0.91	0.19	0.79	0.77	0.99	0.07	0.83	0.42	0.74	0.43	0.91
	t-value	0.008	-0.11	-1.69	-0.29	-0.311	0.003	-5.223	-0.226	0.912	0.359	0.894	0.118
VM10-PM	Sig. (2-tailed)	0.81	0.84	0.21	0.56	0.9	0.83	0.06	0.74	0.53	0.12	0.10	0.07
	t-value	-0.258	-0.216	-1.554	-0.639	0.027	-0.228	-2.928	-0.355	0.701	2.152	2.266	-3.513
VM9-PM	Sig. (2-tailed)	0.53	0.28	0.12	0.17	0.8	0.54	0.12	0.31	0.83	0.44	0.70	0.64
	t-value	0.691	1.286	-2.147	-1.787	0.23	-0.685	-2.145	-1.193	-0.221	0.882	6.005	-0.518
VM8-PM	Sig. (2-tailed)	0.13	0.59	0.55	0.48	0.98	0.91	0.51	0.49	0.92	0.06	0.64	0.69
	t-value	2.011	0.602	-0.672	-0.803	0.024	-0.116	-0.729	0.767	0.103	3.146	3.229	-0.43
VM7-PM	Sig. (2-tailed)	0.91	0.53	0.40	0.35	0.99	0.81	0.33	0.59	0.77	0.07	0.09	0.91
	t-value	0.12	-0.703	-0.965	-1.094	-0.002	-0.256	-1.151	-0.588	0.311	4.161	2.419	0.111
VM6-PM	Sig. (2-tailed)	0.22	0.14	0.63	0.51	0.61	0.65	0.45	0.41	0.82	0.06	0.07	0.79
	t-value	1.522	1.956	0.533	-0.748	-0.555	0.497	-0.865	0.945	-0.235	4.737	4.868	0.288
VM5-PM	Sig. (2-tailed)	0.08	0.25	0.60	0.19	0.62	0.59	0.16	0.92	0.89	0.06	0.08	0.93
	t-value	2.558	1.414	0.575	-1.651	-0.546	0.598	-1.846	-0.105	0.141	4.612	2.591	-0.095
VM4-PM	Sig. (2-tailed)	0.13	0.14	0.20	0.12	0.49	0.86	0.26	0.47	0.45	0.20	0.08	0.86
	t-value	2	1.992	-1.619	-2.082	-0.771	0.19	-1.364	0.807	-0.861	1.617	2.519	0.182
VM3-PM	Sig. (2-tailed)	0.44	0.67	0.46	0.07	0.82	0.96	0.60	0.64	0.87	0.26	0.09	0.83
	t-value	0.874	2.817	-0.827	-3.025	0.236	0.044	0.575	0.518	0.176	1.373	2.378	-0.23

Notes.
VM (Virtual Measurement from CT images); PM (Physical measurements from dry bone); VM11 (FOV 247.5, FC81, Bone 5.0); VM10 (FOV247.5, FC81, Bone 3.0); VM9 (FOV140, FC30, Bone 5.0); VM8 (FOV140, FC30, Bone 3.0); VM7 (FOV247.5, FC30, Bone 5.0); VM6 (FOV247.5, FC30, Bone 3.0); VM5 (FOV140, FC81, Bone 5.0); VM4 (FOV140, FC81, Bone 3.0); VM3 (Soft 5.0).

Table 7. *A paired* t*-test was utilized to conduct a comparison of the Soft Tissue Effect*

Variables	Specimen 1		Specimen 2		Specimen 3		Specimen 4	
	t-value	Sig. (2-tailed)	*t*-value	Sig. (2-tailed)	*t*-value	Sig. (2-tailed)	*t*-value	Sig. (2-tailed)
APDMC	-.209	.848	-.258	.813	-1.062	.366	-1.395	.257
APDLC	-1.435	.247	-2.472	.090	-2.930	.061	-3.048	.056
FBP	-1.384	.260	1.103	.351	1.148	.334	-.644	.565
FVDN	-4.963	.056	-2.579	.082	-1.902	.153	-2.009	.138
FBCB	-.658	.558	-.380	.729	.234	.830	-.371	.735
FEB	-.421	.702	-.267	.807	-.103	.924	-.170	.876
MLD	-.572	.608	-.492	.656	-.363	.741	-.942	.416
VHD	-.995	.393	-.720	.523	-.061	.955	-1.017	.384
MTD	.677	.547	.648	.563	1.929	.060	1.441	.245
FTL	-.760	.513	.083	.939	-.248	.820	.231	.832
FBL	2.037	.134	1.995	.140	4.766	.058	1.929	.149
FML	.231	.832	.220	.840	.272	.804	.282	.796

Table 8. *A paired t-test was utilized to conduct a comparison of the Reconstruction Algorithm*

Variables	Specimen 1 (Bone or soft)		Specimen 2 (Bone or soft)		Specimen 3 (Bone or soft)		Specimen 4 (Bone or soft)	
	t-value	Sig. (2-tailed)	*t*-value	Sig. (2-tailed)	*t*-value	Sig. (2-tailed)	*t*-value	Sig. (2-tailed)
APDMC	-4.533	.051	.352	.748	.415	.706	-1.833	.164
APDLC	-.835	.465	-.983	.398	-2.434	.093	-2.822	.067
FBP	-.442	.688	-1.335	.274	1.135	.339	1.201	.316
FVDN	-1.955	.146	-3.807	.052	-2.130	.123	-1.958	.145
FBCB	.577	.605	-.486	.660	-.129	.906	-.086	.937
FEB	.899	.435	-.463	.675	-.303	.782	-.137	.900
MLD	-1.401	.256	-.659	.557	-.637	.569	-.430	.696
VHD	.858	.454	-.424	.700	-.206	.850	.386	.725
MTD	-.548	.622	-.085	.938	-.462	.675	1.237	.304
FTL	.129	.906	-.805	.480	.097	.929	-.249	.820
FBL	2.153	.120	2.168	.119	2.137	.122	4.336	.023
FML	1.114	.346	.392	.721	.386	.725	.439	.690

Table 9. *A paired t-test was utilized to conduct a comparison of the convolution filter (FC)*

Variables	Specimen 1 (FC81/FC30)		Specimen 2 (FC81/FC30)		Specimen 3 (FC81/FC30)		Specimen 4 (FC81/FC30)	
	t-value	Sig. (2-tailed)	*t*-value	Sig. (2-tailed)	*t*-value	Sig. (2-tailed)	*t*-value	Sig. (2-tailed)
APDMC	-1.870	.158	-2.158	.120	-2.126	.123	-.212	.846
APDLC	-1.926	.150	-.287	.793	-1.247	.301	1.202	.316
FBP	1.062	.366	-2.709	.073	-2.298	.105	.332	.761
FVDN	.997	.392	-1.022	.382	-.381	.728	.958	.409
FBCB	2.303	.105	1.262	.296	2.986	.058	-.424	.700
FEB	.806	.479	-.330	.763	-5.026	.055	-3.088	.054
MLD	-1.421	.250	-1.794	.171	-1.469	.238	1.145	.335
VHD	1.463	.240	-2.241	.111	-9.358	.053	.414	.707
MTD	.175	.872	-3.249	.058	-2.621	.079	-2.281	.107
FTL	2.789	.068	-.624	.577	1.294	.286	1.016	.384
FBL	-.254	.816	-.346	.752	-1.891	.155	-1.020	.383
FML	-.722	.522	-1.430	.248	-2.923	.061	-.082	.939

Table 10. *A paired t-test was utilized to conduct a comparison of the field of view (FOV)*

Variables	Specimen 1 (FOV140/FOV247.5)		Specimen 2 (FOV140/FOV247.5)		Specimen 3 (FOV140/FOV247.5)		Specimen 4 (FOV140/FOV247.5)	
	t-value	Sig. (2-tailed)	*t*-value	Sig. (2-tailed)	*t*-value	Sig. (2-tailed)	*t*-value	Sig. (2-tailed)
APDMC	-4.302	.053	-2.914	.062	-.172	.875	4.686	.068
APDLC	-1.751	.178	-1.050	.371	-.906	.432	2.414	.095
FBP	.393	.721	-3.081	.054	-1.384	.260	-2.348	.100
FVDN	1.440	.245	2.045	.133	-.839	.463	-.540	.627
FBCB	1.356	.268	1.058	.368	2.559	.083	.908	.431
FEB	-.705	.532	-4.143	.026	-.085	.937	-.709	.530
MLD	-1.106	.349	-1.010	.387	-1.161	.330	-2.076	.130
VHD	.157	.885	-.238	.827	-.578	.604	-1.643	.199
MTD	-.788	.488	-1.525	.225	-.886	.441	-2.972	.059
FTL	2.273	.108	1.235	.305	.827	.469	-1.028	.379
FBL	-.896	.436	-1.251	.300	-1.268	.294	-.757	.504
FML	-4.408	.022	.999	.391	-1.040	.375	-1.149	.334

Table 11. *A paired* t-*test was conducted to compare the slice thickness*

Variables	Specimen 1 (Bone3.0/Bone.5)		Specimen 2 (Bone3.0/Bone.5)		Specimen 3 (Bone3.0/Bone.5)		Specimen 4 (Bone3.0/Bone.5)	
	t-value	Sig. (2-tailed)	*t*-value	Sig. (2-tailed)	*t*-value	Sig. (2-tailed)	*t*-value	Sig. (2-tailed)
APDMC	-.135	.901	-1.251	.300	-.630	.573	1.035	.377
APDLC	-1.060	.367	-1.606	.207	.505	.648	.235	.829
FBP	1.290	.287	-1.680	.192	-1.283	.290	.258	.813
FVDN	.152	.889	-1.186	.321	-1.878	.157	.164	.880
FBCB	.793	.485	1.494	.232	.779	.493	-.563	.613
FEB	.231	.832	-.390	.723	-.719	.524	-1.277	.292
MLD	.332	.762	-1.300	.285	-2.015	.137	.711	.529
VHD	.421	.702	-1.846	.162	-3.856	.051	.066	.951
MTD	-.095	.930	-1.301	.284	-2.119	.124	-1.049	.371
FTL	1.667	.194	1.494	.232	-1.492	.232	.630	.573
FBL	-.197	.856	-1.050	.371	-.407	.711	-.767	.499
FML	-.279	.798	-.152	.889	-.409	.710	2.353	.100

constrained as a result of the global scarcity of modern skeletal collections (Dirkmaat, 2014). Consequently, there has been an increasing inclination towards anthropological research that employs X-ray-based or radiographic techniques, primarily due to their focus on living subjects. As a method for the identification of human remains, CT has accumulated popularity in recent years. Additionally, modern technology has been employed by researchers to collect modern population data and create virtual databases of contemporary human skeletal information, primarily due to the limited availability of ethical concerns and modern population collections related to maceration techniques.

The accuracy of estimating biological features from radiographic images has been broadly researched in the existing literature (Giurazza *et al.,* 2013). Traditionally, the most standard approach to establishing a biological profile from damaged remains involved the laborious process of defleshing the remains to analyze the dry bones. However, aside from being time-consuming, this method also gives rise to numerous ethical concerns. Moreover, the development of population-specific standards is hindered in many countries, due to the absence of skeletal modern collections necessary for the creation of formulas specific to populations (Stull *et al.,* 2014).

In recent decades, modern imaging techniques, including 3D-surface topometry systems, MRI, and CT have offered new avenues for anthropological investigations. These advancements in information technologies have paved the way for the emergence of a new field known as Virtual Anthropology (Kullmer, 2008). CT protocols have found widespread application in forensic science, encompassing various areas such as human identification in mass casualty incidents (Høyer *et al.,* 2012; O'Donnell *et al.,* 2011), postmortem examinations (Choling *et al.,* 2009; Plattner *et al.,* 2003; Thali *et al.,* 2003), and both ante and postmortem cases (Dedouit *et al.,* 2007; Haglund & Sorg, 2010; Riepert *et al.,*1995).

The literature has extensively examined the application of CT in disaster victim identification and standards investigation in anthropological research (Dedouit *et al.,* 2007; Grabherr *et al.,* 2009; Kullmer, 2008). Dedouit et al. (2007) have pointed out several advantages of CT over traditional anthropological assessments, as revealed by these studies.

One significant advantage of CT is its non-invasive nature, allowing for the examination of bones without the need for time-consuming defleshing. Additionally, non-invasive techniques are valuable as they enable the virtual assessment of skeletons without damaging the original samples. This is particularly beneficial when dealing with fragile bones (Grabherr *et al.,* 2009). If maceration is not permitted because of cultural practices, non-invasive methods play a crucial role (Verhoff *et al.,* 2008). The visualization of CT data *in situ* allows for the examination of modern populations (Dedouit *et al.,* 2007). Additionally, the storage and re-interpretation of CT images at any given time prevent the loss of valuable information. This feature allows experts from various locations to simultaneously examine the bones without the necessity of traveling, which is especially crucial for time efficiency, particularly in situations involving mass disasters (Dedouit *et al.,* 2010).

Comparisons between direct femur measurements and 3D femur images yielded comparable outcomes for the corresponding linear measurements. The outcomes of this present study align with prior research, which suggests that osteometric measurements gathered from CT images correspond to those acquired using dry bones (Uslu *et al.,* 2005). Furthermore, no significant discrepancies were observed between direct femur measurements and 3D femur images as assessed by the same observer. The overall findings indicate that femur measurements acquired from 3D images of the femur and dry bone are consistent, suggesting that the specific parameters of the data set employed in this research did not have a substantial influence on the outcomes. Furthermore, this research aimed to evaluate the accuracy and reliability of femur measurements derived from 3D reconstructed CT images generated by a medical CT scanner. Additionally, the analysis aimed to explore the potential impact of diverse CT parameters and the impact of soft tissue on the accuracy of 3D CT images of the femur bone.

No statistically notable differences were found in the 12 measurements of 3D images obtained through CT scans conducted with various settings, including slice thickness, FC, FOV, and reconstruction algorithm. Despite variations in image detail resulting from changes in reconstruction parameters, these modifications did not affect the accuracy of femur measurements. The findings of this study support previous research that has confirmed the accuracy and reliability of 3D models through the assessment of linear measurements obtained from CT volume rendering using different FC, bone algorithm, slice thickness, and FOV (Oka *et al.,* 2009; Whyms *et al.,* 2013).

Although no significant changes in linear measurements have been observed with different scan parameters in many studies so far, it is known that these parameters have a significant effect on image quality. It is possible that the difference in image quality may affect the identification of some landmarks and the acquisition of measurements. Especially with the increasing use of images with different protocols taken for various health reasons in anthropological research, investigating the accuracy of these studies has become more important. One limitation of these studies is that the findings of a single CT scanner and a particular bone may not be valid for other devices and bones. Therefore, further studies on different osteometric measurements from various bones will clarify this issue.

Conclusion

In places where modern skeletal collections do not exist, medical CT is growingly utilized as a data source to analyze or enhance forensic anthropological methods. For this reason, new methods are being developed to work with these acquired three-dimensional images. Ultimately, the accuracy and usability of these new methods need to be tested. Finally, it is necessary to investigate whether these techniques can be used interchangeably or compared with each other in virtual and dry bones. Given the clinical challenges associated with protocol standardization, it becomes imperative to establish the reproducibility and repeatability of anthropometric measurements. This is especially crucial due to the considerable variation observed in computed tomography (CT) scan reconstruction and acquisition parameters, both within the same institution and across different institutions.

The primary goal of this investigation was to assess the osteometric measurement accuracy obtained from 3D femur models produced from CT. Additionally, the influence of soft tissue effect and various CT parameters on the measurement accuracy was investigated. The results revealed that there were no statistically meaningful discrepancies noticed, irrespective of the particular CT parameters utilized. Consequently, it can be inferred that reconstruction parameters do not exert a significant impact on the accurate estimation of sex, where emphasis is placed on femur size. Moreover, this study also investigated the distinctions between measurements acquired from dry bone specimens and their corresponding 3D models. The findings of this investigation align with prior scholarly studies, thereby reinforcing the notion that measurements derived from 3D femur images can be effectively compared to those obtained from dry femur specimens (Uslu *et al.,* 2005). From a forensic anthropological perspective, the practical impact of altering imaging conditions on the utilization of 3D reconstructed images of femur bone is negligible. Hence, femur bone virtually modeled from medical CT scans proves to be an adequately accurate resource for anthropological techniques and for constructing a contemporary virtual skeleton database. The findings from this study exhibit that there is no pattern as to whether image acquisition in any way is more or less dependable. That is, the dry bones or 3D reconstituted bones should be used to develop forensic anthropological techniques and vice versa, both landmark recognition and error rates between modalities or different scanning parameters must be established for each measurement.

References

Christiansen, E. L., Thompson, J. R., & Kopp, S. (1986). Intra-and inter-observer variability and accuracy in the determination of linear and angular measurements in computed tomography: An in vitro and in situ study of human mandibles. *Acta Odontologica, 44*(4), 221-229. https://doi.org/10.3109/00016358608997724

Conlogue, G., & Wade, A. D. (2011). Development of a dry bone MDCT scanning protocol for archaeological crania. *Anthropology Presentations, 4*. https://ir.lib.uwo.ca/anthropres/4

Damstra, J., Fourie, Z., Slater, J. J. R. H., & Ren, Y. (2010). Accuracy of linear measurements from cone-beam computed tomography-derived surface models of different voxel sizes. *American Journal of Orthodontics and Dentofacial Orthopedics, 137*(1), 16.e1-16.e6. https://doi.org/10.1016/j.ajodo.2009.06.016

Dedouit, F., Telmon, N., Costagliola, R., Otal, P., Joffre, F., & Rougé, D. (2007). Virtual anthropology and forensic identification: report of one case. *Forensic Science International, 173*(2), 182-187. https://doi.org/10.1016/j.forsciint.2007.01.002

Dedouit, F., Telmon, N., Hervé, R., Francis, E., Joffre, C., & and Daniel, R. (2010). Modern cross-sectional ımaging in anthropology. In M. J. Thali, M. D. Viner & B. G. Brogdon, *Brogdon's forensic radiology* (Second Ed.), (pp. 107-126). CRC Press. https://doi.org/10.4324/9780367805708

Dirkmaat, D. (Ed.) (2014). A Companion to forensic anthropology. John Wiley & Sons. https://doi.org/10.1002/9781118255377

Gaia, B. F., Sales, M. A. O. de, Perrella, A., Fenyo-Pereira, M., & Cavalcanti, M. G. P. (2011). Comparison between cone-beam and multislice computed tomography for identification of simulated bone lesions. *Brazilian Oral Research, 25*(4), 362-368. https://doi.org/10.1590/S1806-83242011000400014

Giurazza, F., Del Vescovo, R., Schena, E., Cazzato, R. L., D'Agostino, F., Grasso, R. F., … Zobel, B. B. (2013). Stature estimation from scapular measurements by CT scan evaluation in an Italian population. *Legal Medicine, 15*(4), 202-208. https://doi.org/10.1016/j.legalmed.2013.01.002

Goo, J. M., Tongdee, T., Tongdee, R., Yeo, K., Hildebolt, C. F., & Bae, K. T. (2005). Volumetric measurement of synthetic lung nodules with multi–detector row CT: Effect of various ımage reconstruction parameters and segmentation thresholds on measurement accuracy 1. *Radiology, 235*(3), 850-856. https://doi.org/10.1148/radiol.2353040737

Grabherr, S., Cooper, C., Ulrich-Bochsler, S., Uldin, T., Ross, S., Oesterhelweg, L., … Mangin, P. (2009). Estimation of sex and age of "virtual skeletons"–a feasibility study. *European Radiology, 19*(2), 419-429. https://doi.org/10.1007/s00330-008-1155-y

Haglund, W. D., & Sorg, M. H. (Eds.) (2010). Advances in forensic taphonomy: Method, theory, and archaeological perspectives. CRC Press. https://doi.org/10.1201/9781420058352

Hildebolt, C. F., Vannier, M. W., & Knapp, R. H. (1990). Validation study of skull three-dimensional computerized tomography measurements. *American Journal of Physical Anthropology, 82*(3), 283-294. https://doi.org/10.1002/ajpa.1330820307

Høyer, C. B., Nielsen, T. S., Nagel, L. L., Uhrenholt, L., & Boel, L. W. T. (2012). Investigation of a fatal airplane crash: autopsy, computed tomography, and injury pattern analysis used to determine who was steering the plane at the time of the accident. A case report. *Forensic Science, Medicine, and Pathology,* 8(2), 179-188. https://doi.org/10.1007/s12024-011-9239-4

İşcan, M. (2005). Forensic anthropology of sex and body size. *Forensic Science International, 147*(2–3), 107-112. https://doi.org/10.1016/j.forsciint.2004.09.069

Joo, I., Kim, S. H., Lee, J. Y., Lee, J. M., Han, J. K., & Choi, B. I. (2011). Comparison of semiautomated and manual measurements for simulated hypo-and hyper-attenuating hepatic tumors on MDCT: Effect of slice thickness and reconstruction increment on their accuracy. *Academic Radiology, 18*(5), 626-633. https://doi.org/10.1016/j.acra.2010.12.013

Kranioti, E. F., Bastir, M., Sanchez-Meseguer, A., & Rosas, A. (2009). A geometric-morphometric study of the Cretan humerus for sex identification. *Forensic Science International, 189*(1), 111.e1-111.e8. https://doi.org/10.1016/j.forsciint.2009.04.013

Kullmer, O. (2008). Benefits and risks in virtual anthropology. *Journal of Anthropological Sciences, 86,* 205-207. https://www.isita-org.com/jass/contents/2008%20vol86/16_Kullmer.pdf

Lopes, P. M. L., Moreira, C. R., Perrella, A., Antunes, J. L., & Cavalcanti, M. G. P. (2008). 3-D volume rendering maxillofacial analysis of angular measurements by multislice CT. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology, 105*(2), 224-230. https://doi.org/10.1016/j.tripleo.2007.08.036

Matteson, S. R., Bechtold, W., Phillips, C., & Staab, E. V. (1989). A method for three-dimensional image reformation for quantitative cephalometric analysis. *Journal of Oral and Maxillofacial Surgery, 47*(10), 1053-1061. https://doi.org/10.1016/0278-2391(89)90180-8

O'Donnell, C., Iino, M., Mansharan, K., Leditscke, J., & Woodford, N. (2011). Contribution of postmortem multidetector CT scanning to identification of the deceased in a mass disaster: experience gained from the 2009 Victorian bushfires. *Forensic Science International, 205*(1), 15-28. https://doi.org/10.1016/j.forsciint.2010.05.026

Oka, K., Murase, T., Moritomo, H., Goto, A., Sugamoto, K., & Yoshikawa, H. (2009). Accuracy analysis of three-dimensional bone surface models of the forearm constructed from multidetector computed tomography data. *The International Journal of Medical Robotics and Computer Assisted Surgery, 5*(4), 452-457. https://doi.org/10.1002/rcs.277

Periago, D. R., Scarfe, W. C., Moshiri, M., Scheetz, J. P., Silveira, A. M., & Farman, A. G. (2008). Linear accuracy and reliability of cone beam CT derived 3-dimensional images constructed using an orthodontic volumetric rendering program. *The Angle Orthodontist, 78*(3), 387-395. https://doi.org/10.2319/122106-52.1

Plattner, T., Thali, M. J., Yen, K., Sonnenschein, M., Stoupis, C., Vock, P., … Dirnhofer, R. (2003). Virtopsy-postmortem multislice computed tomography (MSCT) and magnetic resonance imaging (MRI) in a fatal scuba diving incident. *Journal of Forensic Sciences, 48*(6), 1347-1355. https://doi.org/10.1520/JFS2003162

Ramsthaler, F., Kettner, M., Gehl, A., & Verhoff, M. A. (2010). Digital forensic osteology: Morphological sexing of skeletal remains using volume-rendered cranial CT scans. *Forensic Science International, 195*(1–3), 148-152. https://doi.org/10.1016/j.forsciint.2009.12.010

Rawal, B., Ribeiro, R., Malhotra, R., & Bhatnagar, N. (2012). Anthropometric measurements to design best-fit femoral stem for the Indian population. *Indian Journal of Orthopaedics, 46*(1), 46-53. https://doi.org/10.4103/0019-5413.91634

Riepert, T., Rittner, C., Ulmcke, D., Ogbuihi, S., & Schweden, F. (1995). Identification of an unknown corpse by means of computed tomography (CT) of the lumbar spine. *Journal of Forensic Sciences, 40*(1), 126-127. https://doi.org/10.1520/JFS13775J

Robinson, C., Eisma, R., Morgan, B., Jeffery, A., Graham, E. A. M., Black, S., & Rutty, G. N. (2008). Anthropological measurement of lower limb and foot bones using Multi-Detector Computed Tomography. *Journal of Forensic Sciences, 53*(6), 1289-1295. https://doi.org/10.1111/j.1556-4029.2008.00875.x

Spradley, M. K., & Jantz, R. L. (2011). Sex estimation in forensic anthropology: skull versus postcranial elements. *Journal of Forensic Sciences, 56*(2), 289-296. https://doi.org/10.1111/j.1556-4029.2010.01635.x

Srivastava, R., Saini, V., Rai, R. K., Pandey, S., & Tripathi, S. K. (2012). A study of sexual dimorphism in the femur among North Indians. *Journal of Forensic Sciences, 57*(1), 19-23. https://doi.org/10.1111/j.1556-4029.2011.01885.x

Stull, K. E., Tise, M. L., Ali, Z., & Fowler, D. R. (2014). Accuracy and reliability of measurements obtained from computed tomography 3D volume rendered images. *Forensic Science International, 238*, 133-140. https://doi.org/http://dx.doi.org/10.1016/j.forsciint.2014.03.005

Thali, M. J., Yen, K., Schweitzer, W., Vock, P., Ozdoba, C., & Dirnhofer, R. (2003). Into the decomposed body—forensic digital autopsy using multislice-computed tomography. *Forensic Science International, 134*(2), 109-114. https://doi.org/10.1016/S0379-0738(03)00137-3

Uslu, M., Ozsar, B., Kendi, T., Kara, S., Tekdemir, I., & Atik, S. (2005). The use of computed tomography to determine femoral component size. *Bulletin (Hospital for Joint Diseases (New York, N.Y.)), 63*(1-2), 49-53.

Vandenbussche, E., Saffarini, M., Hansen, U., Taillieu, F., Mutschler, C., Augereau, B., & Gregory, T. M. (2010). Measurement of femoral head penetration in polyethylene using a 3-dimensional CT-scan technique. *Acta Orthopaedica, 81*(5), 563-569. https://doi.org/10.3109/17453674.2010.519163

Verhoff, M. A., Ramsthaler, F., Krähahn, J., Deml, U., Gille, R. J., Grabherr, S., … Kreutz, K. (2008). Digital forensic osteology—possibilities in cooperation with the Virtopsy® project. *Forensic Science International, 174*(2), 152-156. https://doi.org/10.1016/j.forsciint.2007.03.017

Waarsing, J. H., Day, J. S., & Weinans, H. (2004). An ımproved segmentation method for in vivo µCT imaging. *Journal of Bone and Mineral Research, 19*(10), 1640-1650. https://doi.org/10.1359/JBMR.040705

Waitzman, A. A., Posnick, J. C., Armstrong, D. C., & Pron, G. E. (1992). Craniofacial skeletal measurements based on computed tomography: Part I. Accuracy and reproducibility. *The Cleft Palate-Craniofacial Journal, 29*(2), 112-117. https://doi.org/10.1597/1545-1569_1992_029_0112_csmboc_2.3.co_2

Whyms, Brian J, Vorperian, H. K., Gentry, L. R., Schimek, E. M., Bersu, E. T., & Chung, M. K. (2013). The effect of computed tomographic scanner parameters and 3-dimensional volume rendering techniques on the accuracy of linear, angular, and volumetric measurements of the mandible. *Oral Surgery, Oral Medicine, Oral Pathology and Oral Radiology, 115*(5), 682-691. https://doi.org/10.1016/j.oooo.2013.02.008