J Forensic Sci, November 2008, Vol. 53, No. 6
doi: 10.1111/j.1556-4029.2008.00875.x
Available online at: www.blackwell-synergy.com

Claire Robinson,[1] *B.Sc., M.Sc.; Roos Eisma,*[2] *B.Sc., Ph.D.; Bruno Morgan,*[1] *Ph.D., B.M. B.Ch., M.R.C.P., F.R.C.R.; Amanda Jeffery,*[3] *M.B. Ch.B.; Eleanor A. M. Graham,*[3] *B.Sc., M.Sc., Ph.D.; Sue Black,*[2] *O.B.E., B.Sc., Ph.D., D.Sc., F.R.S.E.; and Guy N. Rutty,*[3] *M.D., M.B.B.S., F.R.C.Path., Dip.R.C.Path. (Forensic), F.F.S.Soc., F.F.F.L.M.*

Anthropological Measurement of Lower Limb and Foot Bones Using Multi-Detector Computed Tomography

ABSTRACT: Anthropological examination of defleshed bones is the gold standard for osteological measurement in forensic practice. However, multi-detector computed tomography (MDCT) offers the opportunity of three-dimensional imaging of skeletal elements, allowing measurement of bones in any plane without defleshing. We present our experiences of the examination of 15 human lower limbs in different states of decomposition using MDCT. We present our method of imaging and radiological measurement of the bones including sex assessment. The radiological measurements were undertaken by three professional groups–anthropology, radiology, and forensic pathology–both at the site of scanning and at a remote site. The results were compared to anthropological oestological assessment of the defleshed bones. We discuss the limitations of this technique and the potential applications of our observations. We introduce the concept of remote radiological anthropological measurement of bones, so-called tele-anthro-radiology and the role that this could play in providing the facility for standardization of protocols, international peer review and quality assurance schemes.

KEYWORDS: forensic science, radiology, computed tomography, anthropology, tibia, talus, calcaneus, tele-anthro-radiology

The anthropological analysis of human remains is an established facilitator for identification, as the examination and measurement of bones can assist with all four primary components of biological identity—sex, age, stature, and race. However, when working with recently deceased, this may require the time-consuming examination of defleshed bones and the presence of a trained anthropologist at the site of the autopsy examination. Radiology, usually in the form of plain X-rays or fluoroscopy, is also an established tool utilized in the investigation of human osteological identification, where, for example, dental imaging or imaging of old fracture sites and prosthesis with antemortem comparison can assist in the identification of an individual (1–3). In recent times, there has been growing interest in the use of computed tomography (CT) for forensic investigations. This has included its use in mass fatality investigations (4,5). The two-dimensional (2D) scout views of CT produce an image similar to that of a plain X-ray, both of which have been used to measure the lengths of long bones (6–12) with variable accuracy, due to difficulty in defining critical anatomical points and the potential for foreshortening of the bone if its long axis is not in the imaging plane. The introduction of multi-detector computed tomography (MDCT) has allowed a significant improvement in three-dimensional (3D) image resolution, to greater than seven line pairs per centimeter in all planes, allowing for consideration of 3D images which can be visualized on dedicated software in *x*, *y*, and *z* planes. The potential to image long and small bones without the need for defleshing, and examine and report the images remotely, could greatly facilitate human identification.

This study was undertaken to consider two questions; could modern day MDCT be used to undertake osteological measurements of fleshed long and small bones with an accuracy comparable to that of traditional anthropological examinations of defleshed limbs and if so could this be practically undertaken using imaging taken at one site and reported at a remote site, i.e., tele-anthro-radiology. Although the gold standard for osteological examination remains the examination of defleshed bones, the use of MDCT as reported here would accelerate the process of anthropological measurement and remove the necessity to clean bones which may be more publicly acceptable. Tele-anthro-radiology would also allow the safe study of contaminated remains (biological, chemical, and radiological), with the use of mobile CT (5). The anthropological examination of bones does not just consist of taking measurements but also in the consideration of natural pathology and bony injury. However, with the continued development of MDCT osteological disease and trauma assessment can be undertaken with both 2D and 3D imaging as occurs within the clinical setting. We have considered the accuracy of measurements by four professional groups, the use of teleradiology to transfer the images for reporting, and the practicalities associated with CT derived measurements.

Materials and Methods

Limbs

The study imaged 15 adult human lower limbs in different states of decomposition, which were donated to the Forensic Pathology Unit, Leicester from male and female adults undergoing surgical amputations after giving fully informed written consent. This study

[1] Imaging Department, Leicester Royal Infirmary, Leicester LE2 7LX, UK.

[2] Centre for Anatomy and Human Identification, University of Dundee, DD1 5EH, UK.

[3] East Midlands Forensic Pathology Unit, University of Leicester, Robert Kilpatrick Building, Leicester Royal Infirmary, Leicester LE2 7LX, UK.

Received 20 Oct. 2007; and in revised form 1 Mar. 2008; accepted 8 Mar. 2008.

forms part of a larger identification study currently being undertaken by the Unit (Ethical permission: LREC 06/Q2501/17, 20/02/2006, and 04/Q2501/64).

Imaging

All limbs were imaged within sealed labeled plastic bags by MDCT using a 16-detector GE LightSpeed CT scanner (GE, Chalfont St. Giles, Buckinghamshire, UK). The use of multi-slice scanners makes the use of thin slice widths and 3D reconstructions easier than for single slice technology (5). Each scan was undertaken as a full helical 0.6 sec scan using a 1.25 slice thickness, kV 120, and mA 100 with bone and soft tissue reconstructions at 1.25 mm. The number of images ranged from 454 to 1233 per limb depending upon the size of the limb. All images were transferred in DICOM format for analysis to two different workstations (Voxar 3D; Barco, Kortrijk, Belgium and GE advantage windows; GE). All images were checked by a consultant radiologist (BM) prior to defleshing of the limbs. From previous experience the limb must be placed on a foam pad to ensure distinction between the limb and the table during subsequent computer analysis. Figure 1 shows two pictures of the same bone, a virtual image generated from CT data and a photograph of the defleshed bone superimposed on a clear black background.

Radiological Measurement

Radiological measurements were made by a radiographer (CR), a radiologist (BM), a trainee forensic pathologist (AJ), and a forensic anthropology graduate (RE). The trainee forensic pathologist had little experience in anthropological or radiological measurements. The time taken to undertake the measurements and observations related to the ease of the assessment were recorded.

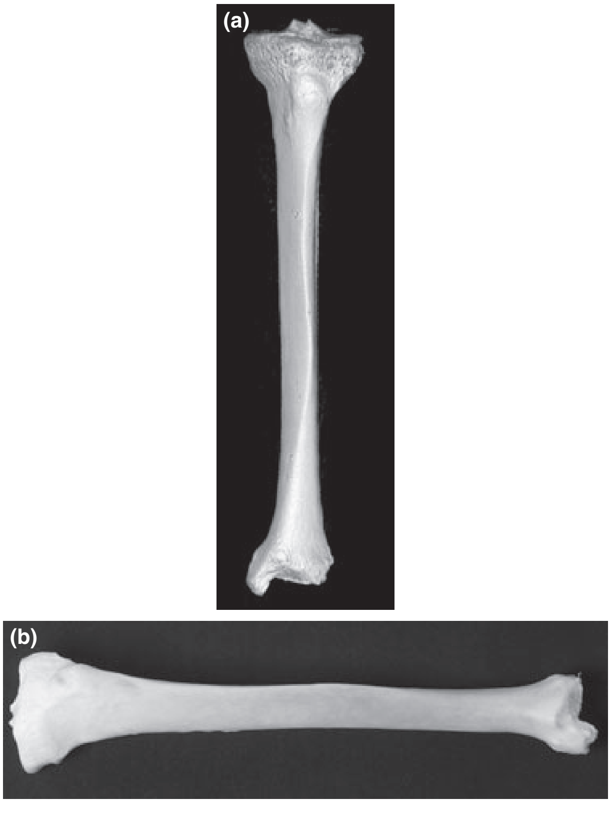

FIG. 1—*(a) A virtual image of a tibia created from CT image data and (b) a photograph of the same bone after defleshing. The photograph is superimposed on a black background for comparison but otherwise unaltered. Note that the images appear different at the ends of the bone. This is because a photograph views the bone from a "point source" which causes perspective changes to the ends of the bone. These do not occur for the picture from CT images due to their parallel acquisition.*

Osteological measurements of lower limb bones using CT have not been reported before and thus there was no defined method to apply to this study. Therefore the radiological measurements method attempted to replicate those taken using an osteometric board or callipers (13–15). This involved taking measurements in planes based on how the bone would lie on an osteometric board (Fig. 2). The image processing used 3D reconstructed images using a "transparent bone" algorithm for the GE software (BM) or 3D multi-planar reconstructed images in the "bone" window for Voxar (CR, AJ, RE). Most CT analysis software packages are capable of these techniques. To ensure that measurements were taken in the correct plane and between the correct points, the bones were rotated using the image viewing software. Figure 3 demonstrates the landmarks used to measure the tibial length and breadth using a 3D "transparent bone" setting. This method allows manipulation of the 3D image in any plane to form a 2D image similar to that from a standard radiograph. Therefore, although a 3D image is used, landmarks can be identified, even if obscured by other bony structures. The 3D image was manipulated by eye to correlate with the plane that the bone would lie in on the osteometric board. The other technique used involved creating a multi-plane reconstruction (MPR) from the 3D data set (a sequence of incremental slices created in any plane). The plane used was based on the three points on which the bone would be expected to lie and parallel incremental slices were then scrolled through to obtain the relevant maximum dimensions, or a perpendicular set of images was reconstructed to give the maximum height. Figure 4 shows both the MPR and "transparent bone" approach for a calcaneum. All measurements were made to the nearest millimeter.

Tibia

The base plane of the tibia is defined at the proximal end by two points on the posterior aspect of the medial and lateral condyles, and on the distal end by a single point along the posterior border of the fibular notch. The base axis lies along the long axis of the bone. Both length and width were measured in this plane. The distal point for length measurement was the distal tip of the medial malleolus. At the proximal end the inter-condylar eminence was excluded, as is standard procedure for some tibial measurements. The width measurement was taken from the maximum width at the medial malleolus to the anterior border of the fibular notch (Fig. 3).

Calcaneus

The base plane of the calcaneus is defined by three points on the plantar (inferior) surface of the bone (Fig. 4). Measurements

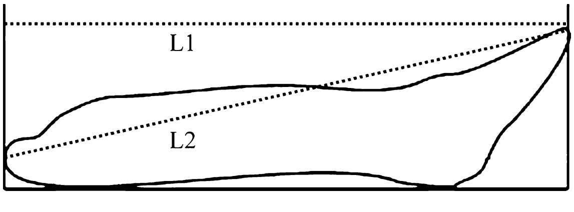

FIG. 2—*A diagrammatic representation of a lower limb, as if lying on the osteometric board. The measured distance (L1) is parallel to the board, not maximum distance between the extremities (L2).*

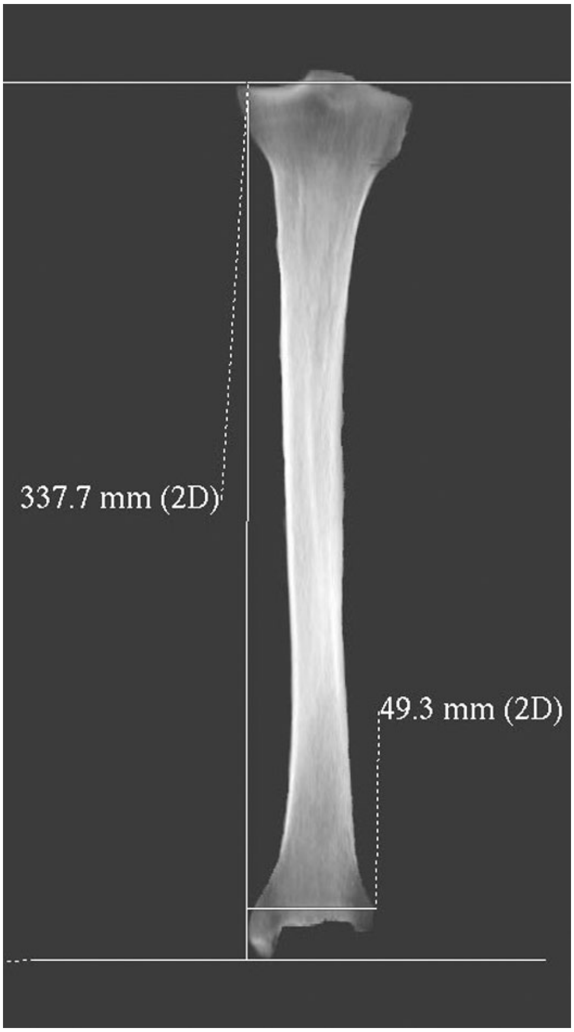

FIG. 3—*A "transparent bone" image, created from a 3D volume rendered reconstruction of CT image data, demonstrating the landmarks for tibial measurements.*

were taken of the length and height of the bone. There was however variation in where exactly the lowest points were located: sometimes the posterior side formed a ridge rather than two distinct points, and sometimes the articular surface for the cuboid extended further down than the anterior tubercle.

Talus

The talus is an irregular bone that is difficult to align, both during a physical measurement and using CT images. There is also individual variation in shape. The base plane lies along the plantar (inferior) surface. The three landmarks that define the plane are the medial and lateral side of the posterior calcaneal articular surface and the anterior calcaneal articular surface. This is not the normal anatomical position, but represents how the bone rests on a surface. The remaining measured length is taken along the longest axis, normally from the lateral tubercle on the infero-posterior rim to the middle of the articular surface for the navicular bone. This axis is not easy to define. The height was measured from the base plane to the highest point which was usually found along the lateral malleolar surface.

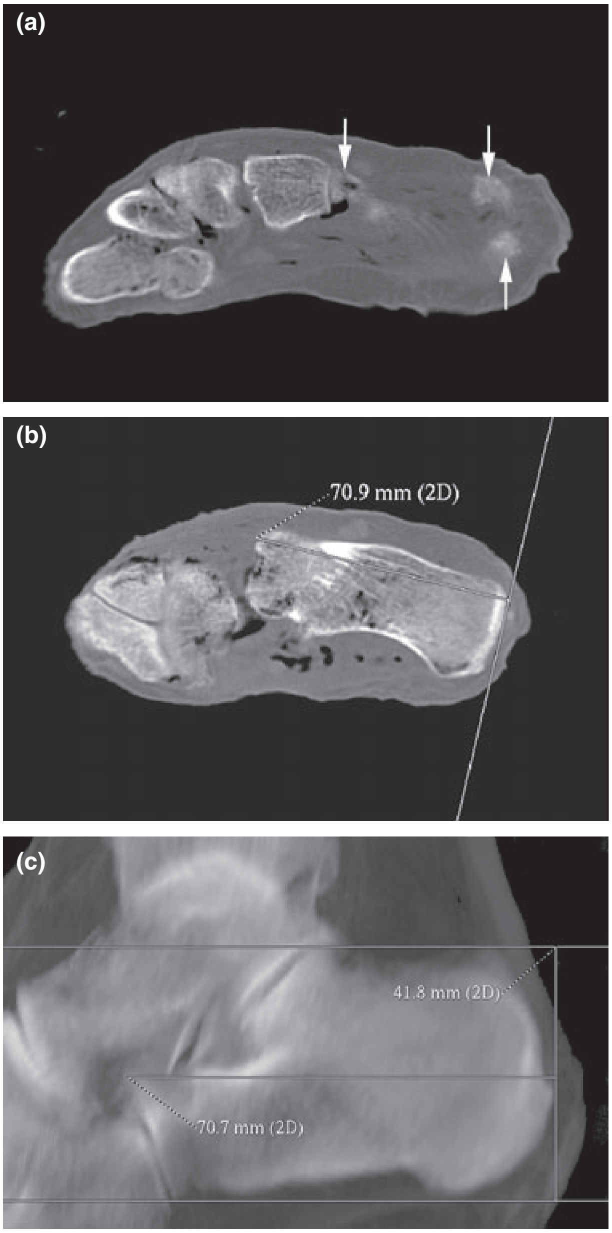

FIG. 4—*(a) The three landmarks used for the base plane for a multi-planar reconstruction (MPR) of the 3D image data set for the calcaneus, (b) scrolling through the parallel image slices created in this plane allows measurement of maximum length of the calcaneus, and (c) the same measurement for this bone using the "transparent bone" technique.*

Maceration

Following radiological imaging the tibia, fibula, talus, and calcaneus were removed from the limbs using standard mortuary bladed instruments. Care was taken not to damage the bone or cartilaginous surfaces. The bones were then cleaned of residual soft tissue by the use of domestic washing powder solution at 60°C using the method described by Mairs et al. (12). Following tissue clearing, the bones were air dried at room temperature prior to measurement.

Osteology Measurements

Osteological measurements were undertaken by a forensic anthropologist (SB) using an osteometric board and/or callipers depending upon the bone. All measurements were made to the nearest mm.

Sex Assessment

Sex was assessed both osteologically and radiologically using "cut off" points as described in previous studies of calcaneal and talar length (16,17).

Tele-Anthro-Radiology

Each limb image data set was uploaded from the Leicester Forensic Pathology Unit computer into a secure internet-based xdrive file store. The time taken to upload each data set was recorded. Access was then granted to the researchers in Dundee who downloaded each image directory in turn into Voxar 3D at this site. Again the time taken to undertake this procedure was recorded.

Statistics

CT measurements were compared with the gold standard, i.e., measurement by a trained and experienced forensic anthropologist. A mean error was calculated for each measurement for the 15 cases to assess any overall differences between the two techniques. This was further assessed by calculating the mean within-subject standard deviation (WSD) for all the CT measurements in comparison to the gold standard and taking the mean of the WSD. The mean WSD × 1.96 gives the limits within which 95% of the CT measurements will fall from the gold standard (18). The consistency of the different reviewers using CT measurements was also assessed by calculating an average "scaled error index" (SEI) in order to compare with previously reported variations in osteometric board measurements (19). This was performed by taking the percentage difference of each CT measurement in comparison to the median of the four CT measurements for each bone and averaging the individual results to give an average SEI, expressed as a percentage.

Results

Imaging

It took ~5 min to scan each limb. As the limb can be scanned through sealed bags, contamination, visual unpleasantness, and health and safety issues related to the handling of fresh or decomposing tissues, as can be experienced with the use of plain X-ray and fluoroscopy, was avoided. Foreign items in the bags such as surgical dressings that could render radiological visualization of the bones difficult can be electronically removed from the images in postprocessing. Depending upon the donation the limbs were either fresh, in different states of decomposition, or frozen following storage, none of which affected the imaging process. However, if the feet are not in their normal anatomical position prior to freezing this makes recognition of bony landmarks more time consuming.

Tele-Anthro-Radiology and Analysis Time

The time taken to upload and download the images is dependent upon the computer used, the type and speed of internet connection, and the traffic on the local network. Theoretically for 1000 DICOM images, each 0.5 Mb in size the download time would range between 40 sec and 1/2 h for network speeds ranging from 100 Mb/sec to the standard telephone line broadband of 2 Mb/sec. Standard broadband teleradiology systems therefore use image compression techniques to decrease image transfer times. In our experience a 1000 DICOM format image set took ~10 min to upload and 5 min to download. The use of satellite broadband and WiFi systems as could be used with mobile CT at a mass fatality incident were not tested on this occasion but would benefit from using image compression techniques to aid transfer times.

The time taken to report the images is dependent upon the experience of the operator and was found to be at most 10 min per case, although this time was increased if an attempt was made to exactly duplicate the plane of the bone lying on three points on the osteometric board as shown in Fig. 4. Thus, this system theoretically allows for the anthropological measurement of a fleshed lower limb comprising of 1000 images at a remote site ~20–30 min following scanning.

Radiological Measurement

The measurements are shown in Table 1.

Nine of the 15 tibiae were incomplete as they were from below knee amputations. In these cases measurements were still taken of the maximum tibial length in a similar method. The bone was aligned in the position it was expected to have been had it been complete. Two legs had metal knee implants which can interfere with alignment and measurement due to the presence of streak artifacts on CT and that the joint also has a different shape from the original bone. The tibia in case 6 had a distinctive spur on the medial side of the medial malleolus and this was included in the measurement.

The calcaneus poses different problems to those associated with the tibia. Some of the extreme points are close to articulations with other bones (talus and cuboid), and can be on a spur next to the articular surface. This can be difficult to resolve, especially as the talus often has a spur (the lateral tubercle) covering the calcaneus. The landmarks used are in more variable positions and it can be difficult to select the right one from a number of possibilities—this may involve a number of measurements at different locations. Image slices need to be thin near articulations, but this can make the spur faint; and cause discrepancy between the osteometric board and CT image measurements.

In cases where there were degenerative changes or deformities in the ankle, measurement was considered more difficult but this did not increase the measurement time significantly. Measurements for the talus were more difficult due to the presence of degenerative change, talo-calcaneal fusion in one case, and the complex anatomy of the bone which made alignment difficult.

The results show no evidence of significant difference in the use of CT or the osteometric board for the measurements. Ninety-five percent confidence limits of the difference between CT and the osteometric board measurements were generally similar for all measurements at ±5 mm except for talar length at ±7 mm.

The average WSD was also calculated for the individual observers for all bones giving 95% confidence limits of 3.3 mm for the anthropology graduate, 4.5 mm for the radiologist, 5.8 mm for the radiographer, and 6.6 mm for the trainee forensic pathologist.

Sex Assessment

Using calcaneal length and a "cut off" of 86 mm, 11 of the 15 (73%) calcaneal bones were correctly sexed by physical measurement and by CT measurement from 10 to 11 out of 15 (67–73%) were correctly assessed. This is close to the reported accuracy of

TABLE 1—*Bone measurements taken with an osteometric board compared to those taken by four different readers using CT images.*

	Osteometry Board	R1	R2	R3	R4	Average	Error	Mean Error	95% CI of Difference	SEI
(a) Tibia										
Tibia length (mm)										
1	361	359	356	360	365	360	1	0.9	4.8	0.58
2	270	271	269	279	270	272	−2			
3	336	338	338	330	337	336	0			
4	418	417	419	419	418	418	0			
5	305	307	305	307	311	308	−3			
6	276	274	275	277	276	276	1			
7	276	277	275	276	277	276	0			
8	230	231	224	223	227	226	4			
9	274	275	273	275	275	275	−1			
10	252	255	256	248	255	254	−2			
11	283	278	281	277	283	280	3			
12										
13	406	400	397	401	401	400	6			
14	312	307	309	307	312	309	3			
15	238	237	237	233	238	236	2			
Tibia width (mm)										
1	49	52	52	50	50	51	−2	0.0	3.5	2.34
2	51	51	51	49	51	51	1			
3	48	50	50	48	49	49	−1			
4	62	61	61	65	62	62	0			
5	45	44	46	47	45	46	−1			
6	59	56	56	50	58	55	4			
7	56	55	55	52	55	54	2			
8	48	44	49	46	48	47	1			
9	52	52	52	47	54	51	1			
10	55	55	54	50	56	54	1			
11	55	58	54	55	55	56	−1			
12	52	51	52	49	54	52	1			
13	47	55	52	49	53	52	−5			
14	56	54	57	58	54	56	0			
15	52	52	52	52	52	52	0			
(b) Calcaneus										
Calcaneus length (mm)										
1	74	75	67	65	77	71	3	1.8	5.3	3.15
2	80	80	78	81	82	80	0			
3	72	68	72	71	74	71	1			
4	96	98	95	97	97	97	−1			
5	81	80	81	80	83	81	0			
6	84	83	81	78	83	81	3			
7	82	76	81	70	82	77	5			
8	79	78	80	69	81	77	2			
9	82	76	82	72	84	79	4			
10	89	86	90	86	92	89	1			
11	92	91	92	93	90	92	1			
12	87	83	90	81	88	86	2			
13	86	84	82	82	87	84	2			
14	90	95	91	84	91	90	0			
15	86	82	81	72	82	79	7			
Calcaneus height (mm)										
1	46	47	46	43	45	45	1	0.3	4.7	3.96
2	47	46	49	49	49	48	−1			
3	42	38	40	41	41	40	2			
4	54	57	59	60	56	58	−4			
5	39	45	40	38	41	41	−2			
6	52	53	51	51	53	52	0			
7	48	51	50	46	47	49	−1			
8	44	44	43	40	43	43	2			
9	50	39	50	44	50	46	4			
10	54	52	57	52	57	55	−1			
11	58	46	57	53	55	53	5			
12	48	48	42	49	43	46	3			
13	43	47	47	49	43	47	−4			
14	52	50	57	51	55	53	−1			
15	47	48	47	46	45	47	1			
(c) Talus										
Talus length (mm)										
1	53	59	50	55	56	55	−2	1.0	7.4	3.86
2	59	65	57	56	60	60	−1			
3	54	50	53	53	56	53	1			
4	76	81	77	69	80	77	−1			

TABLE 1—*Continued.*

	Osteometry Board	R1	R2	R3	R4	Average	Error	Mean Error	95% CI of Difference	SEI
5	55	65	53	58	56	58	−3			
6	67	56	53	54	61	56	11			
7	60	63	60	59	62	61	−1			
8	55	59	57	55	58	57	−2			
9	56	51	58	48	56	53	3			
10	70	71	73	73	71	72	−2			
11	62	65	63	66	64	65	−3			
12	64	52	55	56	54	54	10			
13	65	51	59	56	66	58	7			
14	65	72	65	66	67	68	−3			
15	57	58	56	55	58	57	0			
Talus height (mm)										
1	32	34	28	34	36	33	−1	0.5	4.8	5.65
2	34	36	32	30	36	34	1			
3	31	30	29	31	33	31	0			
4	41	40	38	37	41	39	2			
5	32	30	30	34	34	32	0			
6		34	31	29	34	32				
7	33	35	33	36	35	35	−2			
8	31	38	32	27	32	32	−1			
9	32	35	31	31	33	33	−1			
10	37	37	45	37	38	39	−2			
11	35	33	36	34	35	35	1			
12	35	34	32	30	36	33	2			
13	41	32	33	28	37	33	9			
14	34	41	32	33	36	36	−2			
15	30	27	28	29	31	29	1			

95% CI of the difference and SEI are defined in the Statistics section. (a) Tibia, for case 12 a knee replacement was removed during processing making tibial length measurement invalid; (b) calcaneus; and (c) talus, for case 6 due to bone fusion the height measurement could not be made for the physical measurements. R1, radiographer using CT software; R2, radiologist using CT software; R3, trainee forensic pathologist using CT software; R4, forensic anthropology graduate using CT software; SEI, scaled error index; CT, computed tomography.

80% for this method by direct anthropological measurement (16). For the talus using a "cut off" of 52 mm, only seven subjects were incorrectly assigned by both CT and physical examination (46.7%); this was uniformly due to assignment of male sex due to the "cut off" being too low. This was assumed to be due to different measurement protocol. Using a different "cut off" of 58 mm resulted in correct sex assignment in 13 out of 15 (87%) and from 11 to 14 out of 15 (73–87%) for CT measurement. Again this is compatible with the reported 81% accuracy of this method (17).

Discussion

This study demonstrates that there is no significant difference in the measurements taken by CT when compared with measurements of defleshed bones by direct osteometric methods. Any variations are likely to be due to inter-observer variability in identifying bony landmarks and alignment in both techniques. This variability suggests errors with 95% confidence limits of 5 mm (7 mm for talar length). This study also showed the narrowest 95% confidence intervals for the anthropology graduate perhaps indicating a more consistent alignment of the bone to the planes used with the osteometric board and, second, the radiologist who aligned the bones by eye to mimic the osteometric board but who had more imaging measurement experience. There are few similar studies of inter-observer variability in osteological measurement but comparison with a previous study by Adams and Byrd shows that our "SCI" of 0.58% for talar length compares well with their experience of 0.58% for observers with 10+ years experience. Although they did not measure the calcaneus and talus, the SEI of ~2–6% we found agrees well with their observations for irregular small bones. This suggests that CT measurements are equivalent to those using the osteometric board with similar inter-observer variability. Both tests showed similar results when measurements were used to predict sex.

This study illustrates how images can be sent to a remote site with an anthropological examination being completed in ~25 min after scanning. The use of "teleradiology" opens up the possibilities for anthropological assessment of contaminated body parts at remote safe sites, rapid international peer opinion, external quality assurance schemes, and the international collection of population data.

We chose to use donated lower limbs as they provided a model for both long and small bones, the latter of which may be time consuming and technically challenging to deflesh for anthropological assessment. Whole and partial limbs can be encountered for example in dismemberments or incidents of body disruption as can occur in mass fatality events. The use of both types of limbs caused difficulties for both the anthropological and radiological assessment of the tibiae although we demonstrate how we overcame this and how MDCT can be used to replicate the use of an osteometric board and callipers for partial bone measurement. Thus, our results support that MDCT can be considered to provide comparable accuracy for the measurement of bones.

Thus, this brings into question who is the best person to undertake such examinations? An anthropologist who can be trained to use the software and understands the systems used for anthropological assessment or a radiologist who not only can be trained in anthropological measurement but also is used to reporting natural and pathological disease, bony trauma as well as estimating age of an individual from radiological images. As CT is a gold standard in clinical imaging, the comparison of ante- and postmortem CT images may overtake the present role of plain X-ray comparison in the future, although the person undertaking the investigation must have osteological, radiological, and forensic training.

A number of problems were encountered during the study in relation to the use of MDCT. First the assessment is dependent upon the type of software used. Differences were observed between different CT image analysis software in relation to the image handling and measurements. Many of these obstacles can be overcome by increased experience in using the software but there is no doubt that defining standard approaches in terms of image processing and measurement will be important. Locating the edge of the bone was at times difficult, which was attributed to either bone quality or image definition. A reduction in bone density as can occur in later life may lead to difficulty in image assessment. Small bones which were fused by natural pathology proved difficult to separate into different bones, although this is the same for anthropological examination. To date there are no published internationally agreed protocols in relation to anthropological forensic radiological measurement of bones although there are also problems in relation to the consistency of acquiring physical measurements (19). By sharing our methods, we have shown that these measurements can be achieved with MDCT and in the future standardized, possibly with different criteria to those for physical measurement. However, development of new standards for CT measurement would require validation possibly by using recognized anthropological collections (20) or by using data from clinically acquired CT scans.

Thus, in summary, this study illustrates how modern MDCT can be used to provide comparable measurements of large and small bones without the necessity to deflesh the bones. We recommend that the imaging, which could be undertaken at a scene or temporary mortuary using mobile CT or in a permanent clinical setting, should be performed with a MDCT scanner, imaging at no greater than 1.25 mm. The measurements can be taken at the site of scanning or a remote site using dedicated CT software. This can be undertaken by either a radiologist who understands anthropological assessments or an anthropologist trained in the use of the software and who has an understanding of CT images. By using fleshed bones the process is quicker than traditional anthropological assessment and has both public and health and safety benefits to the operators. Finally, the use of such images will allow the international community to build up and maintain population data with regards to radiological osteological assessments as well as providing the facility for standardization of protocols, international peer review, and quality assurance schemes.

Acknowledgments

We wish to thank Drs. Ralph Bouhaidar and Russell Delaney for their assistance.

References

1. Kahana T, Hiss J. Forensic radiology. Br J Radiol 1999;72(854):129–33.
2. Kahana T, Ravioli JA, Urroz CL, Hiss J. Radiographic identification of fragmentary human remains from a mass disaster. Am J Forensic Med Pathol 1997;18(1):40–4.
3. Harcke HT, Bifano JA, Koeller KK. Forensic radiology: response to the Pentagon attack on September 11, 2001. Radiology 2002;223(1): 7–8.
4. Sidler M, Jackowski C, Dirnhofer R, Vock P, Thali M. Use of multislice computed tomography in disaster victim identification—advantages and limitations. Forensic Sci Int 2007;169 (2–3):118–28.
5. Rutty GN, Robinson C, Jeffrey A, Morgan B. Mobile computed tomography for mass fatality investigations. Forensic Sci Med Pathol 2007;3(2):138–45.
6. Helms CA, McCarthy S. CT scanograms for measuring leg length discrepancy. Radiology 1984;151(3):802.
7. Harris I, Hatfield A, Walton J. Assessing leg length discrepancy after femoral fracture: clinical examination or computed tomography? ANZ J Surg 2005;75(5):319–21.
8. Anderson NG, Fenwick JL, Wells JE. Intrinsic measurement bias on computed tomography scout view is unpredictable: computed tomography pelvimetry using a phantom. Australas Radiol 2006;50(2): 127–31.
9. Aaron A, Weinstein D, Thickman D, Eilert R. Comparison of orthoroentgenography and computed tomography in the measurement of limb-length discrepancy. J Bone Joint Surg Am 1992;74(6):897–902.
10. Verhoff MA, Ramsthaler F, Krähahn J, Deml U, Gille RJ, Grabherr S, et al. Digital forensic osteology–possibilities in cooperation with the Virtopsy((R)) project. Forensic Sci Int 2008;174 (2–3)::152–6.
11. Dedouit F, Telmon N, Costagliola R, Otal P, Joffre F, Rouge D. Virtual anthropology and forensic identification: report of one case. Forensic Sci Int 2007;173 (2–3):182–7.
12. Mairs S, Swift B, Rutty GN. Detergent: an alternative approach to traditional bone cleaning methods for forensic practice. Am J Forensic Med Pathol 2004;25(4):276–84.
13. Buikstra JE, Ubelaker HD. Measurement of adult remains. In: Buikstra JE, Ubelaker HD, editors. Standards for data collection from human skeletal remains: proceedings of a seminar at the Field Museum of Natural History. Arkansas: Arkansas Archeological Survey, 1994.
14. Moore-Jansen PM, Ousley SD, Jantz RL. Data collection procedures for forensic skeletal material. Report of investigations. Knoxville, TN: University of Tennessee, 1994; Report No. 48.
15. Holland TD. Estimation of adult stature from the calcaneus and talus. Am J Phys Anthropol 1995;96(3):315–20.
16. Riepert T, Drechsler T, Schild H, Nafe B, Mattern R. Estimation of sex on the basis of radiographs of the calcaneus. Forensic Sci Int 1996;77(3):133–40.
17. Steele DG. The estimation of sex on the basis of the talus and calcaneus. Am J Phys Anthropol 1976;45(3 Pt. 2):581–8.
18. Bland JM, Altman DG. Statistics notes. 21. Measurement error (vol. 312, pg. 1654, 1996). Br Med J 1996;313(7059):744.
19. Adams BJ, Byrd JE. Interobserver variation of selected postcranial skeletal measurements. J Forensic Sci 2002;47(6):1193–202.
20. Hunt DR, Albanese J. History and demographic composition of the Robert J. Terry anatomical collection. Am J Phys Anthropol 2005; 127(4):406–17.

Additional information and reprint requests:
Professor Guy N. Rutty, M.D., M.B.B.S., F.R.C.Path., Dip.R.C.Path. (Forensic), F.F.S.Soc., F.F.F.L.M.
Forensic Pathology Unit
University of Leicester
Robert Kilpatrick Building
Leicester Royal Infirmary
Leicester LE2 7LX
United Kingdom
E-mail: gnr3@le.ac.uk