Original Article

Title

The use of mid-arm circumference for the estimation of adult body weight: A post mortem computed tomography approach

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Abstract

Purpose: Cadaver body weight (BW) is to be documented, where possible, in all forensic autopsy examinations. However, it may not always be possible to ascertain an accurate BW if, for example, functioning weighing equipment is unavailable or the body is incomplete. This research aimed to translate an adult clinical prehospital method which uses a mid-arm circumference (MAC) measurement to estimate BW to establish a post mortem computed tomography (PMCT) technique for adult cadaver BW estimation.

Method: The clinical method was adapted for PMCT bone and soft tissue methods. Right and left MAC measurements were obtained by four independent observers from sixty-six (45 males and 21 females) consented research adult PMCT scans using the Osirix DICOM viewer. All observers rated MAC quality score on each arm from 0 (very poor) to 3 (good).

Results: In the final group of fifty-five with MAC quality score ≥ 1, MAC measurements correlated well with actual BW (r=0.87) and yielded excellent intra- and inter-observer reliability. There were no statistical differences between the two MAC methods, sexes or side of arm. Mean estimated BW by previous study Equation, BW=(4×MAC)-50, was 0.47 kg greater than mean actual BW with limits of agreement of 12.7 kg; this would be reduced to 9.2 kg if an outlier were excluded.

Conclusions: The study identifies a quick and easy PMCT technique to estimate adult BW using PMCT. However, the result remains only an estimation and caution should be expressed if a result is applied to medico-legal cases.

Introduction

United Kingdom [1] and European [2] wide forensic post mortem examination guidelines require a cadaver body weight (BW) to be recorded in all cases. This weight has a number of possible applications, including assisting in the identification of an individual, calculating a Body Mass Index (BMI), assisting with the interpretation of internal organ weights, as well as toxicological result interpretation and the estimation of time since death using post mortem body cooling [3–5]. Post mortem BW is generally obtained using either calibrated floor or trolley-based measuring scales. The scales should be regularly calibrated, and the body weighed naked. This important autopsy parameter may, on occasion, not be recorded, for example, because the pathologist or mortuary assistant neglects to undertake this task, weighing scales are unavailability or non-functioning or the body is incomplete. Failure to record a BW may cause problems downstream of the autopsy. A BW different to that in life may cause concern to the surviving relatives and lead to a complaint in relation to the conduct of the examination.

The process of BW estimation rather than actual measurement is commonly used in clinical practice, especially in paediatric, prehospital and emergency department practice where weighing facilities may not be readily available, or the patient may not have the capacity to provide their own BW, for example an unconscious trauma patient [6,7]. Several methods have been published to try and predict an adult patient's BW, such as by thermal imaging camera [8] or using anthropometric indices such as height, abdominal circumference, and thigh circumference [9–12]. Mid-arm circumference (MAC) has been re ported to show the strongest correlation with patient's BW among other anthropometric parameters [13] and has been commonly designated as an independent value in adult BW prediction Equations. An example of the BW prediction formulae in adults and children is the simple MACalone based model of Cattermole et al. [13],

(1) $$BW\ of\ combined\ sex_{(kg)} = (4 \times MAC_{(cm)}) - 50$$ [13]

Where an accurate BW is not available a recent clinical CT or postmortem CT scanning (PMCT) may assist. Previous methods have been reported including cumbersome segmentation of whole body CT data [14] or using whole body density estimations performed for CT auto modulation of x-ray tube current [15]. However, both rely on an intact body. There is a clear relationship between BW and height [16]. In clinical practice a BW estimation method for obese individuals using the anthropometric data of MAC and height has been previously reported by Crandall et al. [12].

$$BW_{(kg)} = (2.45 \times MAC_{(cm)}) + (0.6 \times HT_{(cm)}) - 105 \quad [12] \tag{2}$$

We propose that cadaver MAC measurement would be a simple and quick method of estimating BW by PMCT and therefore be a useful method of BW estimation where, for example, functioning weighing equipment is unavailable or the body is incomplete.

Methods and materials

Ethics and case selection

The research was conducted with approval of the local research ethics committee (amendment to original approved submission ref: 04_Q2501_64) and was supported by the local coroners' offices. A 50- case consented dataset which had formed the basis of a previously published research study was used for the initial method development and assessment [17]. As it was found that not all cases in this set had complete right and left arms image datasets, further cases which had been authorised for PMCT investigation by the East Midlands Forensic Pathology Unit were recruited into the study. All cases had a BW and heel-crown height recorded in the mortuary using a trolley-based weighing system (LEEC, Nottingham, United Kingdom).

Post-mortem computed tomography scanning

The PMCT images were obtained using a Toshiba Aquilion 64-slice multidetector CT scanner (Toshiba, Japan). The CT scanning parameters for the scans of the body including upper limbs were as follows: 300 mA, 120 kVp, rotation time 0.5 s, pitch 0.828, slice thickness acquisition 0.5×64 mm, matrix 512×512 pixels and image reconstruction at 2-mm slice thickness/1.6-mm interval using both soft tissue and bone windows.

PMCT MAC measurement

The MAC measurement was performed using OsiriX MD version 7.0.2 64-bit (Pixmeo, Switzerland) blind to the actual cadaver weights. Where possible, both arms were measured. Measurements were made by a forensic anthropologist, two forensic pathologists and one forensic radiologist, all with PMCT experience. All observers commented on their ability to perform measurements on each arm. These comments were summarised to a "quality score" for each arm defined by "3": a good measurement, "2": sub-optimal measurement, "1": poor identification of landmarks and "0": either very poor identification of landmarks or no accurate measurement possible.

Measurements were based on the clinical MAC measurement method described by Cattermole et al., [13], where MAC is measured at the midpoint between the acromion and olecranon processes. Threedimensional multiplanar reconstructions (3D MPR) were orientated to show the acromion, humerus and olecranon and the mid-point was identified on PMCT in two different ways (Fig. 1):

1. Soft tissue (clinical) method: Midpoint of a line from the soft tissue at the tip of shoulder over the acromion to the soft tissue over the olecranon process.
2. Bone method: Midpoint of a line from the upper bone surface of the acromion and lower surface of the olecranon.

Using the "closed polygon tool" the circumference at the midpoint was measured and the BW estimated (Eq. (1)).

One observer who is a forensic anthropologist measured all cases whilst the other observers did not measure cases where they were not confident in identifying the appropriate landmarks. A second observer, one of the forensic pathologists, also measured cases twice to record intra-observer repeatability. These two observers also measured cases using 2 methods above, whilst the remaining simply used the "bone method".

Statistical analysis

Data were collated in an excel spreadsheet and statistical analyses was done either on Microsoft Excel (Microsoft 2019) or the Statistical Package for the Social Sciences (SPSS) Statistics software version 24 (International Business Machines Corporation (IBM), Armonk, USA).

MAC measurements were assessed for agreement for the "bone" and "soft tissue" methods, between limbs, between observations for the same observer (intra-observer agreement) and between observers (inter-observer agreement). Variation is given as mean difference (showing any systematic over or under measurement), within subject standard deviation (wSD), and limits of agreement (LOA = 1.96*wSD). MAC measurements were then assessed for correlation with actual BW at autopsy using Pearson's correlation coefficient (r) with 95% confidence interval. Data were also stratified based on quality score for the measurement.

BW were then estimated by Eq. (1) for all limb measurements and then assessed for agreement with actual BW. Agreement was presented in Bland–Altman plot with mean difference (showing any systematic over or under measurement), within-subject standard deviation and limits of agreement (1.96×SD).

The data were also checked as to whether measurement error was proportional to magnitude of measurement, where assessment of percent error may be more appropriate. Finally, Eq. (2) using height as well as MAC was also used to test whether it improves correlation with BW.

Results

The final study population consisted of 66 subjects with at least one arm available to measure on PMCT images (Table 1). All bodies were intact for purposes of BW measurement in the mortuary.

Thirty (45.5%) of the study population died of unnatural death including from road traffic collisions (23 cases), asphyxia, drowning, and thermal injury. One severely decomposed case with unascertained cause of death was included into this study. The remaining 36 (54.5%) cases died from natural causes.

Comparison of the bone and soft tissue method of MAC revealed almost perfect correlation ($r=0.995$, $p<0.00001$) and mean error of 1.7 mm, 0.55% of the mean MAC measurement of 301.5 mm. The bone measurement, performed by all observers, is therefore used for the rest of the analysis.

Comparison of right versus left arm measurements also shows strong correlation ($r=0.926$, $p<0.00001$). Although the mean right arm measurement is slightly bigger than the left (between 2.4 and 9.4 mm depending on observer), as might be expected, there is no difference between the correlation of MAC measurement and actual BW based on side measured. It was therefore considered appropriate to substitute a left arm measurement if, for example, the right arm measurement was not measured, considered unsatisfactory or the right upper arm was incomplete or absent (score = 0).

MAC measurements correlated well with actual BW ($r=0.75$), but correlation was improved to $r=0.87$ (95% confidence intervals (CI) 0.78 to 0.94, $p<0.00001$) if the 11 cases with a bilateral "quality score" of zero were excluded. The left arm measurements were used in the 4 cases where the right arm score was zero (Fig. 2). All subsequent analysis uses measurements with a quality score >0. Most of these cases were due to the limb not being fully in the imaged field of view, as the scans were not specifically "protocolled" to include the arms. In some cases, the difficulty was due to burns, decomposition or fractures.

There was no difference between the correlation of MAC and BW for the 55 cases between scores of 1,2 and 3, suggesting as long as landmarks are identifiable it is worth taking the measurement. The right arm MAC had better correlation to BW than the left, r= 0.87 (95% CI 0.76–0.94) and 0.81 (95% CI 0.69–0.90), respectively, but this was not statistically significant. Correlation was also better for female sex than male, 0.91 (95% CI 0.79–0.96) and 0.84 (95% CI 0.70–0.94), respectively, but again this was not statistically significant.

Intra observer repeatability was good with a within-subject standard deviation (wSD) of 4 mm. and limits of agreement (1.96*wSD, LoA) = 7.9 mm. Inter-observer repeatability calculated for all 4 observers, based on cases with scores 1–3, showed a wider wSD of 9.04 mm and LoA of 17.7 mm.

Although correlation of MAC and BW is shown to be strong, this does not show how accurately MAC can be used to predict BW, if a direct weight measurement is not available. Fig. 3 shows a Bland– Altman plot of measurement error where BW is estimated from the mean MAC from all observers plotted against the actual measured BW. There is no relationship of magnitude of error to magnitude of measurement. The data show mean estimated measurement 0.47 kg greater than mean actual measurement with limits of agreement of 12.7 kg. Therefore, most measurements would be expected to fall within 12.7 kg of the actual measurement, 17.9% of the mean measured weight of 71.1 kg.

There is one significant outlier where MAC estimates weight 40 kg lower than measured. This is a case of polydrug toxicity with recorded height of 174 m and weight 73.6 kg indicating a BMI of 24.3 kg/m2, which would be the upper limit of healthy weight. Review of the CT images (Fig. 4) suggests this is an inaccurate mortuary weight measurement. LoA would be 9.2 kg if this case were excluded.

Use of both height and MAC to estimate BW using Eq. (2) [12] results in a slightly increased correlation coefficient for estimated vs actual BW than Eq. (1) [13], r= 0.90 (95% CI 0.82–0.95) and 0.86 (95% CI 0.73–0.93), respectively, but this was not statistically significant.

Discussion

Even though a BW is recommended to be recorded by professional organisations in all medico-legal autopsy records [1,2] and forms part of the INTERPOL disaster victim identification (DVI) form, there are several reasons why it may not be recorded. As a result, several methods for the estimation of the deceased's BW have been developed. For skeletal remains, the stature/bi-iliac breadth method by Ruff et al., has become a standard method for weight prediction [16].

This present study successfully translates a clinical method of Cattermole et al., [13], for estimating BW by measuring mean arm circumference, from post-mortem CT scans. The data show that there is no systematic over or under estimation of predicted weight using their formula on measurements created from CT scan images and these predicted weights will usually be within 12.7 kg of the actual measured weight, which is 17.9% of the mean measured weight of 71.1 kg. The variation in estimated weight calculated from different observers is small compared to the magnitude of the difference between actual and estimated BW. This implies that measurement operator and method were not the factors affecting accuracy.

Although this would be a wide variation where precision is required, it may be useful to estimate actual BW if direct measurement is not possible at the investigative site or the body is incomplete. For example, if a dismembered arm is presented to the mortuary, a whole body weight can still be estimated using this method. Clearly this does not require CT images as direct MAC measurement could be performed. However, a PMCT MAC measuring method permits for revisiting a BW after releasing the body from the mortuary, as well as BW estimation as part of remote radiology reporting for example in during a disaster victim identification (DVI) incident [18]. Additionally, it may provide the opportunity to develop an automated software-based algorithm for this approach.

These data are consistent with two previous large studies in children aged 1–10 years [19] and in adults older than 18 years [13], showing a strong relationship between MAC and BW (correlation coefficient of 0.91 and 0.96, respectively).

Two studies using PMCT based BW estimation with the higher correlations have been previously published. However, the whole-body volume method by Jackowski et al. [14] and the radiation dose modulation method of Gascho et al. [15] share similar limitations. Firstly, these techniques require whole-body scanning from head to toe, which may be incompatible with local scanning protocols. Secondly, for the most accurate estimation, the techniques require specific software, computers and CT scanners and require the whole body.

Although we did not directly compare our PMCT derived measurements with the actual arm measurement, the data show good intra and inter-observer reproducibility. We postulate that using bony landmarks on PMCT would actually improve this compared to a “hands on” method. However, despite this the observers reported a number of difficulties in making PMCT measurements that may have caused errors in the MAC calculations.

1. Due to the retrospective method, the arms were incompletely scanned in more than a half of the subjects, either by falling outside the field of view or missing part of the shoulder or elbow.
2. Trauma to the bones or soft tissue could result in inaccurate measurements.
3. Severe burns, gas formation and differential post-mortem oedema could affect soft tissue measurements and also compromise the relationship between MAC and BW.
4. Clinical MAC measurement requires the arm to be bent at the elbow at a 90-degree angle, this is possible prospectively for PMCT, but failure to achieve this may affect the landmarks and the measurement itself.

Our data show that females’ MAC had a higher correlation to post mortem BW than male's, but that this was not statistically significant. A CT study has shown differences in body composition (proportion of bone to total arm circumference) between the sexes, postulating that BW prediction would require different formulae [20].

Even though no statistical difference between soft tissue and bone measuring techniques was detected, the researchers recommend obtaining MAC by using the bone measurement method as it is more practical and user-friendly for the CT-based measurement.

According to some anthropological studies upper limbs are asymmetrical in length with right bias [21]. Inequality of full arm lengths of an individual results different levels of left and right mid-arm measurement locations and might also cause the discrepancy of both MAC values. Furthermore, which arm to use for clinical MAC measurement remains controversial. Some sources suggest using the left MAC measurement to avoid variations in the right due to exercise [22]. In contrast, the NHANES of the U.S. reported the right MAC of the whole population without discussing the reason [23]. In our study the circumference of the right arm was slightly larger than left on average where both measurements were available with slightly better correlation with BW, but that this was not statistically significant.

Conclusions

This study introduces a new PMCT technique to estimate adult BW using right arm's MAC through the simple Equation based on Cattermole et al., [13]. This method is considered a quick and easy method to estimate a post-mortem BW using PMCT, which is not dependent upon imaging the entire body or scanner dependent software. Nevertheless, users should consider this as an estimation only when applying the result to medico-legal cases.

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Figure 1

Example of the bone method. (a) The acronium and olecranon are identified in the sagittal plane. The distance between them is then calculated. (b) The midpoint between the acronium and olecranon is then identified. (c) The midpoint axial slice is created at right angles to the shaft of the humerus and then (d) using the closed polygon tool, the mid-arm circumference measurement is calculated. The soft tissue method uses the method principle but uses the external soft tissue/air interface overlying the acronium and olecranon at stage (a).

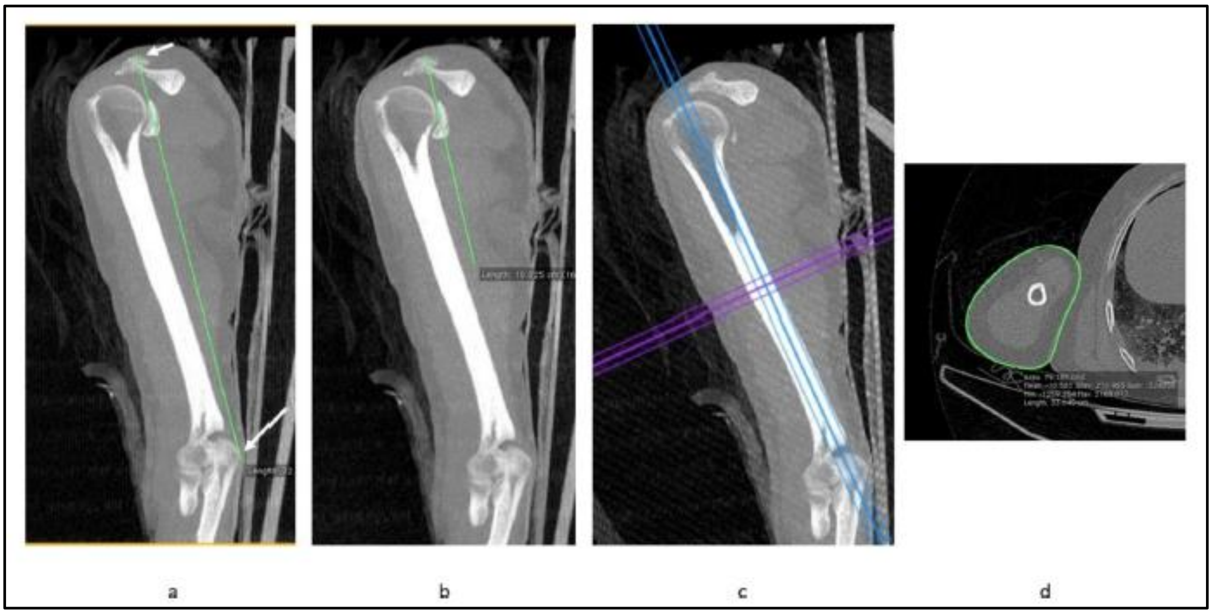

Figure 2

Plot of mean arm circumference vs measured body weight for quality score=0 (×) and quality score 1–3 (•). Trendlines show poor correlation (0.30) for low quality score (—) but good correlation (r= 0.87) for adequate or good quality score (••••)

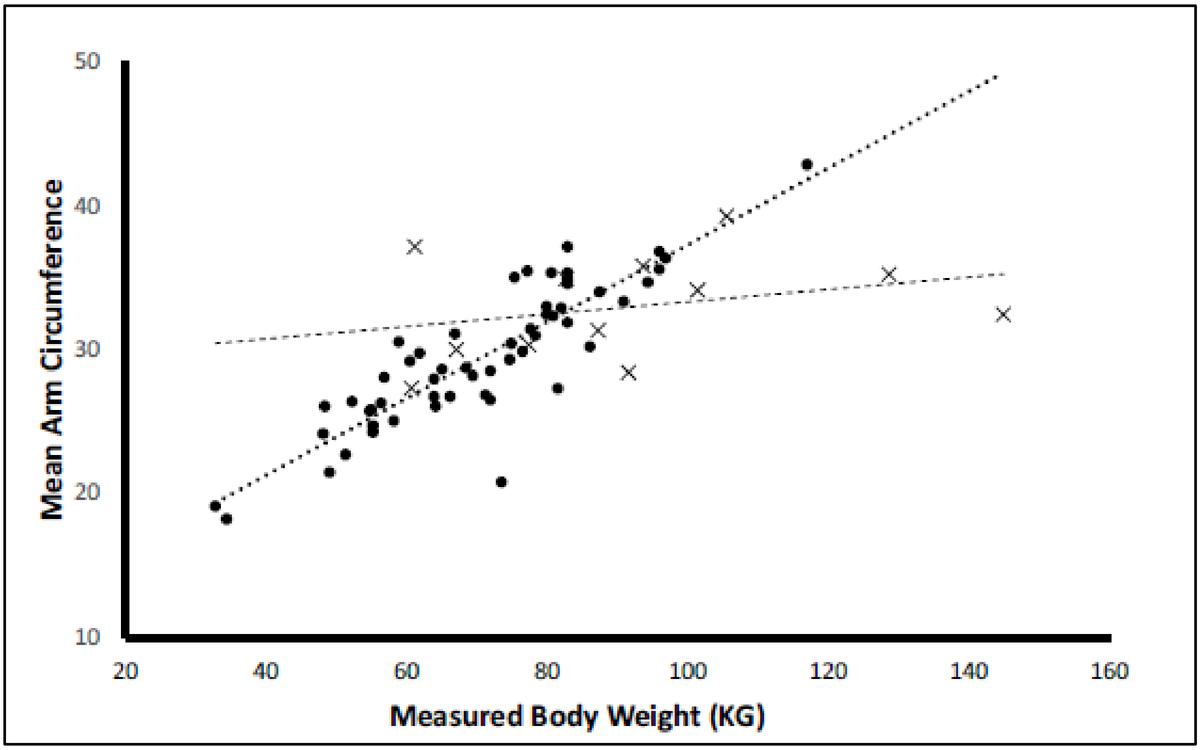

Figure 3

Bland–Altman plot of the error when body weight as estimated using the mean mid-arm circumference measurement for all observers (quality score >0) is compared to measured body weight. Mean estimated weight is 0.47 kg greater than mean measured weight with limits of agreement of 12.7 kg. The outlier with −39.88% prediction error is discussed in the next figure (Fig. 4).

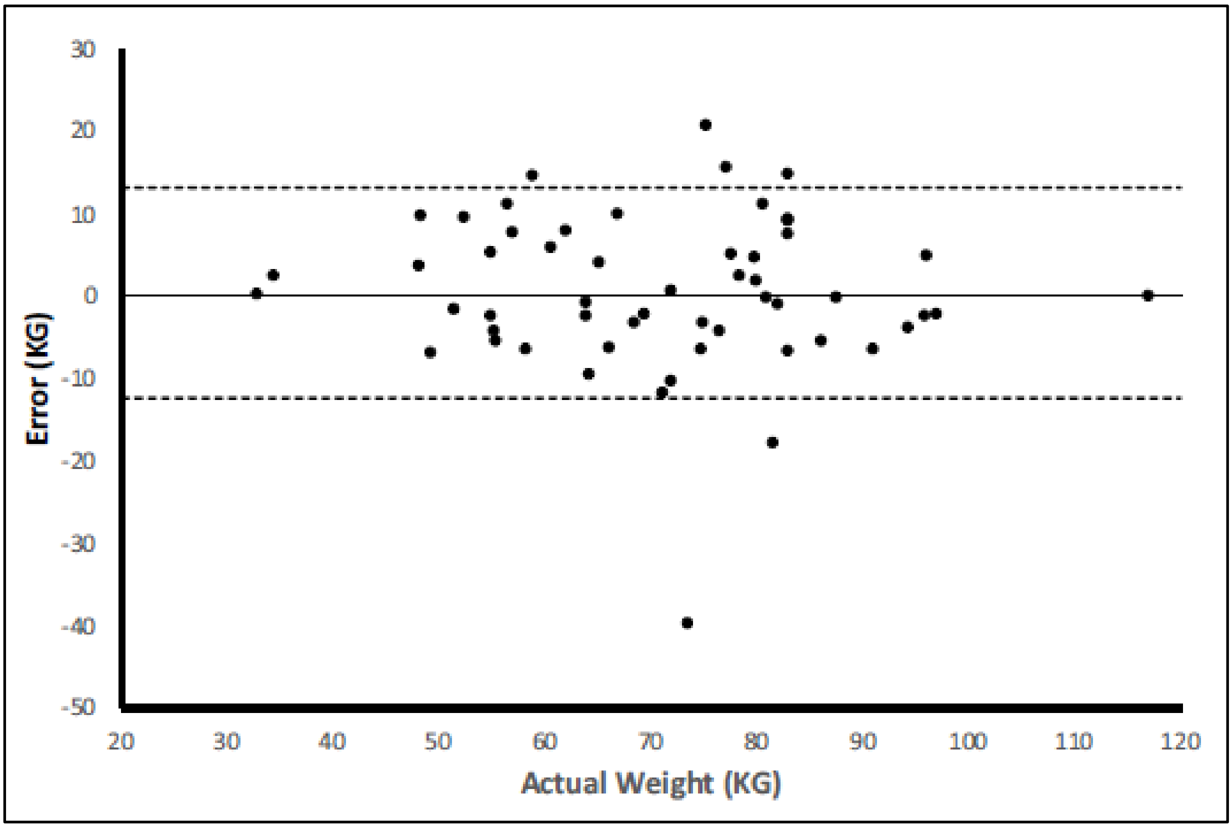

Figure 4

Case of polydrug toxicity in a 174 cm male where arm circumference predicts in weight of 33.7 kg (BMI 11.1 kg/m2) whereas recorded weight was 73.6 kg (BMI 24.3 kg/m2). The reconstructed CT suggests the recorded weight of 73.6 kg is incorrect and actual weight probably lies between the estimated and recorded weight.

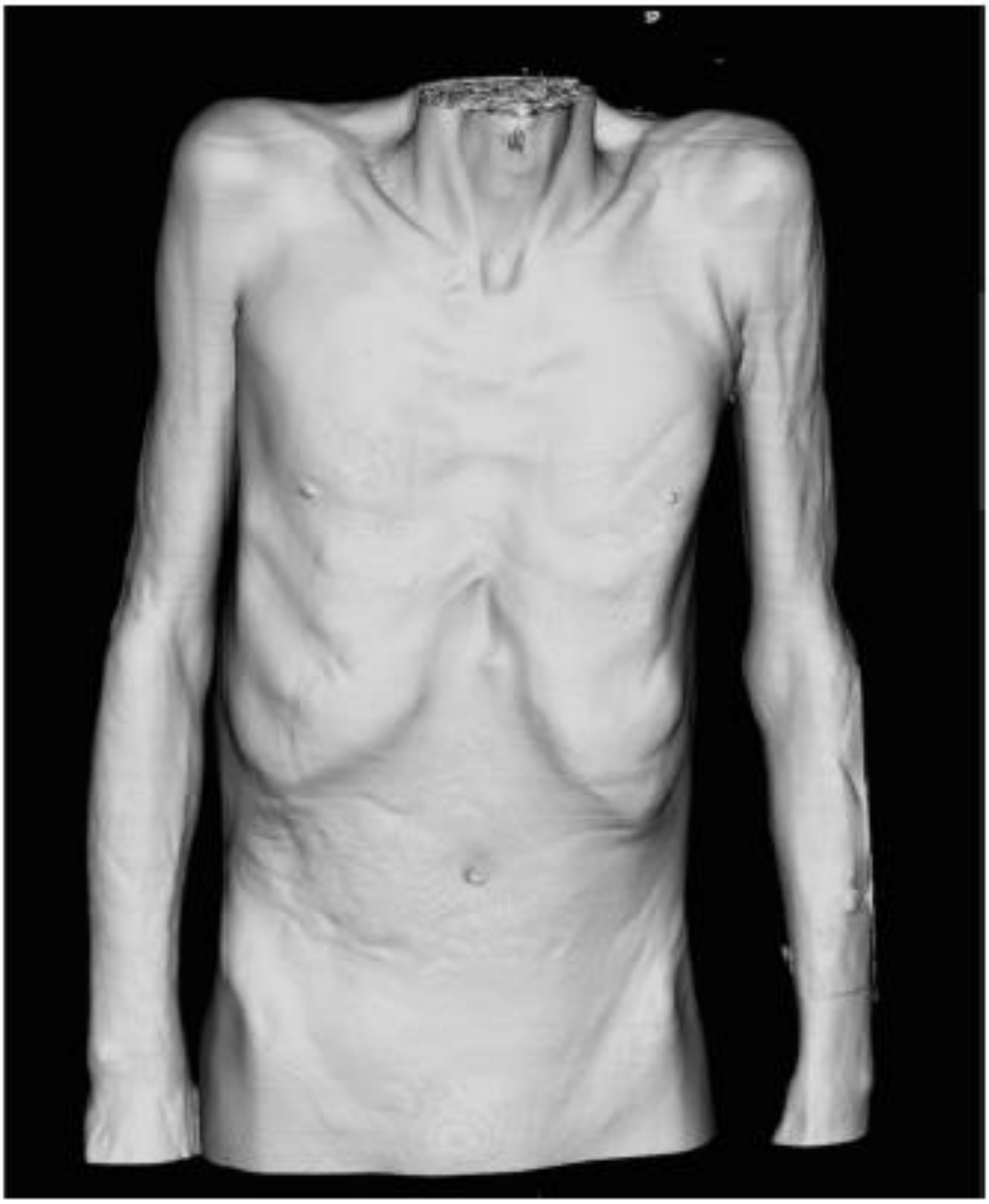

Table 1

Demographic data, body weight and mid-arm circumference measurements for the whole group and those with mean arm circumference measured with a "quality score" > 0.

	All cases	MAC quality score ≥ 1
Number	66	55
Male	45 (68.1%)	38 (69.1%)
Female	21 (31.8%)	17 (30.9%)
Mean Age (years)	59.4 (range 22–93)	58.9 (range 22–93)
Mean Height (cm)	170.7 (range 147–192)	170.4 (range 147–192)
Mean Measured BW (kg)	75.20 (range 32.8–144.7)	71.1 (range 32.8–117.0)
Natural Death	36 (54.5%)	29 (52.7%)
Unnatural Death	30 (45.5%)	26 (47.2%)
Traumatic	23 (34.8%)	19 (34.5%)
Non-traumatic	7 (10.6%)	7 (12.7%)
Average MAC (cm)	30.20	29.60 (male = 30.7, female 27.2**)
Correlation coefficient (95% confidence intervals)	0.75* (0.61–0.89)	0.87* (0.78–0.94)

* p<0.00001, ** p=0.015.