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ORIGINAL ARTICLE

Reliability of body size measurements obtained at autopsy: impact on the pathologic assessment of the heart

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Abstract *Purpose* Assessment of body size at autopsy is important for interpreting organ weight measurements and in some cases body identification. The reliability of post-mortem body size measurements, the causes for perturbations in these measurements from their corresponding pre-mortem values, and the impact of such perturbations on heart weight interpretation have not been fully explored. *Methods* Autopsy body length and weight measurements and pre-mortem height and body weight measurements were compared in 132 autopsies. Clinical records were evaluated for peripheral edema and serum albumin levels. Causes of death, body cavity fluid collections, and heart weights were obtained from the autopsy reports. A subset of patients underwent quantitative post-mortem computed tomography assessment of anasarca. *Results* At autopsy, body weight differed from the pre-mortem value by 11 ± 1 %, compared with -0.2 ± 0.3 % for body length ($P < 0.0001$). The percent change in body weight at autopsy correlated with the presence of peripheral edema (14 ± 2 % vs. 7 ± 2 %, $P = 0.01$), serum albumin < 3.0 g/dL (16 ± 2 % vs. 7 ± 2 %, $P = 0.001$), and the degree of anasarca ($P = 0.01$). In 4 % of autopsies, heart weights were abnormal based on the pre-mortem body weight, but would be classified as normal based on the elevated post-mortem body weight. *Conclusions* At autopsy, body weight is a less reliable parameter than body length in correlating with the corresponding pre-mortem measurement. Autopsy body weights are elevated in part due to peripheral edema/anasarca. Alterations in body weight at autopsy can confound the interpretation of organ weight measurements.

Keywords Autopsy · Body length · Body weight · Body size · Edema

Introduction

Measuring body size at autopsy by assessing body weight and body length is a routine and important aspect of autopsy practice. Body size measurements can impact body identification and, in the hospital setting, surviving relatives may express concern if the body size measurements in an autopsy report do not align with their understanding of the decedent's body size. In addition, body size measurements are important for interpreting the significance of organ weight measurements. Numerous studies have shown that the heart weight in normal individuals is correlated with body size [1–9]. Thus it is recommended to use heart weight tables that adjust for body size when evaluating for cardiomegaly at autopsy [10].

Both body length and body weight are routinely used to determine the normal range for heart weight at autopsy. However, to our knowledge the reliability of these post-mortem measurements to accurately reflect their corresponding pre-mortem values has not been rigorously assessed. It has been suggested that body weight

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measurements at autopsy may be a less reliable assessment of body size than are body length measurements since body weights can be acutely and significantly altered by various conditions [1]. Another concern is that post-mortem body size measurements are not obtained in the same fashion as their corresponding pre-mortem measurements. Body length is usually obtained with a tape measure rather than measuring the height of a standing patient. Likewise post-mortem body weight measurements are often obtained using a floor scale, which requires subtracting the weight of the gurney on which the decedent is transported. In this study, the reliability of post-mortem body size measurements to reflect their corresponding pre-mortem values was assessed. In addition, some of the potential causes for the alterations in post-mortem weight measurements and the impact of these alterations on the interpretation of the heart weight were investigated.

Materials and methods

Patients

The study examined patients who underwent autopsy at Massachusetts General Hospital between July 2010 and June 2013. Patient data was obtained from both the autopsy reports and the clinical records. Patients who were embalmed prior to autopsy, younger than 18 years of age or those who lacked body height or body weight measurements either pre- or post-mortem were excluded, as were patients for whom the latest pre-mortem body weight measurements were taken more than 7 days prior to the date of death. Out of a total of 892 autopsies performed during this time period, 132 cases met the inclusion and exclusion criteria for the study. This study was approved by the Hospital's Human Subjects Institutional Review Board.

Autopsy measurements

At the time of autopsy, body weight was assessed using a standard floor scale (Fairbanks), which was serviced at 6-month intervals and routinely found to have an accuracy greater than 99 %. The body weight was calculated after subtracting the weight of the empty gurney. The accuracy of the floor scale was tested independently through the manual placement of calibrated weights on an empty gurney, which also revealed an accuracy of greater than 99 %. Body length from crown to heel was measured with a tape measure. The total fluid in the pleural, pericardial, and peritoneal spaces was recorded, as was the heart weight and the cause of death.

Clinical parameters

The pre-mortem body height and weight were obtained from the clinical records; values recorded closest to the time of death were used. By exclusion criteria all pre-mortem body weights were obtained within 7 days of death. The pre-mortem serum albumin levels obtained closest to time of death were recorded, only including values obtained within 4 days of death. The presence or absence of peripheral edema noted on clinical examination during the 7 days prior to death was also recorded.

Post-mortem computed tomography

For 11 of the 132 patients, post-mortem whole body CT scanning was performed prior to autopsy as described previously [11]. All cadavers were scanned using a 128-slice, dual-source multidector-row CT (Somatom Definition Flash, Siemens Healthcare). Quantitative analysis of the amount of anasarca was determined using dedicated software (Volume, Syngo Explorer, Siemens Healthcare). Free-hand regions of interests (ROIs) were drawn on CT images to quantify fluid accumulation in the subcutaneous tissues. The volume of fluid in the ROIs was measured using a threshold range of −20 to +50 Hounsfield units [12].

Heart assessments

The heart weights were obtained at autopsy using a Cardinal Detecto model HSDC-20 KG scale after removal of the pericardium and great vessels, and were compared to the upper limits of normal for the heart weights using the pre- and post-mortem body height and body weight measurements from previously published tables [2]. For patients with confounded heart weight assessments in which the heart weight was abnormal using the pre-mortem body weight but normal using the post-mortem body weight, the histologic slides of the heart were evaluated. Myocyte hypertrophy was assessed subjectively on a 4 point scale as none, mild (<50 % increase nuclear size), moderate (50–100 % increase in nuclear size), or severe (>100 % increase in nuclear size) with a normal myocyte nucleus having a diameter of approximately 10 μm. Myocardial interstitial and replacement fibrosis was assessed subjectively on a four point scale as none, mild (<10 % of myocardial area), moderate (10–25 % of myocardial area), or severe (>25 % of myocardial area). Gross ventricular wall hypertrophy was determined to be present if the free wall measurement in the autopsy report exceeded 15 mm for the left ventricle or 5 mm for the right ventricle [2]. The degree of coronary artery disease was

graded as mild (≤ 30 % stenosis), moderate (>30 % but <75 % stenosis), or severe (≥ 75 % stenosis).

Statistical analyses

Continuous data were compared using t test and discontinuous data were compared using Fisher exact test. Multiple groups of continuous data were compared using ANOVA with Bonferroni correction. Linear correlations were assessed using Spearman rank-order correlation coefficient. P values less than 0.05 were considered significant. For factors associated with the % change in body weight at autopsy, raw P values are reported as well as Benjamini–Hochberg adjusted P values (P_{BH}) to correct for multiple comparisons. All results are expressed as mean $\pm$ standard error.

Results

Patient characteristics

There were 132 patients that met the inclusion and exclusion criteria, and their characteristics are listed in Table 1. The study population consisted of 72 males (55 %) and 60 females (45 %), with a mean age of 62 ± 1 years. The mean pre-mortem body weight was 166 ± 4 pounds, and the mean pre-mortem height was 168 ± 1 cm. The mean autopsy body weight was 183 ± 4 pounds, and the mean autopsy body length was 168 ± 1 cm. From the cause of death determined at autopsy, four categories were established as general causes of death; 49 patients were deemed to have expired from cardiovascular disease/stroke, 28 patients from infection, 28 patients from malignancy, and 27 patients from other causes, the latter encompassing trauma ($n = 3$), neurodegenerative disease ($n = 2$),

Table 1 Patient characteristics

Parameter	Value
Number of patients	132
Age (years)	62 ± 1
Gender (M/F)	72/60
Pre-mortem body weight (lbs)	166 ± 4
Pre-mortem height (cm)	168 ± 1
Autopsy body weight (lbs)	183 ± 4
Autopsy length (cm)	168 ± 1
Cause of death (n)	
Cardiovascular disease/stroke	49
Infection	28
Malignancy	28
Other	27

medical lung disease ($n = 14$), and other miscellaneous autoimmune/inflammatory disorders ($n = 8$).

Reliability of post-mortem body size measurements

To assess the reliability of post-mortem body weight and body length measurements, the percentage changes in these two measurements relative to their respective pre-mortem measurements were directly compared (Fig. 1). There was a significantly greater change in the body weight measurements (post-mortem relative to pre-mortem) compared with the body length/height measurements (11 ± 1 vs. -0.2 ± 0.3 %, $P < 0.0001$). This suggests that body length measurements at autopsy are more reliable in recapitulating pre-mortem body size measurements than body weight due to rapid fluctuations in body weight. The average amount of weight gained at the time of autopsy was 17 ± 2 lbs.

Edema and body weight changes at autopsy

The mean time interval between pre-mortem body weight assessment and death was 3.8 ± 0.2 days. There was no correlation between this time interval and the percentage change in body weight ($P = 0.31$, $P_{BH} = 0.35$). Likewise, there was no correlation of the percent change in body weight with patient age ($P = 0.92$, $P_{BH} = 0.92$), gender
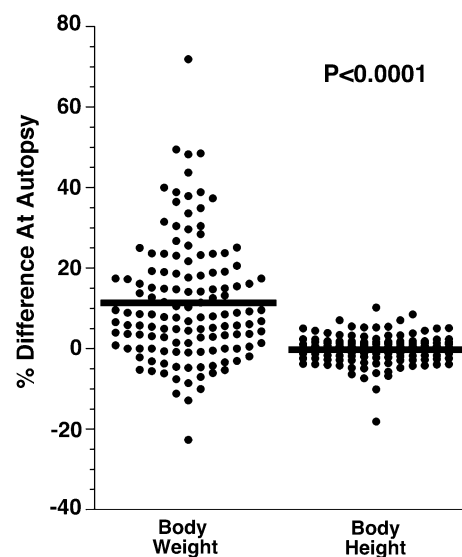

Fig. 1 Alterations in body weight and body length measurements obtained at autopsy. For the 132 patients, the percent difference in body weight at autopsy (in relation to the pre-mortem body weight) at *left* is compared with the percent difference in body length at autopsy (in relation to pre-mortem body height) at *right*. There was a significantly larger percent difference in the body weight measurement at autopsy compared with the body length measurement ($P < 0.0001$)

($P = 0.07$, $P_{BH} = 0.11$), or cause of death ($P = 0.22$, $P_{BH} = 0.29$). At autopsy, the patients had an average of 1.1 ± 0.1 L of combined fluid in the pleural, pericardial, and peritoneal spaces. The percent change in body weight change at autopsy correlated with the amount of body cavity fluid ($r^2 = 0.25$, $P = 0.004$, $P_{BH} = 0.008$). To determine if the body cavity fluid fully accounts for the weight changes at autopsy, the post-mortem body weights were corrected for the weight of the fluid assuming a specific gravity of 1 g/mL. This correction had no impact on the comparison in Fig. 1, with the corrected change in body weight being 10 ± 1 % ($P = 0.0001$ vs. % change in body height). Thus, additional factors beyond body cavity fluid appear to be contributing to the percent change in body weight at autopsy. As shown in Fig. 2, the patients who had peripheral edema on clinical exam before death had a significantly greater percentage change in body weight compared with those patients who did not have peripheral edema (14 ± 2 vs. 7 ± 2 %, $P = 0.01$, $P_{BH} = 0.02$, $n = 118$). One contributor to peripheral edema are low serum albumin levels. As shown in Fig. 2, the patients who had serum albumin levels of <3.0 g/dL had a significantly greater percentage change in body weight compared with those patients who had serum albumin levels ≥ 3.0 g/dL (16 ± 2 vs. 7 ± 2 %, $P = 0.001$, $P_{BH} = 0.008$, $n = 115$).

The comparisons in Fig. 2 suggest that at least some of the increase in body weight at autopsy is a result of soft tissue edema occurring shortly before death. To directly assess the correlation between tissue fluid and the change in body weight at autopsy, the amount of anasarca was directly measured in a subset of 11 patients by post-mortem CT. As shown in Fig. 3, the degree of anasarca by post-mortem CT correlated with the percentage change in body weight at autopsy ($r^2 = 0.67$, $P = 0.01$, $P_{BH} = 0.02$).

Heart weight assessments at autopsy

The increase in body weight at autopsy compared with pre-mortem weight raises the possibility that abnormally heavy hearts might mistakenly be considered of normal weight if post-mortem body weight measurements are used. To determine if the body weight changes at autopsy seen here could influence the interpretation of heart weight measurements, heart weights were obtained from the autopsy reports and compared to the upper limits of normal for both pre- and post-mortem body size measurements using previously published tables. There were no instances in which a heart weight that was considered abnormal based on pre-mortem body height measurement was then found to be normal based on post-mortem body length measurement. However, there were 5 cases (4 %) in which the heart weight was abnormal utilizing pre-mortem body weight

measurement but then found to be normal when using post-mortem body weight measurement ($P = 0.03$, $n = 124$). All five of these patients had some degree of cardiac disease (Table 2; Fig. 4). Conversely, there were two cases in which the lower than expected body weight at autopsy caused a heart weight to appear abnormal that would
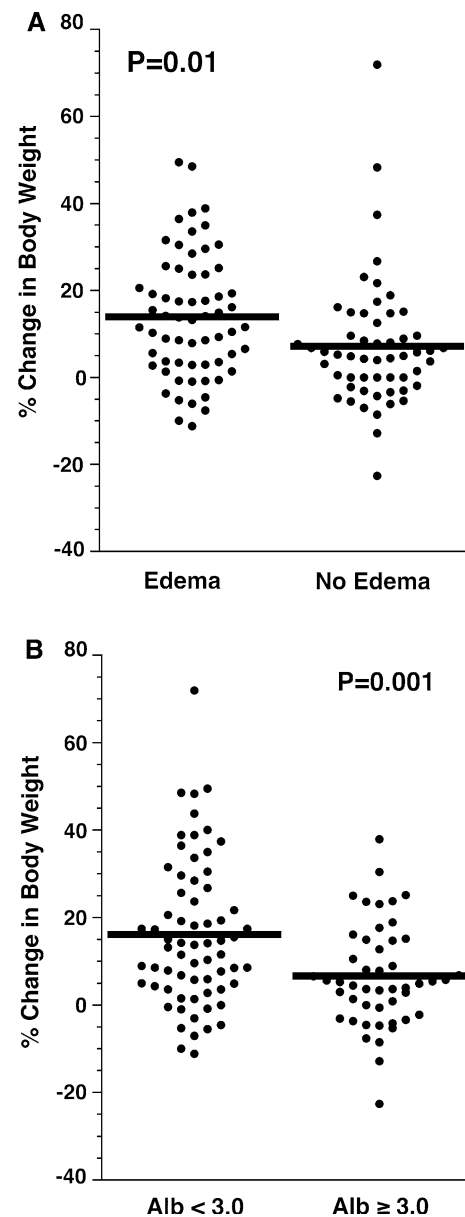

Fig. 2 Association of the autopsy body weight change with the clinical determination of peripheral edema and serum albumin. **a** Patients who had peripheral edema by clinical exam before death had a greater percent change in body weight at autopsy than patients who did not have peripheral edema ($P = 0.01$). **b** Patients who had a serum albumin <3.0 g/dL before death had a greater percent change in body weight at autopsy than patients who had a serum albumin ≥ 3.0 g/dL ($P = 0.001$)
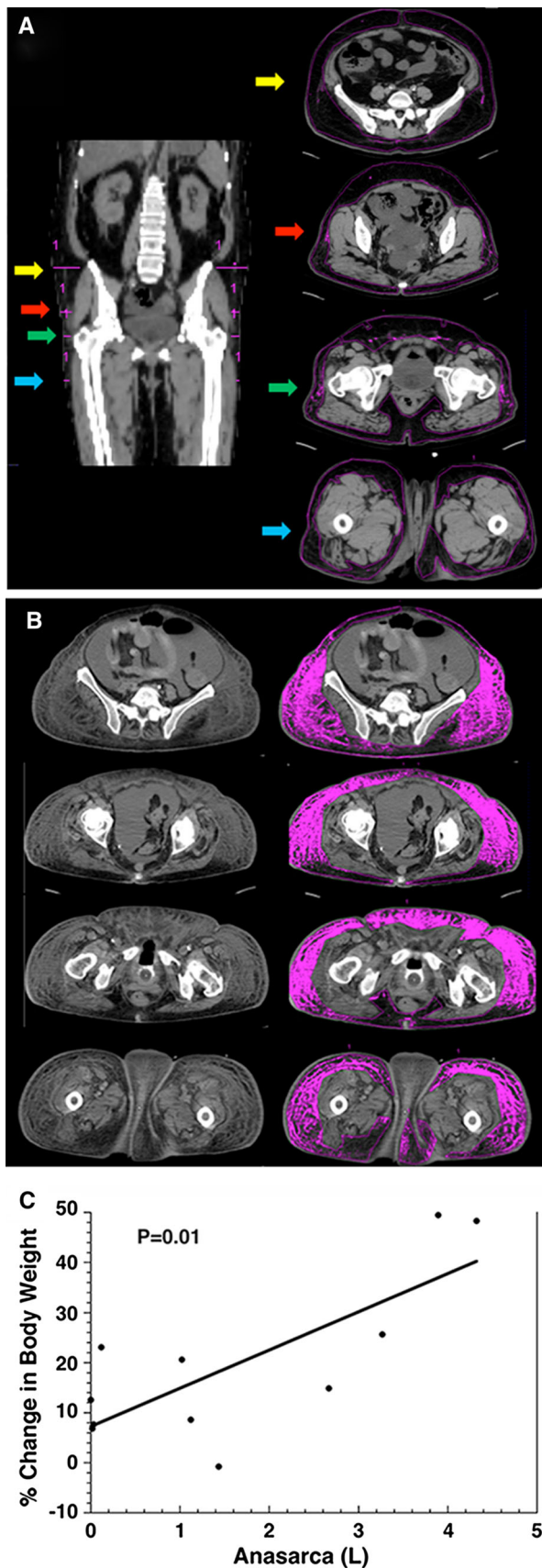
◄**Fig. 3** Correlation of the autopsy body weight change with tissue edema assessed by post-mortem CT. **a** Post-mortem CT of a patient without anasarca showing cross-sectional images at the four levels indicated with the *arrows*. The subcutaneous tissue is outlined in *pink*. **b** Post-mortem CT of a patient with anasarca. The subcutaneous tissue fluid is *shaded pink* (*right*). **c** The volume of anasarca measured by post-mortem CT correlates with the percent change in body weight at autopsy ($P = 0.01$)

otherwise be considered normal based on the pre-mortem body weight.

Discussion

The observations detailed here demonstrate that body weight measurements obtained at autopsy may not be reliable in reproducing pre-mortem body weight measurements. On average patients weighed 17 lbs more at autopsy than before death, and in some cases substantially more. The autopsy pathologist should be aware of this situation if confronted by clinicians or family members questioning the body weight measurement listed in an autopsy report. This study encompassed a hospital-based adult autopsy population comprised of patients with substantial medical disease. It is unclear if these results will readily translate to other patient populations.

The correlation of the percent change in body weight with peripheral edema, low serum albumin, and anasarca on post-mortem CT indicates that one contributing factor is the accumulation of fluid in the subcutaneous tissue. However, this is probably not the only cause for the increase in body weight at autopsy. The patients without edema, without anasarca, and with serum albumins ≥ 3.0 still had an average 7 % increase in body weight at autopsy. Thus other factors are likely contributing to this observation. Such factors could include the acute administration of intravascular fluids just prior to death, as well as the presence of prosthetic devices and instrumentation left on the body after death.

The observations here also indicate that the increase in body weight at autopsy is more than just a curiosity, as it can potentially confound the interpretation of organ weight measurements. In 4 % of cases, the increase in body weight at autopsy was found to potentially confound the evaluation of the heart, causing hearts that were abnormally heavy based on pre-mortem body weight to be potentially considered normal based on post-mortem body weight. Thus while both body weight and body length are often used to determine the range for normal heart weight, the autopsy pathologist should be aware that the post-mortem body weight measurement may be unreliable in some cases, as has been previously suggested [1]. One limitation

Table 2 Patients with confounded heart weight assessment

Patient	1	2	3	4	5
Age (years)	72	69	53	41	56
Gender (M/F)	M	M	M	M	M
Clinical body Wt. (lbs)	200	180	167	132	130
% Change in body Wt.	30.5	16.1	13.7	37.9	28.5
Peripheral edema	Present	Present	Present	Present	Present
Albumin (g/dL)	1.3	3.1	2.7	4.6	1.8
Clinical heart disease	CAD	HTN, Afib, Pericarditis, CAD	Pulmonary Hypertension	Pulmonary Hypertension	PFO, Atrial Dysrhythmia
Pathologic heart assessment					
Heart weight (g)	520	480	470	440	420
LV/RV (mm)	16/6	16/3	15/6	11/4	13/4
Gross LVH	Present	Present	Absent	Absent	Absent
Gross RVH	Present	Absent	Present	Absent	Absent
Myocyte hypertrophy	Severe	Severe	Moderate	Moderate	Moderate
Myocardial fibrosis	Moderate	Moderate	Mild	Mild	Mild
CAD	Severe	NA	Mild	None	Mild
Other	Acute MI	Metastatic calcification, pericarditis		Pericarditis	Left atrial thrombus, PFO

CAD coronary artery disease, *HTN* hypertension, *Afib* atrial fibrillation, *PFO* patent foramen ovale, *LV/RV* left ventricular, right ventricular wall thicknesses, *LVH* left ventricular hypertrophy, *RVH* right ventricular hypertrophy, *NA* not assessed, *MI* myocardial infarction
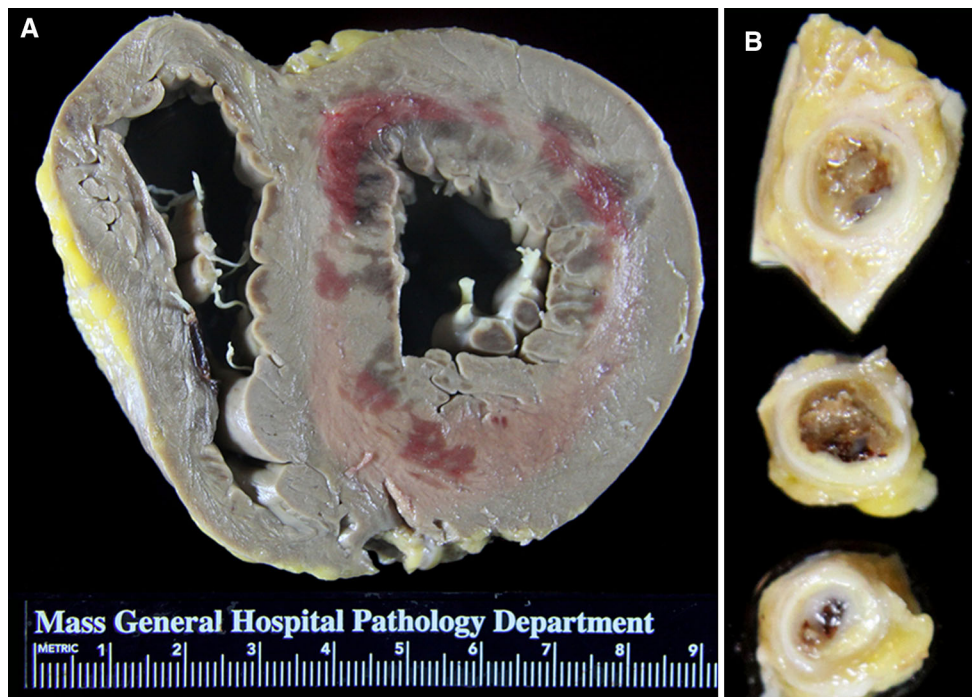

Fig. 4 An abnormal heart that would inappropriately be considered to have a normal weight based on autopsy body weight measurement. Shown are gross photographs of the heart from patient 1 in Table 2. **a** The cross section of the heart shows thickened *left* and *right* ventricular walls and acute myocardial infarction. **b** The coronary *arteries* showed severe occlusive atherosclerotic coronary artery disease

of this study is that it was retrospective in nature, and the heart weights were obtained from the autopsy reports. The weight of the heart at autopsy can be influenced by how the heart is dissected, particularly the degree to which blood clot is removed from the heart prior to weighing [13].

Key points

1. At autopsy, body weight is a less reliable parameter than body length in correlating with the corresponding pre-mortem measurement.
2. On average, autopsy body weight measurements are elevated 11 % compared with pre-mortem body weight measurements.
3. Autopsy body weights are elevated in part due to peripheral edema/anasarca.
4. Alterations in body weight at autopsy can confound the interpretation of heart weight measurements.

Compliance with ethical standards

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