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A new method for the estimation of age at death by using electrical impedance: A preliminary study

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ABSTRACT

Estimation of age at death is an important part of physical and forensic anthropology. The aim of this study was to investigate whether bioelectrical impedance analysis (BIA) of long bones can be used in the field of forensic medicine as a method to estimate age at death. BIA is easy to use and allows repeat measurements to be taken over time, and the equipment is inexpensive and portable. Impedance values (Z values) in 378 long bones (humeri, radii, femora, tibiae) of 40 male (233 bones) and 26 female (145 bones) autopsy cadavers were measured using two wire electrodes (connected to an alternating current device and a measuring device) inserted into the metaphyses of long bones. Computed tomography of the greater trochanter of the femur was also analyzed to evaluate bone mineral density (BMD). The results showed that Z values could be used to estimate age in males, and with an age cut-off point of 50 years in females. When estimating age at death from femur and tibia in males by using BIA, it is not necessary to consider the length of subjects. And it was thought that Z values reflected BMD. Among the long bones, the tibia is the most suitable and easy to use for Z value measurement. Z value measurement is a useful method for quantitative evaluation of age at death that can be performed quickly with inexpensive, portable equipment.

1. Introduction

In the field of forensic medicine, the number of unidentified cadavers has increased as a result of natural disasters and international terrorism. The estimation of age at death of unidentified cadavers is important because it assists in the identification of individuals. There have been previous reports on the evaluation of cranial suture closure [1,2], dental wear [3–6], pubic symphyseal face [7,8], metamorphosis at the rib [9–11], metamorphosis of the acetabulum or auricular surface of the ilium [12–17], histomorphometry of femur or tibia [18–22] and other skeletal elements to estimate age. However, these methods require sufficient ablation of soft tissue as well as equipment and time to prepare histological sections, and because of the qualitative evaluation involved, inter- and intra-observer errors must be taken into consideration [23–25]. There is a need for a faster and simpler method of quantitatively determining age.

In both males and females, bone tissue changes with age, and this is reflected in bone mineral density (BMD) [26–30]. The relationship between BMD and menstrual function has been identified in females [30–32]. Several methods are available for the assessment of BMD. Dual energy X-ray absorptiometry (DEXA), quantitative computed tomography (QCT), and quantitative ultrasound (QUS) have been the most widely used techniques. The analytical equipment used in each of these methods is expensive and not easily transported. For DEXA and QCT in particular, the instruments are very large and expensive to run, and taking measurements is time-consuming.

The estimation of body composition with bioelectrical impedance analysis (BIA) is a method widely used in many homes to measure body fat percentage. BIA is easy to use and allows repeat measurements to be taken over time, and the equipment is inexpensive and portable. The measuring electrodes can also be placed at desired sites of interest for easy measurement. Furthermore, it has been reported that there is a clear correlation between BIA measurements and those obtained with DEXA, indicating its high reliability as a method of evaluating body mass composition [33].

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It has also been reported that, as a predictor for BMD in males, BIA is closely related to BMD [34].

We previously conducted basic research on and investigated the clinical application of BIA as a method of evaluating bone union and callus maturation [35–37]. The aim of this study is to investigate whether BIA of long bones can be used in the field of forensic medicine as a method to estimate age at death and BMD. We also examined which of the long bones is most suitable for determining these characteristics.

2. Materials and methods

This study was approved by the local research ethics committee. From October 2009 through April 2012, autopsies were performed on 40 males and 26 females at the Department of Forensic Medicine, Kyoto Prefectural University of Medicine, to examine 378 long bones. A total of 233 male bones (24 humeri, 65 radii, 66 femora, 78 tibiae) and 145 female bones (13 humeri, 42 radii, 39 femora, 51 tibiae) were examined. To exclude the influence of growth plates and bone fracture, individuals younger than 18 years of age or showing evidence of bone fractures were excluded from the study. Details of the study subjects are shown in Table 1.

2.1. Measurement of impedance (Z) values

Kirschner wire (K-wire) 2.0 mm thick with a threaded tip (total length/threaded length: 150 mm/15 mm, Synthes GmbH, Oberdorf, Switzerland) was used for the electrodes. To eliminate the influence of skin, muscle and other tissue, soft tissue was insulated with Sumitube™ B (Sumitomo Electric Fine Polymer, Inc., Osaka, Japan) (Fig. 1). Sumitube™ B was fixed to the K-wire by applying heat. The K-wire was insulated up to 1 cm from the tip, and only the tip was inserted into bone tissue. Skin incisions of approximately 2 cm were made directly above the predetermined insertion sites. Muscle tissue and periosteum were ablated, and K-wires were inserted using a hand-operated Modeling Drill Chuck (Tamiya, Inc., Shizuoka, Japan). Long bone cortex was penetrated and each of the K-wires was inserted so that the insulated part was in close contact with cortical bone. The tips of the K-wires were positioned in cancellous bone (Fig. 1). One K-wire was inserted in the proximal metaphysis and the other in the distal metaphysis (Fig. 2).

The experimental data from these K-wires was obtained using an alternating current (AC) device (Osteo Grow BS-1000) and a measuring instrument (BA-004, Medical Engineering System Co., Ltd. Tokyo, Japan) (Fig. 3b and c). The frequency was set at 2 ± 0.4 Hz to limit the reactance element of AC current to a negligible range during measurement, and the current output was set at 30 ± 6 μA. The device has been approved by the Ministry of Health, Labor and Welfare in Japan for clinical application in the treatment of intractable bone fracture.

The voltage (E mV) between the electrodes was measured with the BA-004. The reading was taken when the measured value remained constant for up to 1 min. When the E mV value was less than 1 V, following Ohm's Law [38], Z values were calculated using the equation $Z = E/I$ (Fig. 2). Where Z is impedance (kΩ), E is voltage (mV) and I is the alternating current (mA).

Table 1
Data for the measured biometrics and comparison between males and females.

Parameter	Male 40 cases (233 bones)	Female 26 cases (145 bones)	P value
Age (years)	57.2 ± 19.3	63.0 ± 20.0	0.22
Height (cm)	166.5 ± 9.5	151.5 ± 8.3	<0.01**
Weight (kg)	62.0 ± 17.4	48.3 ± 15.2	<0.01**
BMI (kg/m^2)	22.2 ± 4.9	20.8 ± 5.5	0.10

** $P < 0.01$. Mann–Whitney U test.

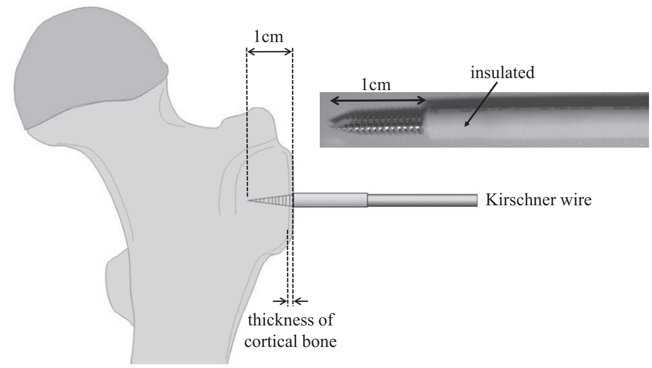

Fig. 1. Installation of a Kirschner wire. Kirschner wire (K-wire) was insulated with Sumitube™ B except for 1 cm at the tip. A Modeling Drill Chuck was used to insert the K-wire into the metaphysis of a long bone until the insulated part was in close contact with cortical bone. The tip of K-wire was positioned in cancellous bone.

The relationships between the obtained Z values and age were examined. Because a relationship between BMD and menstrual function has previously been reported [30–32], female subjects were divided into two groups, <50 years of age and ⩾50 years of age, and the Z values of the two groups were compared. There were 6 cases in the under <50 years of age group, with a mean age of 33.3 ± 9.4 years (range, 18–47 years), and 20 cases in the ⩾50 years of age group, with a mean age of 71.9 ± 11.9 years (range, 51–96 years).

The Z value was obtained by following the formula:

$$Z = \rho \times L/A$$

where ρ is the electrical resistivity (Ωm), L is the length (m), and A is the cross-sectional area (m^2).

According to this formula, the Z value is proportional to the length and is inversely proportional to the cross-sectional area of the bone. However, the cross-sectional area of long bones is not constant and it varies according to both sex and bone location. In this study, we divided the subjects into categories based on sex and bone location, so we could assume that the cross-sectional area of long bones in each group was constant. We were then able to adjust the Z values for length for all the subjects. Therefore the relationships between resulting Z values per unit length (Z_L Ω/cm) and age were plotted so that they could be critically assessed.

Using regression analysis we calculated the significance of the deviation of actual values from the expected values in each group, and applied the Bland–Altman method to evaluate statistical error.

2.2. Correlations between Z values and CT numbers in femora

Before autopsy, CT images were analyzed, including those of the proximal femora, of 51 bones in 26 males (mean age 58.1 ± 20.9 years; range 22–91 years) and 30 bones in 15 females (mean age 67.5 ± 17.0 years; range 35–96 years). We used the OsiriX Imaging Software (Advanced Open-Source PACS Workstation DICOM Viewer, Pixmeo, Geneva, Switzerland). OsiriX is open-source software that allows the user to navigate through series of multidimensional images while adjusting the blending of images from different modalities, image contrast and intensity and the rate of cine display of dynamic images. The software is available to download for free at http://www.osirix-viewer.com/.

Using CT axial images of the center of the greater trochanter of the femur, a 2-cm^2 cross-sectional area of cancellous bone was set