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The difference in spine specimen dual-energy X-ray absorptiometry bone mineral density between in situ and in vitro scans

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Abstract

BACKGROUND CONTEXT: Human cadaveric specimens are commonly used to evaluate bone-implant interface strength in osteoporotic spine fixation. Dual-energy X-ray absorptiometry (DXA) scans are usually carried out on explanted spine specimens to measure bone mineral density (BMD) before in vitro biomechanical studies are carried out.

PURPOSE: The purposes of this study were to verify and quantify the difference in DXA BMD between unexplanted (in situ) and explanted (in vitro) scans and to develop and validate a correction factor (CF) between in vitro and in situ DXA BMD.

STUDY DESIGN: This is a retrospective analysis of past DXA scans of explanted specimens and a repeated measure scan rescan study of in situ and in vitro spine specimens.

METHODS: Dual-energy X-ray absorptiometry scans were previously carried out on 106 male and 83 female lumbar specimens. Using multiple regressions, the correlation functions between *Z* score, BMD, and age were determined for male and female groups. The CF was developed based on difference in BMD between mean in vitro and population data. Next, in situ DXA scans were carried out on the lumbar spine of four full human cadavers, and subsequently, in vitro scans were repeated after explantation. The CF was applied to these in vitro scan data and the resulting corrected BMD compared with in situ scan values.

RESULTS: The specimens had significantly lower *Z* score than population mean. The mean *Z* score was -0.7 ± 1.4 ($p<.001$) for male and -0.3 ± 1.3 ($p=.03$) for female specimens. The difference between in situ and in vitro scans was quantified to be 0.06 g/cm^2 for male specimens and to be a function of age ($6.80\ \text{Age}^{-0.5}-3.76\ \text{Age}^{-0.365}$) for female specimens. In vitro BMD was $96\pm11\%$ of in situ BMD and was significantly different ($p=.04$). Corrected BMD after application of CF was $97\pm11\%$ of in situ BMD and was not significantly different ($p=.13$).

CONCLUSIONS: In vitro BMD scan on explanted specimens measured lower DXA values than in situ BMD scans on full cadavers. A CF when used resulted in more accurate measure of the in situ BMD.

Keywords: BMD; DXA; *T* score; *Z* score; Lumbar spine

Introduction

Consideration of biomechanics is important toward success of spine surgery [1,2]. For more than two decades, biomechanical research using animal models or human cadaveric tissues has been carried out for evaluation of implants and novel surgical techniques [3] and to quantify spinal loading [4] and movements. With an aging population who are more susceptible to osteoporosis, bone quality and stability of devices at the bone-implant interface have been a concern [5]. Accordingly, it is increasingly important to evaluate biomechanically if certain implants or surgical techniques are suitable for use in osteoporotic patients.

Human cadaveric specimens are commonly used in biomechanical studies to evaluate bone-implant interface strength in osteoporotic spine fixation using new surgical

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approaches [6] and surgical devices [7]. They are additionally used to compare between existing techniques [8] and to measure the potential adjacent segment effect [9] in fixation of the osteoporotic spine. A consistent measure of bone quality in both in vivo and in vitro setting is necessary to translate in vitro biomechanical data into clinical practice.

It is currently common practice to measure in vitro bone mineral density (BMD) of explanted specimens using dual-energy X-ray absorptiometry (DXA) and to use the corresponding *T* score to classify the bone quality as osteoporotic, osteopenic, or normal [10–12]. To define a specimen as osteoporotic based on *T* score obtained from in vitro BMD scan, an assumption is made that in vitro BMD scan data on explanted specimens are equivalent to in vivo BMD scan data on patients. The data from the study by Svendsen et al. [13] on the impact of soft tissue challenged the validity of this assumption. Differences in DXA BMD values between unexplanted (in situ) and explanted (in vitro) spine, hip, and forearm tissues were found in their study using 14 human cadaveric specimens. They determined that DXA measurement was dependent on surrounding soft tissue and its composition and that a correlation exists between in situ and in vitro DXA BMD. Their results indicated that in vitro scan data could be applied with a correction factor (CF) to obtain a corrected DXA value. This corrected DXA value would be equivalent to values from in situ full cadaver scans and presumably from in vivo patient scans.

The first aim of the present study was to verify the existence of a difference in DXA BMD between unexplanted (in situ) and explanted (in vitro) scans and to quantify this difference. The second aim of this study was to develop a CF between in vitro and in situ DXA BMD and to validate this CF.

Methods

This study consisted of two protocols. The first protocol involved analyses of previous in vitro scan data and development of the CF. The second protocol involved repeated in situ and in vitro scans of human cadaveric specimens and the application and validation of the CF.

Protocol 1

Dual-energy X-ray absorptiometry scans were previously carried out on 106 male and 83 female lumbar specimens of mixed ethnicity. The scans were carried out as part of numerous biomechanical studies in our institution over many years by MMK. All scans were carried out in the anteroposterior (AP) direction on a DXA machine (Discovery A; Hologic Inc., Bedford, MA, USA) with specimens placed above a 14-cm-deep water bath. Thoracolumbar specimens explanted from unembalmed donors were sealed in plastic bags and stored in freezers at −20°C. Dual-energy X-ray absorptiometry scans were carried out on the lumbar regions of the specimens after 24 hours of thawing at room temperature. To eliminate edge effect, scan analyses excluded the terminal vertebrae on each specimen.

Age, AP BMD, *Z* scores, and *T* scores of all specimens were tabulated. Male and female populations were treated separately. Statistical *Z* tests were carried out to determine if the mean sample *Z* scores of male and female specimens were significantly less than zero. *Z* score reflects the standard deviation of BMD from age-matched population data, and a mean sample *Z* score significantly less than zero would imply lower BMD values than the population mean. Using correlation analyses, the correlation curves between BMD and age and between *T* score and BMD were determined. Next, using multivariate regression analyses, the *Z* score was correlated as a function of BMD and age. For male samples, a linear correlation function was used, whereas for female samples, a power correlation was used. Population reference curves between BMD and age were subsequently obtained from these multiple regression correlation functions by setting *Z* as zero. A CF between DXA BMD of in vitro and in situ spinal specimens was determined from the difference between population and sample correlation curves.

Protocol 2

First, the in situ lumbar AP BMD of four full human cadavers was measured on a DXA machine (Discovery A). All four donors were female. Two of the donors were 69 years of age, and the other two were 70 years old. The cadavers were kept within full-length body bags during DXA scans with the body bag zippers positioned to the side and away from the scanned regions. The lumbar spines were subsequently explanted, sealed in plastic bags, and stored in freezers at −20°C. Three of the specimens were harvested as T12–S segments, whereas one was a L1–S segment. Next, in vitro DXA scans were carried out using the same procedure described in Protocol 1. Nineteen lumbar vertebral bodies were included. In addition to scans with specimens placed above a 14-cm-deep water bath, a second set of scans was carried out with each specimen placed over a bag of rice.

The variables measured in each scan were BMD, bone mineral content (BMC), and bone area. Using each specimen as its own control and to cancel out the effects of inter-specimen variability, BMD, BMC, and bone area were normalized against their respective in situ BMD scan values. Using the CF determined in Protocol 1, the corrected BMDs for all 19 vertebrae were determined and were normalized against their respective in situ BMD scan values. Statistical *Z* tests were carried out on normalized in vitro BMD, BMC, bone area, and corrected BMD to determine if they were significantly different from in situ variables. A p value of less than .05 was considered statistically significant.