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Original Article

3D Topographical Scanning for the Detection of Osteoporosis

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Abstract

Objectives: Osteoporosis is associated with greater risk of fracture, which can lead to increased morbidity and mortality. DEXA scans are often inaccessible for patients, leaving many cases of osteoporosis undetected. A portable 3D topographical scan offers an easily accessible and inexpensive potential adjunct screening tool. We hypothesized that 3D scanning of arm and calf circumference and volume would correlate with DEXA T-scores. **Methods**: 96 female patients were enrolled. Patients were consented and completed a topographical scan of bilateral arms and lower legs with a mobile 3D scanner for arm and calf circumference and volume in clinic. Patient charts were then retrospectively reviewed for DEXA T-scores. **Results**: Forearm DEXA T-score was positively correlated with arm circumference ($r = 0.49$, $p<0.01$), arm volume ($r=0.62$, $p<0.01$), and calf volume ($r=0.47$, $p<0.01$). Femoral neck DEXA T-score was positively correlated with calf circumference ($r=0.36$, $p<0.01$) and calf volume ($r=0.36$, $p<0.01$). **Conclusions**: Our results showed significant correlations between DEXA T-scores and topographical measurements from mobile device acquired 3D scans, although these were in the "moderate" range. Mobile device-based 3D scanning may hold promise as an adjunct screening tool for osteoporosis when DEXA scanning is not available or feasible for patients, although further studies are needed to elucidate the full potential of its clinical utility. At a minimum, identifying a patient as high risk may promote earlier diagnostic DEXA scanning.

Keywords: Osteoporosis, DEXA, Screening, Fracture prevention, Sarcopenia

Introduction

The US population is aging, and the healthcare system needs to be well equipped for detecting and treating conditions associated with elderly patients[1]. Osteoporosis, as defined by the Consensus Development Conference, is a systemic skeletal disease characterized by low bone mass and microarchitectural deterioration of bone tissue with a consequent increase in bone fragility and susceptibility to fracture[2]. In the United States, the prevalence of osteoporosis in women >65 years old is over 25% with the number of annual osteoporosis-related fractures estimated to exceed 2 million[3,4]. Osteoporosis-related fractures are associated with increased mortality, decreased quality of life, and high costs[5]. The mortality rate following osteoporotic hip fracture is particularly high, at 8% in men and 3% in women. In the US, approximately 31,000 deaths occur within 6 months of hip fracture annually[5]. Additionally, hip fractures are associated with high levels of morbidity such as pneumonia, chronic pain, UTIs, pressure sores, inability to return to ambulation, and inability to return to living independently[5]. Given this, the US Preventive Services Task Force, as well as numerous other groups, have published osteoporosis screening guidelines which call for screening of women >65 years old[1].

Dual-energy X-ray absorptiometry (DEXA) is the gold standard in osteoporosis screening which measures bone mineral density (BMD)[1]. By DEXA, osteoporosis is defined as a T-score of 2.5 standard deviations or less than the average BMD for a 30-year-old (peak BMD). Unfortunately, screening

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is severely underutilized, with some studies reporting at least 40% of women eligible for screening not receiving it[6-8]. The reason for the high rate of undetected cases of osteoporosis is likely multifactorial. DEXA scans can be time consuming for patients, with the need to attend a follow up appointment, and require dedicated trained technologists to perform the studies. Many healthcare institutions do not have adequate resources to provide widely-available DEXA scans in their communities. Additionally, disparities in socioeconomic status, health insurance type, transportation, and ability to take time off work are likely contributory[6,7,10-13]. This opens the door for the use of new or adjunct screening tests that are efficient with no need for a separate appointment, allowing more patients to be screened.

In efforts to expand access to screening, low-cost imaging alternatives to the DEXA scan, such as quantitative ultrasound, have emerged[15,16]. Further, simple anthropometric measures, notably calf and arm circumference, have been correlated with DEXA scan T-scores, muscle mass, and strength[17-20]. This holds true even in obesity, as it is suggested the excess weight bearing has a muscle training effect in this population[18]. In addition to circumference, increased muscle volume has also been shown to correlate with BMD[21,22].

Recently, low cost, portable topographical scanning technology has become available to digitally acquire 3D scans using mobile devices[23]. This method of body measurement has the potential to be used as an osteoporosis screening adjunct, especially in populations with limited access to DEXA scanning. Advantages of this digital 3D scanning over manual measurement of circumference include increased accuracy in ensuring the largest circumference of the extremity is obtained and the potential for applying machine learning algorithms to 3D scans in order to improve DEXA scan predictions. In addition, extremity volume is able to be obtained. In this study, we hypothesized that 3D scanning of arm and calf circumference and volume will correlate with DEXA T-scores.

Materials and Methods

A prospective observational study was performed at a single academic institution. Inclusion criteria were female patients 40 years or older who presented to the Stanford Orthopaedic Surgery Bone Health clinic with a DEXA scan completed within 10 months prior to enrollment or scheduled within the 30 days after enrollment. Exclusion criteria were patients unable to complete the consent and assent process, and patients who had already begun treatment for bone health (e.g., bisphosphonates). Stanford Orthopaedic Surgery Bone Health clinic treats at risk patients for fracture prevention, and thus has a patient population conducive to this study.

If the patient consented to participate, manual measurements of bilateral upper and lower extremity circumference at the largest region of the bicep and calf were taken. Then, a 3D topographical scan was performed in a private room in the clinic. Patients were age 40-94.

Figure 1. Structure Sensor 3D Camera on iPad.

The topographical scan involved a 360-degree extremity scan using a Structure Sensor 3D camera mounted to an iPad (Figure 1). To prepare for scanning, clothing covering the upper arm and lower legs were removed (e.g., socks off and sleeves pulled up). Scans of the bilateral upper and lower extremities were performed, taking approximately 5 minutes total per patient. These scans were then used to measure largest arm and calf circumferences. Arm and calf volume were also calculated with TechMed 3D MSoft (Québec, Canada) (Figure 2). In some instances, one of the patient's extremity scans taken in clinic was of poor technical quality (e.g., left calf) but the rest of that patient's scans were satisfactory. This can happen if the patient moves suddenly and inadvertently. In this case, the data taken from the rest of that patient's extremity scans were included. Lastly, patient charts were retrospectively reviewed to collect all available DEXA T-scores (including at the forearm, femoral neck, and lumbar spine) within 10 months prior or 30 days after presentation to clinic. For all bilateral measurements, an average between the two sides was calculated. In cases where only one side of a bilateral measurement was available, this measurement was used as the "average" for correlation calculations. Correlation coefficients between manual measurements, topographical-based measurements, and DEXA T-score

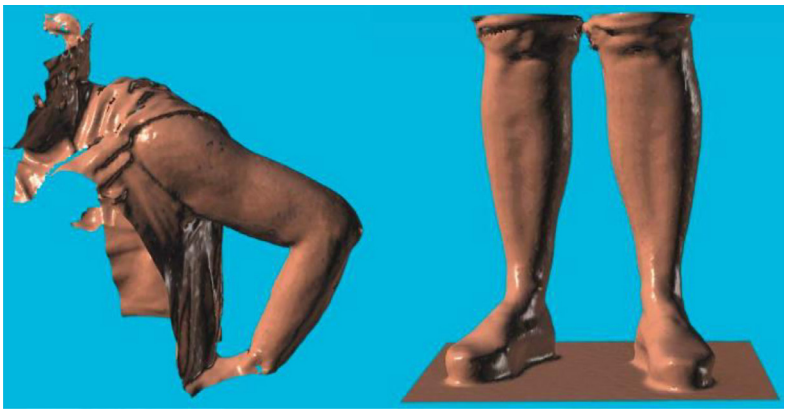

Figure 2. Arm and Calf 3D Scans.

were calculated using SAS version 9.4 software using Pearson's correlation coefficient.

Results

96 female patients were enrolled with mean age of 70.2 (SD = 10.4). The mean DEXA T-scores were -2.0 (SD = 0.9) at the femoral neck, -2.3 (SD = 1.6) at the forearm, and -1.7 (SD= 1.2) at the lumbar spine. Average extremity measurements are detailed in Table 1.

Forearm DEXA T-score was positively correlated with arm circumference ($r = 0.49$, $p<0.01$), arm volume ($r=0.62$, $p<0.01$), and calf volume ($r=0.47$, $p<0.01$). Femoral neck DEXA T-score was positively correlated with calf circumference ($r=0.36$, $p<0.01$) and calf volume ($r=0.36$, $p<0.01$). (Table 2).

The average arm and calf circumference measured with the 3D topographical scan was strongly positively correlated to manually measured arm and calf circumference ($r=0.75$, $p<0.01$; $r=0.72$, $p<0.01$). Average arm and calf volume were also positively correlated with manually measured arm and calf circumference ($r=0.54$, $p<0.01$, $r=0.51$, $p<0.01$) (Table 3).

Characteristic	N (%), Mean ± SD	N data available
Female sex	96 (100%)	96
Age	70.4 ± 10.3	94
BMI	23.9 ± 4.62	85
DEXA T-score		
Forearm	-2.3 ± 1.6	30
Femoral Neck	-2.0 ± 0.9	75
Lumbar Vertebra	-1.7 ± 1.2	78
Average Circumference (manual)		
Arm	28.0 ± 4.0	94
Calf	37.1 ± 3.0	93
Average Circumference (3D scan)		
Arm	30.7 ± 3.9	92
Calf	35.7 ± 4.0	93
Average Volume (3D scan)		
Arm	1333.4 ± 397.6	79
Calf	2254.1 ± 591.3	82

Table 1. Baseline Characteristics.

Discussion

To the best of our knowledge, this is the first study investigating the relationship of extremity circumference and volume to DEXA T-scores using a 3D topographical scan. Our hypothesis was that arm and calf circumference and volume would correlate with DEXA-T-scores given previous investigations using manual measurements[17-22]. Interestingly, our results showed forearm and femoral neck T-scores were more significantly correlated with arm and calf circumference and volume than lumbar T-scores. This is likely explained by the well documented limitation of DEXA scans in degenerative spine, especially given the age of our patient population[24]. The overall low DEXA T-score values of our sample are likely due to nature of the patient population of patients being evaluated at the bone health clinic. Also of interest is that the strongest correlation with forearm DEXA T-score was arm volume, which cannot be easily obtained

	DEXA T-scores					
	Forearm		Femoral Neck		Lumbar Vertebrae	
	Corr coefficient	p value	Corr coefficient	p value	Corr coefficient	p value
3D scan, Circumference						
Arm Circumference, average	**0.49**	<0.01	0.3	<0.01	0.23	<0.01
Calf Circumference, average	0.29	<0.01	**0.36**	<0.01	0.04	<0.01
3D scan, Volume						
Arm Volume, average	**0.62**	<0.01	0.23	<0.01	0.15	<0.01
Calf Volume, average	**0.47**	<0.01	**0.36**	<0.01	0.05	<0.01
Correlation coefficients >0.3 are bolded.						

Table 2. Correlation between DEXA T-scores and 3D scan anthropometric measurements.

Manual Measurement	3D Circumference	3D volume
Arm, Average	0.75 *	0.54*
Calf, Average	0.72 *	0.51*
** = p value <0.001*		

Table 3. Correlation between manual circumference and 3D Scan measurement.

by a manual measurement. Overall, our results showed that 3D scan measurements of arm and calf circumference and volume were correlated with DEXA T-scores, proving our hypothesis to be correct.

There are multiple potential physiological explanations for why 3D topographical measurements correlate with DEXA T-scores. Smaller arm and calf circumferences have been shown to be potential markers of poor nutritional status, sarcopenia, physical performance, and frailty[25,26]. Poor nutritional status may result in insufficient nutrient availability for bone regeneration leading to osteopenia and osteoporosis[26,27]. Additionally, exercise is a well-known protective factor against osteoporosis, and frailty could contribute to a vicious cycle of a sedentary lifestyle and continued muscle wasting and progression of osteoporosis[27]. Lastly, in women specifically, decreases in estrogen following menopause is a well-known mediator in bone loss. In addition to bone loss, low estrogen levels have also been linked to decreases in muscle mass which would present in our study as lower topographical measurements[28]. The physiologic mediators linking osteoporosis as measured by DEXA T-score and topographical measurements are likely multifactorial but could include poor nutritional status, frailty and associated low levels of exercise, and low estrogen levels.

Evidence of underutilization of the DEXA scan has been well documented[6-10,13,29]. The reasons behind this have been explored, and several studies have shown evidence of disparities in race, sex, socioeconomic status, and health insurance type[6,7,10-13]. Similar disparities are seen in bone health outcomes, such as hip fracture incidence, highlighting the importance of actionable change to address these issues[30]. Lower socioeconomic status has been correlated with no show at follow-up appointments[31]. Driving forces behind the barriers to obtaining screening tests in general included lack of insurance, cost, having to take time off work, lack of childcare, and lack of transportation[32]. This highlights the value of creating adjunct screening tests that can be performed quickly, inexpensively, and without an additional appointment to optimize bone health outcomes for all patients when they may not be able to otherwise be screened for osteoporosis.

Total body volume and segmental body volume have been explored as tools for detection of various medical conditions[33]. This has previously been performed through water/air displacement, although this is often not easily accessible for patients and only allows for total body volume measurement[34]. Recently, 3D scanning has been shown to have strong correlations with these traditional methods for assessing volume[33]. However, the full clinical potential of these measurements has yet to be elucidated[35]. In addition to our results, others have shown manual extremity circumference measurements to correlate with 3D scanning measurements; however, 3D scanning allows for a more accurate assessment[36]. Our results showed multiple correlations between DEXA T-scores and 3D topographical measurements of circumference and volume. The clinical implications of our results are that this technology could be

used as an adjunct screening test in cases where patients express monetary or temporal limitations to getting their DEXA scan. Physicians could be equipped with a mobile 3D scanner in clinic and get an estimation of the patient's risk in less than 10 minutes. Although this would not provide an exact measure of the patient's BMD, it would help to address the disparities in osteoporosis screening by allowing for earlier detection and treatment in patients who would not have otherwise received it.

There are limitations to this study. Firstly, the DEXA scans used in this study were performed at multiple facilities which could result in small variations between participant T-scores. Secondly, not every patient had forearm, lumbar, and femoral neck DEXA scores as well as circumference and volume measurements for each extremity. This, in many instances, is because a certain scan such as a forearm DEXA scan was not clinically relevant at the time of treatment, or a 3D scan was unable to be fully processed by our software. Another limitation of our study is that our sample size of 96 patients is relatively small, but served it's purpose as a proof-of-concept. Further studies with larger and more diverse sample sizes could provide additional evidence for the utility of mobile 3D scanning and are being planned for the future. Additionally, a limitation of our study is the retrospective nature of chart review for DEXA T-scores, introducing potential bias and missing data. Lastly, under our methodology, the 3D scan processing included some manual components. These components included selecting the body part of interest from the rest of the body and aligning it in our measurement software. As with any manual process or measurement, there is variation that can be introduced. We hope to address this in the future by creating a system for automatic processing of the scans. Despite these limitations, we believe that 3D scanning is a promising tool for an osteoporosis screening adjunct.

In conclusion, our results show significant positive correlations between DEXA scan measurements, the gold standard for osteoporosis screening, and 3D scan anthropometric extremity measurements. 3D scanning has the potential to offer a quick, accurate, noninvasive, and inexpensive method to estimate BMD when DEXA scanning is not available.

Ethics approval

Approval was obtained from the Stanford University Institutional Review Board, IRB #60296.

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