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Original Article

Repeatability of Volume and Regional Body Composition Measurements of the Lower Limb Using Dual-energy X-ray Absorptiometry

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Abstract

Lower limb lymphedema is a dynamic condition in which tissue composition and volume measurements are affected. Various definitions of lower limb lymphedema exist but volume differences between the limbs are widely used. It is therefore necessary to have a readily available noninvasive measurement technique allowing multiple measurements of the lower limbs. This study investigated the repeatability of duplicate volume and regional body composition measurements of the lower limb using the GE Lunar Prodigy dual-energy X-ray absorptiometry (DXA) scanner Prodigy (GE Medical Systems, Madison, WI). Twenty-seven participants (54 limbs), 14 women and 13 men aged 33–71 years with body mass index ranging from 14 to 32 kg/m^2 were recruited. Duplicate whole-body DXA scans were performed with repositioning between examinations. Regions of interest were manually drawn for the thigh, lower leg, and foot, and total volume was calculated using the density of bone mineral content, fat, and lean mass. The repeatability of the volume of the lower limb and regional thigh and lower leg tissue composition (bone mineral content, fat, and lean mass) was good with intraclass correlation coefficient values of 0.97 to 0.99, and narrow limits of agreement on the Bland–Altman plots. These results confirm DXA to be a highly repeatable method for volume and tissue composition measurements of the lower limb. In a population at risk of lymphedema, DXA offers a clinically readily available noninvasive method allowing multiple measurements of volume and tissue composition on a routine basis, important for diagnosing, monitoring, managing, and researching lymphedema.

Key Words: Body composition; dimensional measurement accuracy; dual-energy X-ray absorptiometry; lower extremity; lymphedema.

Introduction

Lower limb lymphedema (LLL) refers to swelling of the leg due to failure of the lymphatic system to support lymphatic circulation and the drainage of lymphatic fluid. It can be caused by lymphatic interruption due to, for instance, cancer treatment. LLL is associated with high levels of physical and psychosocial distress *(1)*. No cure exists, but LLL can be managed with early diagnosis, treatment, and diligent care of the affected limb. There is no universally accepted standard definition of LLL *(2)*. The diagnosis of LLL is typically made after a thorough history and physical examination. Widely used noninvasive measurement techniques of lymphedema include assessing volume differences between the affected and contralateral limb with water displacement (also known as water plethysmography), indirectly with circumferential measurement, a

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perometer (infrared measuring device), and bioimpedance spectroscopy (BIS). However, previous studies have shown poor repeatability of volume measurements with water displacement and indirectly with circumferential measurements *(3)*. Perometers are widely used for volume measurements of lymphedema. However, perometers and BIS analysis are not widely available, which DXA scanners on the contrary are. This is due to the widespread use of DXA for measuring bone mineral density in assessing osteoporosis and other conditions that cause bone loss or affect bone composition. Our previous study showed that dual-energy X-ray absorptiometry (DXA) assessing volumes of breast cancer-related arm lymphedema and the contralateral arm had excellent repeatability and the method was superior to water displacement and circumference measurements *(3)*. DXA scan is clinically convenient, with low cost and low radiation exposure corresponding to 4–8 μSv. For comparison, the worldwide average effective dose from natural background radiation is 7 μSv/day *(4,5)*.

The initial swelling and volume change of the region with lymphedema are associated with inflammation caused by protein-filled fluid in the subcutaneous tissue. This inflammation may partially explain the tissue composition changes of the affected limb over time with increasing fat deposition, and these changes can be demonstrated with DXA, which provides quantitative measurements of bone mineral content (BMC), fat mass, and lean mass; the latter encompasses the remaining tissue after BMC and fat mass have been subtracted. Swelling of an extremity due to lymphedema will primarily result in increase in lean mass, and later in fat mass *(6)*. Other techniques of assessing tissue composition include computed tomography, magnetic resonance imaging, and BIS. However, routine clinical volume and tissue composition measurements with computed tomography, magnetic resonance imaging, and BIS are not feasible due to costs, radiation exposure, time-consuming examinations and interpretations, which all can be overcome using DXA.

The aim of this study was therefore to assess the repeatability of DXA scans for volume and regional body composition measurement of the lower limb as part of a larger investigative study. To our knowledge, the repeatability of DXA for volume and regional body composition of the lower extremities has not been reported previously.

Materials and Methodology

Participants

The first 27 participants in a larger investigative study, in which DXA scans were performed on all 4 limbs, were included in this study: 14 women and 13 men aged 33–71 years. Inclusion criteria were weight < 136 kg (weight limit of the DXA table) and disease-free melanoma survivors with no radioisotope scan within 3 days. The patients had been treated for stage IB-III primary cutaneous melanoma with wide local excision and unilateral sentinel lymph node biopsy and/or complete lymph node dissection in the axilla and/or groin at least 1 year previously. The exclusion criteria were pregnancy, surgery performed within 30 days, and physically unable to climb the scan table and/or to lie still. All scans were performed during February 2015.

The study was approved by the Danish Regional Committee on Biomedical Research Ethics (journal no.: H-4-2014-127) and the Danish Data Protection Agency (2012-58-0004, local journal no.: HEH-2015-003, I-Suite no.: 03436), and registered with https://clinicaltrials.gov; all subjects gave written informed consent.

Methods

All participants had their height measured to the nearest 0.01 m using a stadiometer and body weight measured to the nearest 0.1 kg in minimal clothing using a SECA weight scale (Hamburg, Germany) before their scan. Body mass index was calculated as weight (kg)/height^2 (m^2). Whole-body DXA scans were performed using the same DXA scanner (Lunar Prodigy DXA mini fan beam scanner serial number DF+13189, GE Medical Systems, Madison, WI) and the same software (Prodigy Med enCore version 15; GE Medical Systems, Madison, WI) was used for all the scans and analyses. A standardized quality control was carried out daily with a variable composition phantom (Lunar).

The participants were consistently positioned lying supine on the scan table with the head at the top end of the table just below the upper scan margin. If the patients were too tall for the table, they were positioned with the head just above the upper scan margin to ensure sufficient scan lines of the lower extremities. The patients were centered within the sides of the table scan margins. The arms were placed straight at the patient's side with a space between the patient's arms and sides. The hands were positioned palms down and not overlapping with the thighs. The legs were kept anatomically positioned with the feet slightly apart. A Velcro strap was placed around the feet to prevent rotation of the lower legs and feet. A radiolucent pillow for the head was supplied for participants who could not lie flat. Identical preparation (e.g., lightly dressed, trousers and socks/stockings off, no metal items, jewelry or watches, daytime scan) was applied for all participants. A whole-body scan was conducted (approximately 8–12 min, depending on the size of the participant). After repositioning (oblique positioning for scan of the left and right arms, respectively), repeat whole-body scans were performed for the 27 participants for the purpose of this study.

Nonremovable artifacts (such as orthopedic implants or jewelry that could not come off) were documented and registered with the software's high-density detection option, which subtracted the relevant pixels during analysis. The automatic point typing of artifacts, bone mass, fat and lean mass was checked and manually corrected, if necessary.

Regions of interest (ROIs) were manually drawn for the thighs, lower legs, and feet using simple anatomical landmarks (inferior border of the pubic bones, knee joint, and talocrural joint). One observer (first author) drew lines