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Could Radiofrequency Echographic Multi-Spectrometry (REMS) Overcome the Limitations of BMD by DXA Related to Artifacts? A Series of 3 Cases

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Dual-energy X-ray absorptiometry (DXA) is considered the gold standard in the evaluation of bone mineral density (BMD) and in the diagnosis of osteoporosis. The diagnostic sensitivity of BMD at lumbar spine is frequently reduced by the presence of artifacts. This study aimed to show the usefulness of radiofrequency echographic multi-spectrometry (REMS) in determining lumbar BMD in the presence of artifacts with DXA measurements. We present 3 cases in which REMS technology, by the analysis of native raw unfiltered ultrasound signals, appears to be able to recognize and overcome the most common artifacts that affect the value of the BMD by DXA, thus allowing a better assessment of fracture risk.

Key Words—bone mineral density (BMD); dual-energy X-ray absorptiometry (DXA) artifacts; osteoporosis; radiofrequency echographic multi-spectrometry (REMS); vertebral fracture

As a result of population aging, osteoporosis currently represents one of the major health problems worldwide. Dual-energy X-ray absorptiometry (DXA) is considered the gold standard in the evaluation of bone mineral density (BMD) and in the diagnosis of osteoporosis; in fact, in the absence of any pre-existing fragility fracture, the diagnosis of osteoporosis relies on an accurate assessment of BMD.1, 5 Moreover, BMD by DXA is the most commonly used method to assess fracture risk and to monitor the efficacy of pharmacological treatments.5, 4 However, limitations of DXA are also important to consider. In particular, several studies have shown that the diagnostic sensitivity of BMD by DXA can be reduced by the fact that many DXA examinations have errors in image analysis and identification of artifacts.5, 6, 7 Lumbar spine is the site most frequently affected by artifacts and alterations that may produce false BMD results.5, 8 In fact, degenerative changes of the lumbar spine due to osteoarthritis, osteophytes, and vascular calcifications or vertebral fractures will produce a false overestimation of effective BMD values and consequently a significant underestimation of fracture risk.6, 7, 8, 9 Moreover, the treatment of vertebral fractures by vertebroplasty, especially when it involves two or more lumbar vertebrae, limits the possibility of obtaining an adequate evaluation of BMD.6 The
International Society for Clinical Densitometry (ISCD) Official Position recommends excluding from the DXA analysis both the vertebrae with substantial degenerative changes and those with a greater than 1.0 T-score difference with respect to the adjacent vertebrae. However, vertebral body exclusions led to a small improvement in fracture prediction and reduced measurement precision and the clinical value of DXA for monitoring. These considerations have encouraged the research toward diagnostic methods complementary or alternative to the current gold-standard DXA. Recently, an innovative nonionizing technology, called radiofrequency echographic multispectrometry (REMS), has been introduced. The operating principle is based on the analysis of native raw unfiltered ultrasound signals, the so-called radio-frequency ultrasound signals, acquired during an echographic scan of the lumbar vertebrae and/or femoral neck. The analysis of native unfiltered ultrasound signals permits the retention of maximum information about the characteristics of the investigated tissues, which are normally filtered out during the conventional process of B-mode image reconstruction. The bone health status is assessed through the comparison of the analyzed signal spectra with previously derived reference spectral models for the considered pathological and normal conditions. The precision and diagnostic accuracy of REMS compared to DXA have already been validated. Moreover, several recent studies have reported that the REMS T-score is able to predict the occurrence of incident fragility fractures in women, representing a promising approach to enhance osteoporosis diagnosis in clinical routine.

The aim of these 3 case reports was to show the usefulness of REMS technology in determining lumbar BMD in the presence of any lumbar spine alterations, which can cause artifacts or pitfalls with DXA measurements.

We retrospectively reviewed the clinical and densitometric data of 3 postmenopausal women referred to the outpatient Clinic for Osteoporosis of the Department of Internal Medicine at the University Hospital of Siena (Italy) for an evaluation of BMD by DXA. In all 3 cases, the densitometric examinations showed the presence of important artifacts at the lumbar spine; therefore, the patients were offered the opportunity to undergo REMS scan on the spine to assess whether REMS technology may provide more information on bone status. The study was approved by the Ethics Committee of our institution, and informed consent was obtained from all 3 participants. All DXA scans were performed using a Discovery W (Hologic, Waltham, MA) scanner according to the standard clinical routine procedures. Medical reports always included both the DXA-based BMD value (expressed as g/cm²) and the corresponding T-score value, based on the standard reference database for caucasian women integrated in the DXA scanner software. REMS scans were performed employing a dedicated echographic device (EchoStation; Echolight Spa, Lecce, Italy), equipped with a convex transducer operating at the nominal frequency of 3.5 MHz and used as recommended by the manufacturer. In a REMS investigation, the probe is placed on the abdomen or on the hip in order to visualize the target bone interface and the operator has to set the appropriate values of scan depth and transducer focus. Subsequently, the software detects the sought bone interfaces in the sequence of acquired frames and identifies the regions of interest for the diagnostic evaluation. The analysis of single scan line spectra allows the automatic exclusion of signals corresponding to artifacts, such as calcifications or osteophytes, thanks to the identification of unexpected spectral features. The selected measured data are finally synthetized in a patient-specific spectrum of the considered bone target, which undergoes an advanced comparison with gender-, age-, site-, and body mass index-matched reference spectral models extracted from a dedicated database. Actually, the spectral modifications introduced by the physical properties of the bone structure that has backscattered the ultrasound signals are identified by the comparison procedure, resulting in a BMD estimation and in the consequent diagnostic classification as healthy, osteopenic, or osteoporotic. Data processing methodologies implemented in the REMS approach were detailed in previous papers.

Case Descriptions

1. Case report no. 1: A 68-year-old woman was referred to the outpatient Clinic for Osteoporosis of the Department of Internal Medicine at the
University Hospital of Siena (Italy) for an evaluation of BMD by DXA. She had presented an atraumatic vertebral fracture 2 months before (Fig. 1 A). Lumbar spine BMD by DXA showed normal values (T-score L1–L4 = −0.1) (Figure 1B); instead, the evaluation by REMS technology showed BMD value indicative for osteoporosis (T-score L1–L4 = −2.6). The presence of vertebral collapse results in an overestimation of the BMD performed by DXA, which does not occur with the REMS examination. In particular, a BMD value by REMS of the fractured vertebra (L1) was indicative of osteoporosis (<−2.5 DS) and lower with respect to the other lumbar vertebrae.

2. **Case report no. 2**: A 79-year-old woman was referred to the outpatient Clinic for Osteoporosis for an evaluation of BMD by DXA. The patient had a history of two previous vertebral fractures treated with vertebroplasty (L2 and L4) (Figure 2A). The assessment of BMD by DXA in this patient is not diagnostic due to the presence of polymethylmethacrylate cement used for vertebroplasty. As evident in Figure 2B, according to the current ISCD 2019 guidelines, the analysis is possible only for L3 and even this presents normal BMD values. The patient underwent a REMS examination of the spine, which showed a BMD indicative of osteoporosis (T-score L1–L4 = −2.8) (Figure 2C). In this case, REMS technology was able, by the evaluation of raw signals, to exclude the presence of artifacts due to polymethylmethacrylate cement, thus allowing a correct evaluation of BMD also in the presence of vertebroplasty.

3. **Case report no. 3**: An 81-year-old woman came to our observation for an evaluation of BMD by DXA. The patient did not report a history of fracture but was suffering from back pain for a long time. The X-ray confirmed the severe osteoarthritis at the lumbar spine with multiple osteophytes (Figure 3A). The assessment of BMD by DXA showed normal values (T-score L1–L4 = −0.5; Figure 3B). Instead, the BMD assessment by REMS showed a severe osteopenia (T-score L1–L4 = −2.4) with T-score values < −2.5 for L2 and L3 (Figure 3C). This case suggests that the evaluation of BMD by REMS may overcome the underestimation of BMD by DXA in patients with osteoarthritis at the lumbar spine with multiple osteophytes.

**Discussion**

To our knowledge, this series of 3 clinical cases represents the first report on the usefulness of REMS to enhance the diagnosis of osteoporosis when lumbar spine BMD by DXA is impaired by artifacts. BMD measurement at the lumbar spine and proximal femur...
by DXA remains the current gold standard for the World Health Organization osteoporosis classification and fracture risk evaluation. However, the lumbar spine is the site most frequently affected by artifacts and alterations that may elevate BMD, thus giving a significant underestimation of fracture risk. While external artifacts (items on patients or on scanner bed, clothing, etc) are quite easily identifiable and avoidable, internal artifacts (osteoarthritis and other degenerative changes, vertebral fractures, vascular calcifications, etc) are often responsible for errors and pitfalls and may affect BMD accuracy and precision. Several authors reported that osteoarthritis in the lumbar spine is common in men and women over the age of 60 years. This relates to the development of osteophytes and facet joint degeneration, and it also increases the BMD of lumbar spine measured in the anteroposterior view by DXA. In particular, several studies have reported that osteophytes can inflate BMD by DXA up to 15–20%. Despite higher BMD levels, women with

Figure 2. Lateral radiograph of lumbar spine (A) in a woman with vertebroplasty of L2 and L4; BMD evaluation by DXA at lumbar spine (B); and BMD evaluation by REMS at lumbar spine (C).

Figure 3. Lateral radiograph of lumbar spine (A) in a woman with arthritis; BMD evaluation by DXA at lumbar spine (B); and BMD evaluation by REMS at lumbar spine (C).
osteoporotic vertebral fractures are a common finding in patients undergoing DXA. These fractures typically occur at the thoracolumbar passage and are characterized by reduced height and trabecular impaction with a consequent increase in the areal BMD.\textsuperscript{5, 8} Vertebral fractures are often treated with vertebroplasty, which involves the use of polymethylmethacrylate cement and is responsible for the inability to obtain an accurate BMD. REMS technology by the analysis of native raw unfiltered ultrasound signals appears to be able to recognize and overcome the most common artifacts that affect the value of the BMD by DXA, making the correct definition of the bone state also at the level of the vertebrae presenting artifacts. This may be important because, according to the meta-analysis by Marshall et al., measurement of the BMD at lumbar spine would be the best predictor for vertebral fracture risk.\textsuperscript{19}

In conclusion, REMS technology may represent a promising approach to enhance osteoporosis diagnosis in clinical routine. Further studies are warranted in order to confirm these preliminary data and to establish the usefulness of REMS for a better fracture risk evaluation in patients with artifacts by DXA at lumbar spine.

References