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Radiofrequency echographic multi-spectrometry-based measurement of bone mineral density in patients with severe motor and intellectual disability: An opportunity for patients with severe scoliosis and hip dislocation

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A R T I C L E I N F O

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A B S T R A C T

Purpose: Radiofrequency echographic multi-spectrometry (REMS) is an ultrasound technology currently used for the densitometric evaluation of osteoporosis and has been validated against dual-energy X-ray absorptiometry. However, the use of REMS for bone densitometry in patients with severe motor and intellectual disabilities (SMID) remains to be reported. This study aimed to investigate whether REMS technology can be used for densitometric evaluation of osteoporosis in patients with SMID with hip dislocation and severe scoliosis.
Methods: Sixty-five patients with SMID, who resided in a long-term care facility and received comprehensive medical and rehabilitation care, underwent REMS scans of the femoral neck and/or lumbar spine. Data regarding anthropometric parameters (height and weight), bone mineral density (BMD), clinical diagnostic classification, physical ability, presence of scoliosis and hip dislocation, and frontal radiographs of both hip joints were obtained.
Results: We included 29 men and 34 women (mean age: 52.6 years). All patients underwent successful scanning at either the femoral neck (82.5 %) or lumbar spine (95.2 %). BMD measurements obtained using REMS revealed low values, with a mean BMD, T-score, and *Z*-score of 0.67 g/cm^2, −2.39 standard deviation (SD), and − 1.38 SD, respectively, at the femoral neck and 0.66 g/cm^2, −2.70 SD, and − 1.87 SD, respectively, at the lumbar spine. The average Cobb angle of the lumbar spine was 34.0°; furthermore, dislocation rates did not significantly differ between those with and without successful BMD measurements ($p = 0.073$). Lumbar BMD T-scores were significantly correlated with femoral neck BMD T-scores ($p < 0.001$, $r = 0.530$).
Conclusion: All patients with SMID were able to undergo measurements of either spinal or femoral neck BMD; furthermore, 77.7 % of the patients underwent measurements at both the lumbar spine and femur. Our data suggest that REMS is useful for measuring BMD in patients with SMID who are residing in institutions.

1. Introduction

Osteoporosis, a disorder of bone metabolism characterized by the loss of bone mass and changes in the macro- and microstructure of skeletal tissues, is a major cause of non-traumatic or low-energy trauma fractures commonly known as fragility fractures (Lane et al., 2000; Matcuk Jr et al., 2016). This condition can be primary, resulting from age-related changes such as the effects of menopause in women, or secondary, resulting from cancer, metabolic diseases, nutritional disorders, or immobility (Polymeris et al., 2013).

Osteoporosis diagnosis relies on bone mineral density (BMD) measurement, which is expressed as real BMD (g/cm^2) or volumetric BMD

Abbreviations: REMS, radiofrequency echographic multi-spectrometry; DXA, dual-energy X-ray absorptiometry; SMID, severe motor and intellectual disabilities; BMD, bone mineral density; YAM, young adult mean.

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(g/cm^3) (Fuggle et al., 2019). Dual-energy X-ray absorptiometry (DXA) is the clinical reference technique for BMD evaluation (Anthamatten and Parish, 2019; Liu et al., 2019). DXA measures X-ray attenuation passing through tissues, with BMD being calculated from this attenuation (Ishizu et al., 2024). Osteoporosis diagnosis involves comparison of individual results with a T-score obtained from a healthy reference population (Borgström et al., 2020; Kanis et al., 2019). DXA is the main method for BMD measurement in osteoporosis (El-Hajj Fuleihan et al., 2017; Carey and Chih-Hsing, 2022); however, it may yield falsely elevated values in the lumbar spine of patients with scoliosis due to the curve magnitude and osteophyte presence (Bessant and Keat, 2002; Pappou et al., 2006). Furthermore, femoral rotation may affect femoral neck BMD (Rosenthall, 2004). In Japan, the term severe motor and intellectual disabilities (SMID) refers to limited physical function (bedridden or sedentary) and an intelligence quotient ≤35. Patients with SMID experience severe osteoporosis secondary to immobility and nutritional disorders (Frighi et al., 2019; Sakai et al., 2020). As fragility fractures occur in ≈5 % of these patients annually (Morishita et al., 2015; Hagino et al., 2022), they require treatment for osteoporosis. BMD measurement is specifically required to assess osteoporosis severity, select osteoporosis treatment, and evaluate the efficacy of this treatment. However, patients with SMID are limited in terms of physical activities and often live in institutions, which impedes regular hospital visits for DXA measurements. They also typically have muscle tone impairment of either the hypertonic or hypotonic type as well as a bent or twisted trunk caused by spasticity, which is difficult to treat. This often results in severe scoliosis, hip joints with a limited range of motion, and long-term hip dislocation (Rutz and Brunner, 2013; van Timmeren et al., 2016; Huser et al., 2018; Yoshida et al., 2018).

Radiofrequency echographic multi-spectrometry (REMS) is a newly developed technique that analyzes bone quantity and quality using a non-ionizing approach based on an analysis of the backscatter of the ultrasound signal (Cortet et al., 2021). In this study, BMD was calculated using REMS to generate a patient-specific spectrum of a bone of interest. Subsequently, this BMD measurement was compared to a proprietary database of reference ultrasound spectral models. The corresponding T-score and *Z*-score values were then derived using a normative reference database (National Health and Nutrition Examination Survey). This method has been validated by several studies focusing on specific age groups (Di Paola et al., 2019; Bojincă et al., 2019; Adami et al., 2020; Kirilova et al., 2019). Moreover, the diagnostic accuracy of REMS compared with that of DXA has been investigated in a European multicenter clinical setting, which showed a very high correlation between the BMD and T-score values measured using DXA and REMS in a population of women aged 30–90 years. REMS showed excellent performance in the identification of patients with osteoporosis in the lumbar spine and femoral neck, with sensitivity and specificity values above 90 %, a positive predictive value of 82 %–86 %, and a negative predictive value of ≥97 % (Cortet et al., 2021). Furthermore, REMS has been shown to be a reliable diagnostic method for osteoporosis in men (Adami et al., 2024).

Accordingly, the present study aimed to investigate whether REMS could be used to measure BMD of the spine and femoral neck in patients with SMID, who frequently present hip dislocation and severe scoliosis, and to establish a method for measuring BMD in patients whose bone morphology hampers the use of DXA.

2. Materials and methods

2.1. Patients and measurements

For this single-center, cross-sectional, observational study, we recruited patients admitted to Akitsu Ryoikuen (Tokyo, Japan), which is a facility offering disability care. This facility provides long-term care for patients with SMID, offering appropriate medical and rehabilitation services. The inclusion criteria were as follows: enrollment in Akitsu Ryoikuen, age ≥ 20 years, and provision of written informed consent from the patients themselves or their families. Patients for whom signed informed consent was not provided by themselves or their families were excluded.

From May 2023 to December 2023, patients underwent BMD measurements using REMS scanning of the spine and femoral neck. Anthropometric parameters (height and weight), clinical diagnostic classification, physical ability, and the presence of scoliosis and dislocation were assessed. Additionally, frontal radiographs of both hip joints were obtained. At the facility, the progression of scoliosis in the hip joints and spines of these patients is studied every other year using longitudinal and bilateral frontal radiographs of the hip joints. Radiographs obtained within the past 2 years were used to investigate the presence of scoliosis and hip dislocation. The Cobb angle was defined as the angle between the extension line of the upper endplate of the top-most inclined vertebral body and the extension line of the lower endplate of the bottom-most inclined vertebral body in a curved segment of the spine on radiography. The Cobb angle was set at 0° in patients without scoliosis.

REMS measurements were performed as described by Di Paola et al., 2019).

Patients with SMID typically exhibit a flexed or twisted trunk due to severe spasticity. When imaging the lumbar spine, this posture may be limited by scoliosis, hip contracture, or hip dislocation. In such cases, a stable supine position with a cushion, which is commonly used in daily life, was employed for imaging on a case-by-case basis. Femoral imaging is often conducted with the patient in a flexion contracture position, regardless of the presence of dislocation. In cases of unilateral hip dislocation, imaging was focused on the non-dislocated hip, while images were captured on both sides in cases of bilateral high hip dislocation.

REMS scans of the lumbar spine and proximal femur were performed using an EchoStation echographic device (Echolight Spa, Lecce, Italy). Automatic REMS data processing was performed as previously described (Di Paola et al., 2019). Scanning of the lumbar spine involved moving the convex probe transabdominally along the L1–L4 vertebrae in accordance with the instrument software user manual (EchoStudio; Echolight Spa). Conversely, proximal femoral scans were performed by positioning the convex probe parallel to the femoral head-neck axis in order to visualize the interface between the femoral head, neck, and transverse plane. For each acquisition, the operator set the transducer focus (range 21–100 mm) and scan depth (range 60–210 mm) to visualize the target bone interface (i.e., the vertebral surface or the femoral neck) at approximately half of the reconstructed B-mode image depth.

The study variables encompassed the patients' age, sex, height, weight, presence of hip dislocation, Cobb angle for scoliosis assessment, and success rate of REMS measurement at the femoral neck. Additionally, we included BMD, T-scores, and *Z*-scores obtained using REMS of the femoral neck. Furthermore, we incorporated the success rate of REMS measurement at the lumbar spine along with BMD, T-scores, and Z-scores available using REMS of the lumbar spine.

2.2. Statistical analyses

Patients were divided into two groups: those with and without successful BMD measurements of the femoral neck. Age, sex, height, weight, and the presence or absence of hip dislocation were compared between the groups. The Mann–Whitney *U* test was used to examine significant between-group differences in the continuous coefficients of age ~~and Cobb angle~~. Fisher's exact test was used to determine statistically significant associations between successful REMS measurement and the presence of hip dislocation. We calculated Pearson's correlation coefficients between the T-scores of the lumbar spine and femoral neck when both datasets were obtained. The significance level was set at $p < 0.05$, using the Bell Curve for Excel 2016 (Social Research and Information, Inc., Tokyo, Japan).

An a priori power analysis was conducted using G*Power (Faul et al., 2009), based on a χ^2 test, with an effect size = 0.4, alpha value = 0.05, and power (1 - beta probability) = 0.80. Accordingly, the sample size was calculated to be 50. The post-hoc power analysis was based on a χ^2 test with an effect size = 0.530, alpha value = 0.05, and sample size = 63. Therefore, the power of this study was 0.99. A post-hoc power analysis revealed that the sample size used was sufficient to detect significant differences.

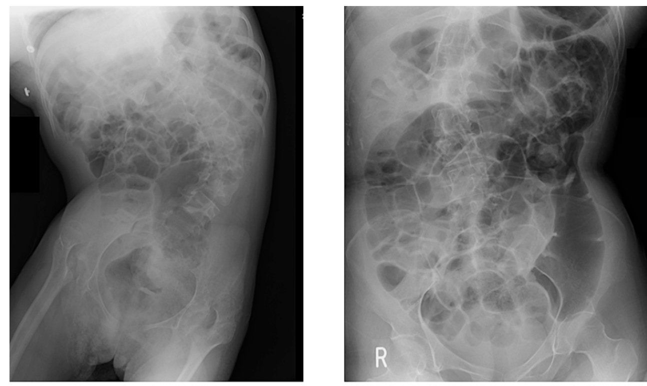
2.3. Ethics

This study was approved by the Research Ethics Committee of Tokyo Medical and Dental University (approval number: M2022–021, August 1, 2023) and was conducted in accordance with the principles of the Declaration of Helsinki. Written informed consent to participate in the study was obtained from the participants or their parents or guardians in cases of participants with diminished capacity to provide consent on September 6, 2023.

3. Results

The Akitsu Ryoikuen facility had 175 institutionalized adult residents (age ≥ 20 years); among them, 63~~5~~ were recruited for this study. All patients underwent scanning of the femoral neck and lumbar spine for BMD measurements (Table 1).

The patient cohort included 29 men and 34 women, with an average age of 52.6 years. The clinical diagnostic classifications of the participants in the SMID group were as follows: cerebral palsy (n = 46), developmental disorders (n = 10), encephalopathy (n = 5), and genetic abnormalities (n = 2). In terms of physical ability, 10 patients could walk with assistance, 18 could sit by themselves, and 34 were bedridden. The definition of physical disability in patients with SMID is the inability to walk. Therefore, the 10 patients who required walking assistance did not meet the definition of SMID and were termed "SMID peripherals;" however, these patients lived in the same institute and were not excluded from this study. Additionally, there were 15 patients with previous fragility fractures among the included patients, with none of them presenting multiple fractures. Bone densitometry of the lumbar spine was successful in 60 patients (95.2 %) and unsuccessful in 3 (4.8 %) patients (Fig. 1a); furthermore, bone density scanning of the femur was successful and unsuccessful in 52 (82.5 %) and 11 (17.5 %) patients, respectively. However, BMD at one or the other site could be measured



(a) (b)

Fig. 1. Representative radiographs of patients with severe motor and intellectual disabilities
(a) Cobb angle of 96°, bilaterally high dislocated hips. (b) Gas retention.

Table 1
Characteristics of the patients.

	Total	Lumbar spine measurement (+)	Lumbar spine measurement (−)	p	Femoral measurement (+)	Femoral measurement (−)	p
n. (%)	63	60 (95.2)	3 (4.8)		52 (82.5)	11 (17.5)	
Age							
average ± SD	52.6 ± 12.7	52.1 ± 12.7	61.0 ± 11.5	N/A[f]	53.8 ± 13.1	48.2 ± 9.8	0.113[c]
(range)	(22–77)	(22–77)	(49–72)		(22–77)	(32–61)	
Sex (M/F)	29 / 34	28/ 32	1/2		24/ 28	5/6	
Cobb angle (°)							
average ± SD	34.0 ± 32.9	34.2 ± 33.2	28.3 ± 30.7	N/A[f]			
(range)	(0–122)	(0–122)	(0–61)				
Hip subluxation or luxation							0.073[d]
n. (%)	19 (29.2)				13 (25.0)	6 (54.5)	Cramer's V: 0.244
Height (cm)							
average ± SD[a]	149.3 ± 9	149.7 ± 8.9	143.7 ± 10.4		149.9 ± 7.96	147.6 ± 12.8	
(range)	(129–167)	(129–167)	(132–152)		(131–165)	(129–167)	
Weight (kg)							
average ± SD[a]	39.6 ± 5.3	39.8 ± 5.4	37.3 ± 4.6		40.1 ± 5.3	38.2 ± 5	
(range)	(30–55)	(30–55)	(32–40)		(30–55)	(30–47)	
BMD [b]							
average ± SD[a]		0.66 ± 0.12			0.67 ± 0.09		
(range)		(0.53–0.87)			(0.61–0.83)		
T-score							
average ± SD[a]		−2.70 ± 0.79			−2.39 ± 0.73		p < 0.001[e]
(range)		(−4.5–1.0)			(−0.2–3.5)		r = 0.530
Z-score							
average ± SD[a]		−1.87 ± 0.63			−1.38 ± 0.77		
(range)		(−0.2–3.2)			(−1.1–2.8)		
T-score < −2.5 SD							
n. (%)		39 (65.0)			29 (55.8)		

N/A: The sample size was small; therefore, no statistical analyses were conducted for these variables.
[a] SD: Standard deviation.
[b] BMD: bone mineral density.
[c] Mann–Whitney tests were used to compare variables between the two groups.
[d] Fisher's exact tests were conducted between the two groups.
[e] Pearson's correlations were examined between the T-scores of the lumbar spine and femoral neck.

in every patient.

The mean Cobb angle was 34.0° (range, 0° to 122°). Among patients with successful and unsuccessful measurement of lumbar spine BMD, the average Cobb angles were 34.2° and 28.3°, respectively. Among patients with successful and unsuccessful femoral BMD measurement, 13 (25.0 %) and 6 (54.5 %) patients had a hip dislocation, respectively, with no significant difference. Furthermore, age did not significantly differ according to success of lumbar spine or femoral neck BMD measurements. The BMD of the femoral neck was notably low (0.66 g/cm^2), with corresponding T-score and *Z*-score of −2.31 standard deviation (SD) and −1.37 SD, respectively. Similarly, the BMD of the lumbar spine was low (0.67 g/cm^2), with corresponding T-score and Z-score of −2.71 SD and − 1.87 SD, respectively. According to criteria from the World Health Organization regarding osteoporosis (WHO Study Group, 1994), if a patient has a peak bone mass 2.5 SD below the reference value, their T-score is −2.5 SD, and they are considered to have frank osteoporosis.

As per our results, ≈65.0 % and 55.8 % of the patients with SMID had a T-score of ≤ − 2.5 SD for the lumbar spine BMD and femoral neck BMD, respectively. The BMD T-scores for the lumbar spine were significantly correlated with those of the femoral neck ($r = 0.530$, $p \leq 0.001$) (Fig. 2).

4. Discussion

In this study, REMS was successfully used to measure BMD in institutionalized patients with SMID. BMD could be measured in the lumbar spine of 95.2 % of the included patients with SMID. These patients had an average 34.2° Cobb angle deformation of the spine. The Cobb angle did not significantly differ between patients with successful and unsuccessful BMD measurement of the lumbar spine. Successful BMD measurement was achieved in the patient with the most severe scoliosis and a Cobb angle of 122°. Therefore, the success of BMD measurement in patients with SMID was not related to the severity of scoliosis. Gas retention was often observed in the abdomen of patients with SMID (Fig. 1b) and could impede bone identification. When intestinal gas obscures bone visibility, gentle pressure applied to the abdomen with a probe can temporarily displace the gas, allowing bone visualization. In patients with severe scoliosis, who have more pronounced abdominal displacement, bones might be captured in areas with less intestinal gas accumulation. Given the daily variability in gas retention, the success of BMD measurement may vary, with successful measurements being achievable on different days.

BMD at the femoral neck was successfully measured in 82.5 % of the patients; among them, 25.0 % had hip dislocation. The hip dislocation rate was similar between the groups with and without successful femoral neck BMD measurement. Femoral neck BMD measurement was feasible in 68.4 % and 88.6 % of the patients with and without hip dislocation, respectively. However, hip dislocation was not associated with the successful measurement of femoral neck BMD. We believe that BMD measurement at the femoral neck is impeded by hip flexion contractures, which are present in almost all patients. The hip joint is often dislocated in patients with SMID owing to high spasticity or low muscle tension. During childhood, hips typically maintain a concentric joint position. However, they may transition to an eccentric joint position, leading to subluxation and eventual dislocation, resulting in severe hip dislocation. In many of our included patients, the hips were not in maximum extension due to spasticity. Even in those with hips in the concentric position, the relationship between the pelvis and femoral neck changed in patients who progressed to subluxation or dislocation. While many patients with SMID experience muscle impairment, often characterized by hypertonic muscles, some may exhibit hypotonic muscles.

In cases of flexion contracture, most of the femoral neck is present in the acetabulum, which interferes with acoustic contact between the probe and femoral neck. Therefore, to approach the femoral neck, the probe should slide anteromedially along the femur rather than along its anterior aspect; furthermore, the femoral neck can be identified by moving the probe slightly anteromedially from the anterior face of the femur.

In cases with highly dislocated hips, the femoral heads are typically dislocated posteriorly with externally rotated femurs. The femoral neck should be approached, the pelvis bypassed, and the probe tilted from the superior margin of the greater trochanter of the femur toward the neck in the dislocated hip. This approach should be planned based on radiographs to ensure the success of femoral neck BMD measurement.

BMD measurements performed with the REMS method were successful at one or both sites in all the included patients (95.2 % at the

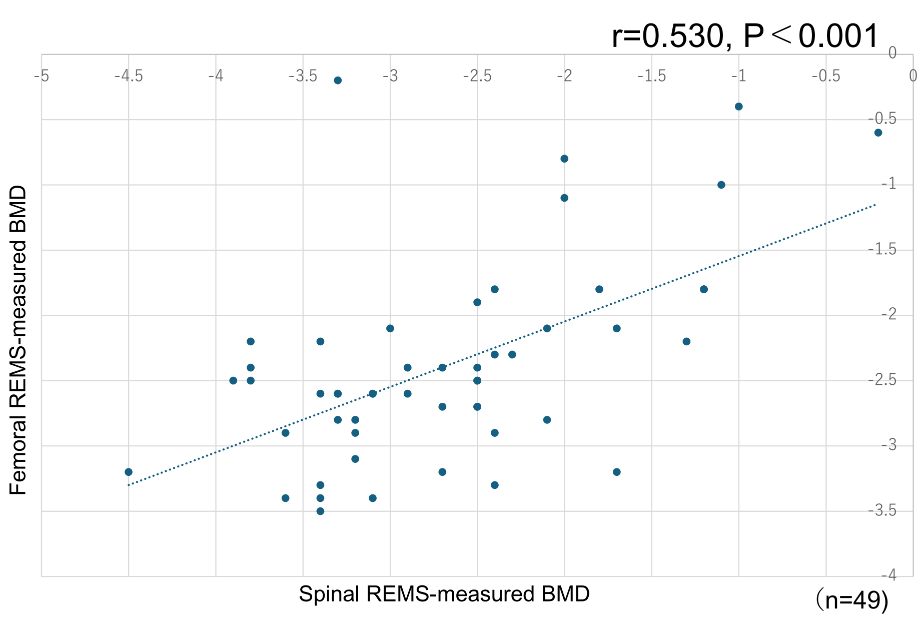


Fig. 2. Correlation between spinal and femoral REMS-measured BMD.
The correlation plot illustrates the relationship between spinal and femoral REMS-measured BMD values.
The number of patients who underwent both spinal and femoral measurements is indicated ($n = 49$). The x-axis and y-axis represent spinal and femoral REMS-measured BMDs, respectively.
BMD, bone mineral density; REMS, radiofrequency echographic multi-spectrometry.

lumbar spine, 82.5 % at the femoral neck, and 77.7 % at both sites). BMD measurement at the lumbar spine and femoral neck is not universally feasible in all cases of SMID owing to the associated bone morphology. Specifically, in 17.5 % of patients, imaging was only possible for the lumbar spine, and in 4.8 %, only one of the hips could be imaged. However, the success rate can be increased by combining the two sites.

The T-scores of the lumbar BMD achieved using REMS were significantly correlated with the T-scores of the femoral neck BMD. In patients with scoliosis, spinal BMD values obtained using DXA are less valuable for monitoring osteoporosis than hip BMD values; these patients exhibit discordantly high spinal BMD values despite significant hip osteoporosis. This discrepancy is correlated with aging and the magnitude of curvature (Pappou et al., 2006). Compared with DXA, REMS has shown superior diagnostic capability for osteoporosis in populations with varying severity levels of osteoarthritis or a history of vertebral fracture (Caffareilli et al., 2022; Caffareilli et al., 2024). Additionally, REMS provides a more accurate measurement of BMD, mitigating the overestimation observed with DXA due to factors such as vertebral deformities, abdominal aortic calcification, and diabetes mellitus (Fassio et al., 2023; Ishizu et al., 2024).

In the present study, the BMD of the lumbar spine and femoral neck measured by REMS in patients with SMID yielded T-scores of −2.70 and − 2.39, respectively. Adults with cerebral palsy have decreased BMD, which is associated with male sex, age, decreased gross motor function, loss of ambulatory function, low body mass index, decreased total fat mass, and decreased total fat-free mass (Won and Jung, 2021).

REMS is quite useful for patients with SMID who reside in a facility where they do not require to be transported to the hospital, and lumbar and femoral neck BMD can be measured frequently without radiation exposure. REMS has been shown to discern severe bone status impairment between patients with osteogenesis imperfecta-I and osteogenesis imperfecta-III–IV. It can facilitate identification of new parameters derived from REMS analyses that can effectively characterize bone quality. This could be especially valuable in individuals with rare skeletal diseases who are at an increased risk of fractures (Caffarelli et al., 2023).

REMS has emerged as a preferred method for assessing bone status in young individuals, particularly in pregnant and lactating women, by offering a radiation-free alternative. Moreover, its utility extends to the evaluation of various secondary osteoporosis conditions, notably in hospitalized patients with mobility limitations, given its portability for bedside and clinical use. These innovative attributes underscore the potential for REMS to inspire further research into its role in bone evaluation and longitudinal monitoring across the lifespan.

In this study, differences were observed between ambulatory patients labeled as “SMID peripherals” and non-ambulatory patients with SMID. Given the novelty of REMS, there remain no reports regarding its application in patients with SMID. Therefore, further research is warranted to explore its characteristics and progression in this specific population.

In the future, we intend to use the REMS method to examine the individual BMD characteristics in patients with SMID, as well as to identify the effects of nutrition, physical activity, severity of the underlying disease, and aging on BMD in this patient population in order to evaluate treatments and outcomes.

This study has some limitations. First, it was a single-center study. Further multicenter studies are required to validate our findings. Second, the validity of these data must be demonstrated in BMD follow-up studies ~~and in patients with actual osteoporosis~~.

5. Conclusion

All patients diagnosed with SMID could undergo BMD measurements at either the lumbar spine or femoral neck, with 77.7 % of patients undergoing successful measurements at both sites. REMS can be used to measure BMD in the lumbar spine and femoral neck of patients with SMID, in whom BMD measurements by DXA are often discontinued due to severe scoliosis or hip dislocation. Additionally, REMS is useful for measuring BMD in patients with SMID who reside in institutions.

CRediT authorship contribution statement

Tomoko Sakai: Writing – review & editing, Writing – original draft, Project administration, Data curation, Conceptualization. **Masanobu Hirao:** Writing – review & editing, Data curation. **Yusuke Takashina:** Writing – review & editing, Data curation. **Ryo Kitagawa:** Writing – review & editing, Data curation. **Tsutomu Oishi:** Validation, Supervision, Data curation.

Declaration of competing interest

None.

Data availability

Data will be made available on request.

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References

Adami, G., Arioli, G., Bianchi, G., Brandi, M.L., Caffarelli, C., Cianferotti, L., Gatti, D., Girasole, G., Gonnelli, S., Manfredini, M., Muratore, M., Quarta, E., Quarta, L., 2020. Radiofrequency echographic multi spectrometry for the prediction of incident fragility fractures: a 5-year follow-up study. Bone 134, 115297. https://doi.org/10.1016/j.bone.2020.115297.

Adami, G., Brandi, M.L., Caffarelli, C., Casciaro, E., Conversano, F., Di Paola, M., Fassio, A., Gatti, D., Giusti, F., Gonnelli, S., Lombardi, F.A., Muratore, M., Pisani, P., Rosini, M., 2024. Bone health status evaluation in men by means of REMS technology. Aging Clin. Exp. Res. 36, 74. https://doi.org/10.1007/s40520-024-02728-4.

Anthamatten, A., Parish, A., 2019. Clinical update on osteoporosis. J. Midwifery Womens Health 64, 265–275. https://doi.org/10.1111/jmwh.12954.

Bessant, R., Keat, A., 2002. How should clinicians manage osteoporosis in ankylosing spondylitis? J. Rheumatol. 29, 1511–1519.

Bojincă, V.C., Popescu, C.C., Decianu, R.D., Dobrescu, A., Bălănescu, Ș.M., Bălănescu, A. R., Bojincă, M., 2019. A novel quantitative method for estimating bone mineral density using B-mode ultrasound and radiofrequency signals-a pilot study on patients with rheumatoid arthritis. Exp. Ther. Med. 18, 1661–1668. https://doi.org/10.3892/etm.2019.7746.

Borgström, F., Karlsson, L., Ortsäter, G., Norton, N., Halbout, P., Cooper, C., Lorentzon, M., McCloskey, E.V., Harvey, N.C., Javaid, M.K., Kanis, J.A., International Osteoporosis Foundation, 2020. Fragility fractures in Europe: burden, management and opportunities. Arch. Osteoporos. 15, 59. https://doi.org/10.1007/s11657-020-0706-y.

Caffarelli, C., Al Refaie, A., Mondillo, C., Manasse, G., Versienti, A., Tomai Pitinca, M.D., Conticini, E., Frediani, B., Gonnelli, S., 2024. The advantages of radiofrequency echographic multispectrometry in the evaluation of bone mineral density in a population with osteoarthritis at the lumbar spine. Diagnostics (Basel). 14, 523. https://doi.org/10.3390/diagnostics14050523.

Caffarelli, C., Al Refaie, A., Mondillo, C., Versienti, A., Baldassini, L., De Vita, M., Tomai Pitinca, M.D., Gonnelli, S., 2023. Radiofrequency echographic multispectrometry (REMS): a new option in the assessment bone status in adults with osteogenesis imperfecta. J. Imaging. 9, 210. https://doi.org/10.3390/jimaging9100210.

Caffarelli, C., Tomai Pitinca, M.D., Al Refaie, A., De Vita, M., Catapano, S., Gonnelli, S., 2022. Could radiofrequency echographic multispectrometry (REMS) overcome the

overestimation in BMD by dual-energy X-ray absorptiometry (DXA) at the lumbar spine? BMC Musculoskelet. Disord. 23, 469. https://doi.org/10.1186/s12891-022-05430-6.
Carey, J.J., Chih-Hsing Wu, P., Bergin, D., 2022. Risk assessment tools for osteoporosis and fractures in 2022. Best Pract. Res. Clin. Rheumatol. 36, 101775 https://doi.org/10.1016/j.berh.2022.101775.
Cortet, B., Dennison, E., Diez-Perez, A., Locquet, M., Muratore, M., Nogués, X., Ovejero Crespo, D., Quarta, E., Brandi, M.L., 2021. Radiofrequency echographic multi spectrometry (REMS) for the diagnosis of osteoporosis in a European multicenter clinical context. Bone 143, 115786. https://doi.org/10.1016/j.bone.2020.115786.
Di Paola, M., Gatti, D., Viapiana, O., Cianferotti, L., Cavalli, L., Caffarelli, C., Conversano, F., Quarta, E., Pisani, P., Girasole, G., Giusti, A., Manfredini, M., Arioli, G., Matucci-Cerinic, M., Bianchi, G., Nuti, R., Gonnelli, S., Brandi, M.L., Muratore, M., Rossini, M., 2019. Radiofrequency echographic multispectrometry compared with dual X-ray absorptiometry for osteoporosis diagnosis on lumbar spine and femoral neck. Osteoporos. Int. 30, 391–402. https://doi.org/10.1007/s00198-018-4686-3.
El-Hajj Fuleihan, G., Chakhtoura, M., Cauley, J.A., Chamoun, N., 2017. Worldwide fracture prediction. J. Clin. Densitom. 20, 397–424. https://doi.org/10.1016/j.jocd.2017.06.008.
Fassio, A., Andreola, S., Gatti, D., Bianco, B., Gatti, M., Gambaro, G., Rossini, M., Viapiana, O., Negrelli, R., Adami, G., 2023. Radiofrequency echographic multi-spectrometry and DXA for the evaluation of bone mineral density in a peritoneal dialysis setting. Aging Clin. Exp. Res. 35, 185–192. https://doi.org/10.1007/s40520-022-02286-7.
Faul, F., Erdfelder, E., Buchner, A., Lang, A.G., 2009. Statistical power analyses using G*power 3.1: tests for correlation and regression analyses. Behav. Res. Methods 41, 1149–1160. https://doi.org/10.3758/BRM.41.4.1149.
Frighi, V., Morovat, A., Andrews, T.M., Rana, F., Stephenson, M.T., White, S.J., Fower, E., Roast, J., Goodwin, G.M., 2019. Vitamin D, bone mineral density and risk of fracture in people with intellectual disabilities. J. Intellect. Disabil. Res. 63, 357–367. https://doi.org/10.1111/jir.12581.
Fuggle, N.R., Curtis, E.M., Ward, K.A., Harvey, N.C., Dennison, E.M., Cooper, C., 2019. Fracture prediction, imaging and screening in osteoporosis. Nat. Rev. Endocrinol. 15, 535–547. https://doi.org/10.1038/s41574-019-0220-8.
Hagino, T., Ochiai, S., Senga, S., Yamashita, T., Saito, M., Wako, M., Taniguchi, N., Ando, T., Haro, H., 2022. Risk factors for long bone fractures in patients with severe motor and intellectual disabilities: a 6-year follow-up retrospective study. Prog. Rehabil. Med. 7, 20220018. https://doi.org/10.2490/prm.20220018.
Huser, A., Mo, M., Hosseinzadeh, P., 2018. Hip surveillance in children with cerebral palsy. Orthop. Clin. North Am. 49, 181–190. https://doi.org/10.1016/j.ocl.2017.11.006.
Ishizu, H., Shimizu, T., Sakamoto, Y., Toyama, F., Kitahara, K., Takayama, H., Miyamoto, M., Iwasaki, N., 2024. Radiofrequency echographic multispectrometry (REMS) can overcome the effects of structural internal artifacts and evaluate bone fragility accurately. Calcif. Tissue Int. 114, 246–254. https://doi.org/10.1007/s00223-023-01167-z.
Kanis, J.A., Cooper, C., Rizzoli, R., Reginster, J.Y., Scientific Advisory Board of the European Society for Clinical and Economic Aspects of Osteoporosis (ESCEO), The Committees of Scientific Advisors and National Societies of the International Osteoporosis Foundation (IOF), 2019. European guidance for the diagnosis and management of osteoporosis in postmenopausal women. Osteoporos. Int. 30, 3–44. https://doi.org/10.1007/s00198-018-4704-5.
Kirilova, E., Kirilov, N., Popov, I., Vladeva, S., 2019. Bone mineral density of lumbar spine and femoral neck assessed by novel echographic approach-radiofrequency echographic multi spectrometry (REMS). Clin. Cases Miner. Bone Metab. 16, 14–17.
Lane, J.M., Russell, L., Khan, S.N., 2000. Osteoporosis. Clin. Orthop. Relat. Res. 139–150 https://doi.org/10.1097/00003086-200003000-00016.
Liu, J., Curtis, E.M., Cooper, C., Harvey, N.C., 2019. State of the art in osteoporosis risk assessment and treatment. J. Endocrinol. Invest. 42, 114–164. https://doi.org/10.1007/s40618-019-01041-6.
Matcuk Jr., G.R., Mahanty, S.R., Skalski, M.R., Patel, D.B., White, E.A., Gottsegen, C.J., 2016. Stress fractures: pathophysiology, clinical presentation, imaging features, and treatment options. Emerg. Radiol. 23, 365–375. https://doi.org/10.1007/s10140-016-1390-5.
Morishita, S., Hara, H., Date, S., Tokura, H., 2015. Report of questionnaire survey (in Japanese). Bull west Jpn. Assoc. Inst. Children Severe Disabil. 15, 42–56.
Pappou, I.P., Girardi, F.P., Sandhu, H.S., Parvataneni, H.K., Cammisa Jr., F.P., Schneider, R., Frelinghuysen, P., Lane, J.M., 2006. Discordantly high spinal bone mineral density values in patients with adult lumbar scoliosis. Spine (Phila Pa 1976) 31, 1614–1620. https://doi.org/10.1097/01.brs.0000222030.32171.5f.
Polymeris, A., Michalakis, K., Sarantopoulou, V., 2013. Secondary osteoporosis – an endocrinological approach focusing on underlying mechanisms. Endocr. Regul. 47, 137–148. https://doi.org/10.4149/endo_2013_03_137.
Rosenthall, L., 2004. Range of change of measured BMD in the femoral neck and total hip with rotation in women. J. Bone Miner. Metab. 22, 496–499. https://doi.org/10.1007/s00774-004-0513-3.
Rutz, E., Brunner, R., 2013. Management of spinal deformity in cerebral palsy: conservative treatment. J. Child. Orthop. 7, 415–418. https://doi.org/10.1007/s11832-013-0516-5.
Sakai, T., Honzawa, S., Kaga, M., Iwasaki, Y., Masuyama, T., 2020. Osteoporosis pathology in people with severe motor and intellectual disability. Brain Dev. 42, 256–263. https://doi.org/10.1016/j.braindev.2019.12.010.
van Timmeren, E.A., van der Putten, A.A., van Schrojenstein, Lantman-de Valk, H.M, van der Schans, C.P., Waninge, A., 2016. Prevalence of reported physical health problems in people with severe or profound intellectual and motor disabilities: a cross-sectional study of medical records and care plans. J. Intellect. Disabil. Res. 60, 1109–1118. doi:https://doi.org/10.1111/jir.12298.
WHO Study Group, 1994. Assessment of fracture risk and its application to screening for postmenopausal osteoporosis. Report of a WHO Study Group 843, 1–129. World health organ. Tech. Rep. Ser.
Won, J.H., Jung, S.H., 2021. Bone mineral density in adults with cerebral palsy. Front. Neurol. 12, 733322 https://doi.org/10.3389/fneur.2021.733322.
Yoshida, K., Kajiura, I., Suzuki, T., Kawabata, H., 2018. Natural history of scoliosis in cerebral palsy and risk factors for progression of scoliosis. J. Orthop. Sci. 23, 649–652. https://doi.org/10.1016/j.jos.2018.03.009.