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Original article

Estimating regional bone mineral density-based T-scores using clinical information; tools validated for postmenopausal women in Sri Lanka

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ABSTRACT

Objectives: This study aims to develop and validate a country specific osteoporosis risk assessing tool for Sri Lankan postmenopausal women.

Methods: Community-dwelling postmenopausal women were enrolled to development (n = 602) and validation (n = 339) samples. Clinical risk factors (CRFs) of osteoporosis were assessed. Bone mineral densities (BMD) of femoral neck, total hip and lumbar spine were assessed by dual energy X-ray absorptiometry (DXA) scan. Radial ultrasound (US) bone scan was done. Linear regression analysis was performed in development sample considering regional BMDs as dependent and CRFs as independent variables. Regression equations were developed to estimate regional BMDs using best predictive CRFs. Sensitivity, specificity, positive and negative predictive values (PPV and NPV) were assessed to validate the new tools.

Results: Age, body weight and US T-scores showed positive correlations with BMDs of all 3 sites. Two osteoporosis risk assessing tools (OPRATs) were developed as OPRAT-1 and OPRAT-2. Prevalence of osteoporosis, in the validation sample was 74.3%. Sensitivity were high in both tools (OPRAT-1 and OPRAT-2; 83.2% and 82.5%) while specificity were moderate (44.8% for both). PPV of OPRAT-1 and OPRAT-2 were 79.5% and 81.2%. Both tools showed moderate NPV (OPRAT-1 and OPRAT-2; 51% and 47%).

Conclusions: Both OPRAT-1 and OPRAT-2 have high performance in screening postmenopausal women in Sri Lanka for risk of osteoporosis. OPRAT-2 is more convenient and can be used in any healthcare setting with limited resources to identify women who will be benefitted by DXA. OPRAT-1 can be used if the radial US facility is available.

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1. Introduction

Osteoporosis is an emerging public health concern all over the world mainly affecting the aging population. The current global prevalence of osteoporosis is over 200 million [1,2]. In Sri Lanka approximately 45% of women over 50 years are likely to have osteoporosis [3]. Fragility fracture is the clinical outcome of osteoporosis and hip fracture, the most sinister complication of the disease, is linked with increased mortality, morbidity, and health care cost [4–6].

Although the diagnosis of osteoporosis is based on bone mineral density (BMD), the restricted availability of the technology limits its use as a screening tool, especially in resource limited countries. Osteoporosis risk assessing tools which are based on clinical information are being used as an alternative to screen patients for osteoporosis or high fracture risk.

Risk calculators such as Osteoporosis Self-Assessment Tool for Asians (OSTA), Osteoporosis Risk Assessment Instrument (ORAI), and Simple Calculated Osteoporosis Risk Estimation (SCORE) are simple devices validated for local populations [7–12]. They are

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based on a combination of clinical risk factors (CRF), each given a weightage according to the importance. These tools vary with regards to the sensitivity and specificity in identifying high risk patients and performance [9,10,13–15].

Osteoporosis risk assessment tools need to be country specific since the associations between CRFs and osteoporosis or fracture risk have geographical variation. Many countries have developed their own models using either own data or data from surrogate populations. The Korean Osteoporosis Risk-Assessment Model (KORAM) has been developed specifically for Korean postmenopausal women and it has 84.8% sensitivity and 51.6% specificity in identifying high risk postmenopausal women [11]. Furthermore, Osteoporosis Pre-screening Model for Iranian Postmenopausal women (OPMIP) demonstrates sensitivity and specificity of 73.2% and 61%, respectively, in detecting high risk postmenopausal women [16].

In Sri Lanka, DXA facility is restricted to a few major cities covering only a small proportion of country's population. Furthermore, no validated methods are available to detect osteoporosis or high fracture risk. In this study, we aim to fill this lacuna by developing and validating a country specific osteoporosis risk assessing tool for Sri Lankan postmenopausal women.

2. Methods

2.1. Participants

Community dwelling post-menopausal women (n = 605) were selected from Galle district, Sri Lanka by a stratified random sampling method. After initial screening, 602 postmenopausal women were included in the study sample that was used to develop the tool. Women who were cognitively impaired, failed to give consent, had diseases that can affect bone health (malabsorption, hyperparathyroidism, hyperthyroidism, hypogonadism) or were on medications that could affect bone metabolism (thyroxin, thiazide) were excluded.

The tools developed were validated on a separate sample of postmenopausal women selected from the same locality using the same inclusion criteria 6 months after the initial study. Among 364 women, 25 were excluded (cognitively impaired or failed to give consent) and the final validation sample included 339 postmenopausal women.

The study was approved by the Ethical Review Committee, Faculty of Medicine, University of Ruhuna, Sri Lanka (Ref No. March 09, 2016:3.3) and followed the Declaration of Helsinki. All patients agreed to participate in the study and provided written informed consent.

2.2. Measurements

A survey of CRFs was conducted using a pre-designed and content validated data sheet. This survey included details about demographic and anthropometric data, reproductive history, medical history and co-morbid conditions, personal and family history of osteoporotic fractures, behavioral factors such as smoking, alcohol consumption, and glucocorticoids use.

Weight and height were measured adhering to standard protocols. BMDs of the lumbar spine (L1-L4), femoral neck (FN), and total hip (Hip) were measured with DXA scan (Hologic Discovery W, Hologic Inc, Bedford, MA, USA). Women were categorized as osteoporosis, osteopenia or normal, based on the BMD T-scores adhering to the World Health Organization (WHO) criteria [17,18]. Quantitative ultrasound (QUS) (Sunlight Mini Omni, Israel) of the radius of the non-dominant side was performed in randomly selected 260 participants of tool development sample and 207 participants of tool validation sample. QUS measures the quality of bones as speed of sound (SOS, m/s) penetration. SOS data and SOS associated T-scores were gathered from patients who underwent QUS scans. All DXA and QUS scans were done by 2 trained technicians adhering to the manufacturers' protocols. The machines were calibrated on each day prior to scanning.

2.3. Statistical analysis

A woman was considered to have osteoporosis if the T-score of the lumbar spine (L1-L4), femoral neck or total hip region was ≤ -2.5. Descriptive statistics; means (SD) and medians (IQR) were calculated for continuous numerical variables. Frequency distributions and percentages were used for categorical variables.

In the tool development process Pearson's correlation was used to identify clinical risk factors associated with T-scores. These factors were used in multilinear regression models (MLR) as independent variables and T-scores as dependent variables to assess the osteoporosis predicting ability. It was aimed to predict regional T-scores than BMD since absolute BMD is not used in the detection of osteoporosis. Separate regression analyses were conducted with and without QUS T-scores. Regression equation to predict regional T-scores was developed by multiplying each predictor variable with its relevant unstandardized coefficient (B) and adding them to the constant of the model. The best model to predict regional T-scores was selected based on R^2 (coefficient of determinations) which assessed the predictive ability of the model.

In the validation of the tools, T-scores of hip, FN, and spine were estimated for all participants in the validation sample using the osteoporosis risk assessing tools developed above. Actual T-scores of the spine, hip, and FN were compared with the respective estimated values using the paired *t*-test. Bland-Altman plots were constructed to assess the systematic difference between estimated and actual T-scores. Adhering to the WHO recommendations, the diagnosis of osteoporosis was made when the T-score was less or equal −2.5 in the total spine, total hip or femoral neck. The sensitivity, specificity, PPV and NPV of new osteoporosis risk assessment tools with regards to their ability to discriminate women with and without osteoporosis were calculated.

The OSTA index was calculated for all study participants in the validation sample. They were categorized in to high (<−4), intermediate (−4 to −1), and low risk (>−1) groups [7]. The new tools were compared with the OSTA index.

3. Results

3.1. Characteristics of the development and validation samples

The development and validation samples contained 602 and 339 community dwelling postmenopausal women, respectively. Table 1 shows the descriptive characteristics of these samples.

The prevalence of osteoporosis in the development sample was 65.3% and another 28.5% had osteopenia. Further, 74.3% women in the validation sample had osteoporosis while another 21.5% had osteopenia.

3.2. Development of the tools

In bivariate analysis, anthropometric variables and QUS measures were associated ($P < 0.001$) with BMD and BMD based T-scores of hip, femoral neck, and spine (Table 2). Number of participants with parental history of hip fractures, long-term glucocorticoid use, previous history of fractures (after 45 years age), smoking or consumption of alcohol were very low and did not show significant associations with BMD or regional T-scores.

Table 1
Descriptive characteristics of development and validation samples.

Variable	Development sample		Validation sample	
	Mean (SD)/N (%)	Range	Mean (SD)/N (%)	Range
Age, yr	67.3 (8.3)	43–89	63.8 (9.3)	40–87
Body weight, kg	53.8 (10.1)	27–84	51.8 (10.4)	24–86
Height, cm	148.5 (6.3)	129.0–172.0	147.8 (5.6)	130.0–163.0
BMI, kg/m^2	24.4 (4.2)	11.8–37.9	23.6 (4.4)	12.7–37.7
Waist, cm	80.3 (9.9)	53–103	77.9 (9.8)	57–110
Hip, cm	94.8 (9.6)	64–122	92.3 (9.1)	72–119
Glucocorticoid use	32 (5.3%)		76 (22.4%)	
Parent fractured hip	11 (2%)		14 (4.1%)	
Previous fractures	86 (14.3%)		53 (15.6%)	
Alcohol use	0		0	
Current smoking	0		0	

SD, standard deviation; BMI, body mass index.

Table 2
Pearson correlations (*r*) between anthropometric measures, bone mineral density/speed of sound and T-scores.

Variable	Hip		FN		Spine	
	BMD	T-score	BMD	T-score	BMD	T-score
Age	−0.47	−0.43	−0.46	−0.41	−0.22	−0.20
Body weight	0.58	0.56	0.58	0.56	0.49	0.47
Height	0.25	0.21	0.30	0.27	0.22	0.20
BMI	0.51	0.50	0.49	0.48	0.43	0.42
SOS/T-score	0.45	0.41	0.45	0.40	0.42	0.38

Hip, total hip; FN, femoral neck; Spine, L1-L4; BMD, bone mineral density; BMI, body mass index; SOS, speed of sound. P-values of all the associations were <0.001.

The MLR analysis revealed that the 2 clinical risk factors; age and body weight, either with or without QUS T score have a greater ability to predict regional T-scores in postmenopausal women (Table 3). The best model with the highest R^2 value was selected to predict the respective regional T-score.

Two osteoporosis risk assessment tools were devised (with and without QUS data) based on the outcome of MLR analysis. Formulae with E1 contained QUS data and formulae with E2 does not contain QUS data.

1. **Osteoporosis Risk Assessment Tool-1 (OPRAT-1)** - Estimated regional T-scores are denoted as T.Hip.E1, T.Spine.E1 and T.FN.E1 were calculated using below regression formulae.

$$T.Hip.E1 = -1.635 + (-0.029*age) + (0.044*bodyweight) + (0.18*T_US)$$

$$T.FN.E1 = -1.889 + (-0.028*age) + (0.045*bodyweight) + (0.171*T_US)$$

$$T.Spine.E1 = -6.203 + (0.019*age) + (0.052*bodyweight) + (0.287*T_US)$$

If at least one of these estimated T-score was ≤ -2.5, then the patient was considered to have osteoporosis.

2. **Osteoporosis Risk Assessment Tool 2 (OPRAT-2)** - Estimated regional T-scores are denoted as T.Hip.E2, T.Spine.E2 and T.FN.E2 were calculated using below regression formulae.

$$T.Hip.E2 = -1.696 + (-0.038*age) + (0.049*bodyweight).$$

$$T.FN.E2 = -1.984 + (-0.036*age) + (0.050*bodyweight)$$

$$T.Spine.E2 = -5.239 + (-0.01*age) + (0.058*bodyweight)$$

If at least one of these estimated T-score was ≤ -2.5, then the patient was considered to have osteoporosis.

Table 3
Outcome of the multilinear regression analysis.

Dependent variable	Independent variables considered in the model		R^2
	Model number	Predictor variables	
T- FN	1	Constant + Body weight	0.38
	2	Constant + Body weight + US T-score	0.40
	3[a]	Constant + Body weight + US T-score + age	0.44
T-Hip	1	Constant + Body weight	0.33
	2	Constant + Body weight + US T-score	0.41
	3[a]	Constant + Body weight + US T-score + age	0.45
T-spine	1	Constant + Body weight	0.22
	2	Constant + Body weight + US T-score	0.29
	3[a]	Constant + Body weight + US T-score + age	0.31
QUS-T-score was not considered as a predictor variable in below analyses.			
T-FN	1	Constant + Body weight	0.31
	2[a]	Constant + Body weight + age	0.38
T-Hip	1	Constant + Body weight	0.31
	2[a]	Constant + Body weight + age	0.39
T-spine	1	Constant + Body weight	0.22
	2[a]	Constant + Body weight + age	0.23

QUS, quantitative ultrasound; FN, femoral neck.
[a] Indicate the models with best predictive ability.

3.3. Validation of OPRAT-1 and OPRAT-2

Regional T-scores were estimated for all participants in the validation sample using the formulae in OPRAT-1 and OPRAT-2. Table 4 depicts mean comparisons between the actual and estimated regional T-scores. Standard error of mean (SEM) of actual and estimated T-scores are comparable in OPRAT-1 and OPRAT-2.

Bland-Altman plots were constructed to assess the agreement between the estimated (by OPRAT-1 or OPRAT-2) and actual T-scores of the validation sample (Figs. 1 and 2). In all plots, > 95% of values were within the limits of agreement (mean of difference ±1.96 SD).

The prevalence of osteoporosis in the validation sample, estimated based on the DXA derived T-score was 74.3%. This figure was not statistically different (P < 0.001) from the estimations made by the OPRAT-1 (75.4%) and OPRAT-2 (75.5%). The OSTA index revealed 32.4% were at high risk of osteoporosis while 34.5% were at intermediate risk. The remaining study participants were at low risk of osteoporosis.

The sensitivity of OPRAT-1 and OPRAT-2 were 83.2% and 82.5%, respectively, while specificity remained at 44.8% in both tools. Further, PPV and NPV of OPRAT-1 was 79.5% and 51%, respectively, while the corresponding values were 81.2% and 47% in OPRAT-2, respectively. The OSTA showed 76.2% sensitivity and 59.8% specificity. The PPV and NPV of OSTA were 84.6% and 46.4%, respectively.

The similar standard error of estimate (SEE) and R^2 values of OPRAT-1 and OPRAT-2 depict their comparable predicting ability of regional T-scores (Table 5).

4. Discussion

This study developed 2 osteoporosis risk assessing tools ie, OPRAT-1 and OPRAT-2 which could predict regional T-scores of hip, spine and FN of Sri Lankan postmenopausal women. Each tool consisted of 3 formulae to estimate spine, hip and FN T-scores. OPRAT-1 uses age, body weight and radial QUS T-score data to estimate regional T-scores. OPRAT-2 is a simpler tool and needs only age and body weight to estimate T-scores. Therefore OPRAT-2 can be easily used as a screening tool of high osteoporosis risk in postmenopausal women. Numerous osteoporosis screening tools have been developed and validated in other countries, regions or ethnicities such as OSTA, ORAI, ORACLE and OSIRIS [7,9,19–21]. None of them has been validated for Sri Lankan population previously.

OPRAT-1 and OPRAT-2 were developed using multilinear regression analyses based on the hypothesis that clinical risk factors of osteoporosis could predict regional T-scores. In contrast, most of currently available osteoporosis risk prediction tools have been developed as scoring systems assigning a weigh for the clinical risk factors used in the tool [7,9,16]. Age and body weight were clinical risk factors considered as potential predictors of BMD T-scores and thus used in the final regression analyses to develop the new tools. Advanced age and low body weight are well known determinants of osteoporosis and fragility fractures [22–26]. Age and body weight, together, contribute to bone mass greater than other risk factors [23,25,26]. Therefore, these 2 factors have been used in many osteoporosis risk prediction models either alone or in combination with other clinical risk factors such as oestrogen use, race, presence of rheumatoid arthritis, non-traumatic fractures, current hormone replacement therapy, smoking, regular exercises, and others [7,20]. OSTA uses only age and body weight to calculate the osteoporosis risk [7]. Tools such as ORAI, SCORE, OSIRIS, and São Paulo Osteoporosis Risk Index (SAPORI) are using clinical risk factors other than age and body weight [9,19,20,27]. However, this study did not reveal significant associations between parental history of hip fractures, long-term glucocorticoid use, previous history of fractures (after 45 years age), smoking or consumption of alcohol, and regional T-scores.

Bone QUS is used to assess osteoporosis, although limitations exist [28–31]. OPRAT-1 was developed on the assumption that QUS data, when combined with other CRFs, would be a better predictor of BMD based T-scores. We were unable to find previously developed osteoporosis risk prediction tools using QUS inputs.

The validation study proves that both OPRAT-1 and OPRAT-2 perform well as screening tools of osteoporosis. Both tools had high and similar osteoporosis predicting ability. Further, both OPRAT-1 and OPRAT-2 have comparable sensitivity performance with OSTA. Sensitivity, specificity, NPV and PPV statistics of our study are concordant with previously developed osteoporosis risk assessment indices such as OST, ORAI, SCORE, KORAM, and OSIRIS [7,9–12].

We used the T-score cut-off value of −2.5 in any of the skeletal sites (femoral neck, hip, spine) described in the WHO guidelines to diagnose osteoporosis in this study. Different cut-off values were used in various osteoporosis risk assessing tools. The OST originally used only the FN BMD T-Score ≤ −2.5 to identify osteoporosis [7] but, Saravi later considered T-score ≤ −2.0 in FN, spine or total hip in Argentinian postmenopausal women, and achieved a higher sensitivity (83.7%) [32]. Similar to our analysis, the WHO criteria have been used Su et al in Taiwan [8] and Reginster et al in France [19] to diagnose osteoporosis.

We used 2 independent study samples, selected using the same criteria for the development and validation of OPRAT-1 and OPRAT-2. A study sample drawn from all 9 provinces of the country would be more rational in developing country specific risk assessment tools. But this could be a daunting task due to logistics and cost considerations. The OST was built using 860 postmenopausal women from 8 Asian countries [7], but contribution from an individual country was lower than our study. Further, we used community-dwelling women in this study to avoid selection bias, though some studies did not include community samples. OSIRIS was built on data from 1303 postmenopausal women selected from

Table 4
Comparison of actual and estimated T-scores in validation study sample.

Tool	Variable	Actual T-scores Mean (SD)	Estimated T-scores Mean (SD)	Mean (SD) of difference	SEM	P-value
OPRAT-1	T - Spine - T.Spine.E1	−3.10 (1.35)	−2.92 (0.75)	−0.18 (1.12)	0.08	0.021
	T - Hip - T.Hip.E1	−1.48 (1.18)	−1.59 (0.77)	0.11 (0.91)	0.06	0.086
	T - FN - T.FN.E1	−1.95 (1.18)	−1.71(0.76)	−0.24 (0.94)	0.06	<0.001
OPRAT-2	T - Spine - T.Spine.E2	−3.14 (1.38)	−2.88 (0.64)	−0.26 (1.17)	0.06	<0.001
	T - Hip - T.Hip.E2	−1.46 (1.20)	−1.59 (0.70)	0.12 (0.93)	0.05	0.014
	T - FN - T.FN.E2	−1.93 (1.16)	−1.69 (0.70)	−0.23 (0.92)	0.05	<0.001

FN, femoral neck; OPRAT, Osteoporosis Risk Assessment Tool; SD, standard deviation; SEM, standard error of mean. E1, estimated 1; E2, estimated 2.
This table shows mean (SD) comparison of actual and estimated regional T-scores. Paired *t*-test was performed for the analysis and P < 0.05 was considered statistically significant.

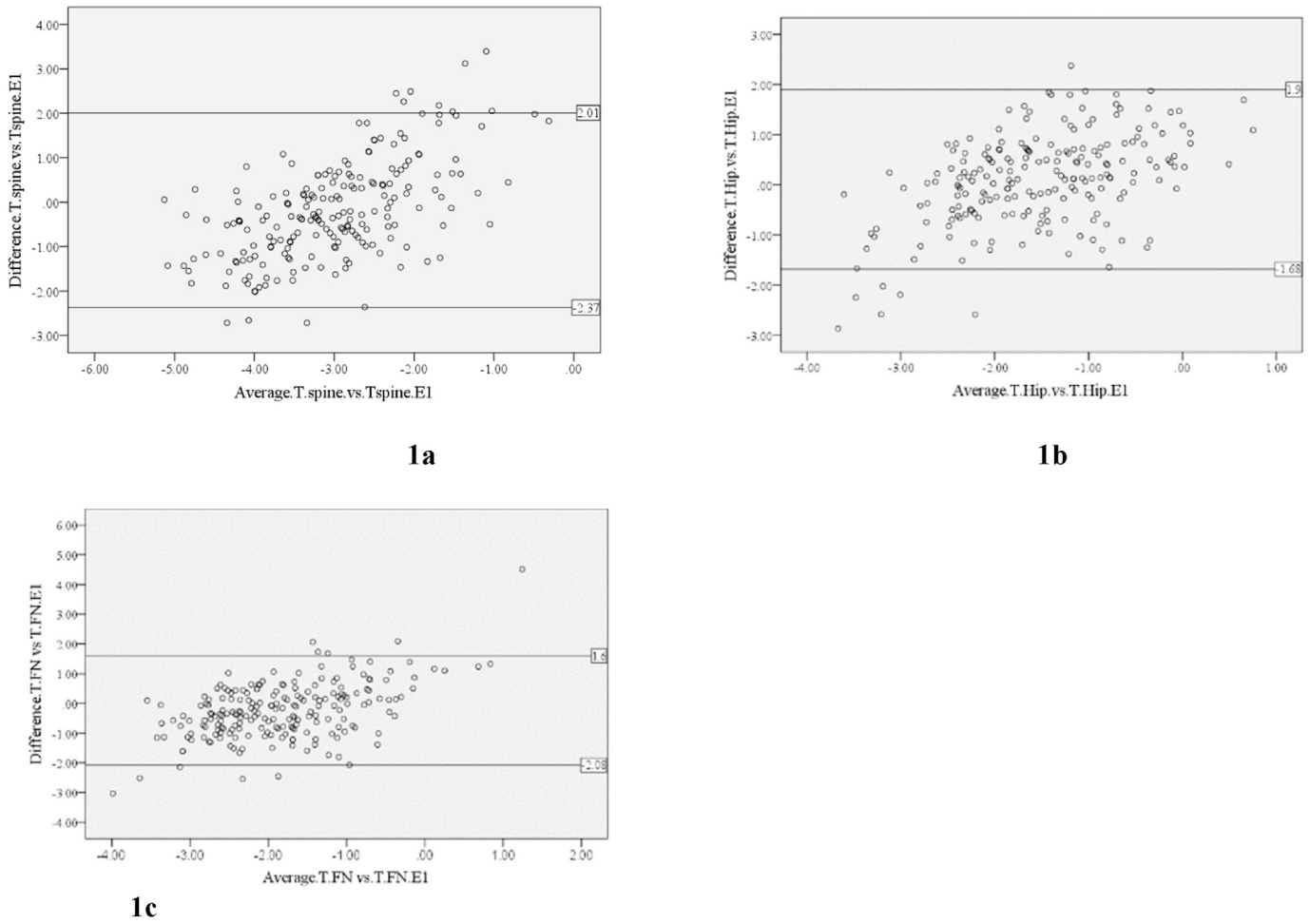

Fig. 1. Bland-Altman plots of actual and OPRAT-1 estimated regional T-scores. 1a-actual T-spine and OPRAT-1 estimated T.spine.E1, 1b-actual T-Hip and OPRAT-1 estimated T.Hip.E.1, 1c-actual T-FN and OPRAT-1 estimated T.FN.E1.

an outpatient osteoporosis clinic [12]. Further, Reginster et al validated OSIRIS in 798 postmenopausal women referred by rheumatologists at visits to routine check-ups or follow-ups [19].

There are a few limitations in this study. These formulae contain only age and body weight, and the other clinical risk factors such as previous fracture and parental history of hip fracture were not considered due to low numbers. Both OPRAT-1 and 2 consist of 3 separate formulae to estimate T-scores of the hip, FN, and spine. Hence all 3 calculations should be done to make a clinical decision. This perhaps is time consuming and less user friendly. Furthermore, the study participants were limited to 1 province and this may limit the generalizability of the findings.

5. Conclusions

In conclusion, both OPRAT-1 and OPRAT-2 can be used as screening tools to identify postmenopausal women with high risk of osteoporosis. OPRAT-2 is more convenient and practical in any setting as it uses only data of age and body weight. The OPRAT-1 requires radial QUS data, which is a major limitation.

To the best of our knowledge, these are the first osteoporosis risk assessing tools developed for Sri Lankan postmenopausal women using country specific data. This study suggests that OPRAT-2 is a useful screening tool for osteoporosis to identify patients who need bone densitometry scanning. It can be used even in a primary care setting or in general use as a self-screening tool. Further, this is an affordable and simple tool that can be used with basic resources. Therefore, it is a low-cost osteoporosis screening method and would be advantageous to use in rural healthcare centres of Sri Lanka where DXA facilities are not accessible. Finally, facilitation of osteoporosis early identification will enable to initiate preventive and therapeutic strategies aiming at reducing the health and socioeconomic burden while improving quality of life of postmenopausal women.

Conflicts of interest

No potential conflict of interest relevant to this article was reported.

CRediT author statement

Hewa Walpola Amila Sewwandi Subasinghe: Conceptualization, Methodology, Writing - review & editing, Funding acquisition. **Sarath Lekamwasam:** Conceptualization, Methodology, Writing - review & editing, Supervision. **Patrick Ball:** Conceptualization, Methodology, Resources, Funding acquisition, Supervision. **Hana Morrissey:** Methodology, Resources, Writing - review & editing, Funding acquisition, Supervision. **Eisha Waidyaratne:** Supervision, Writing - review & editing.

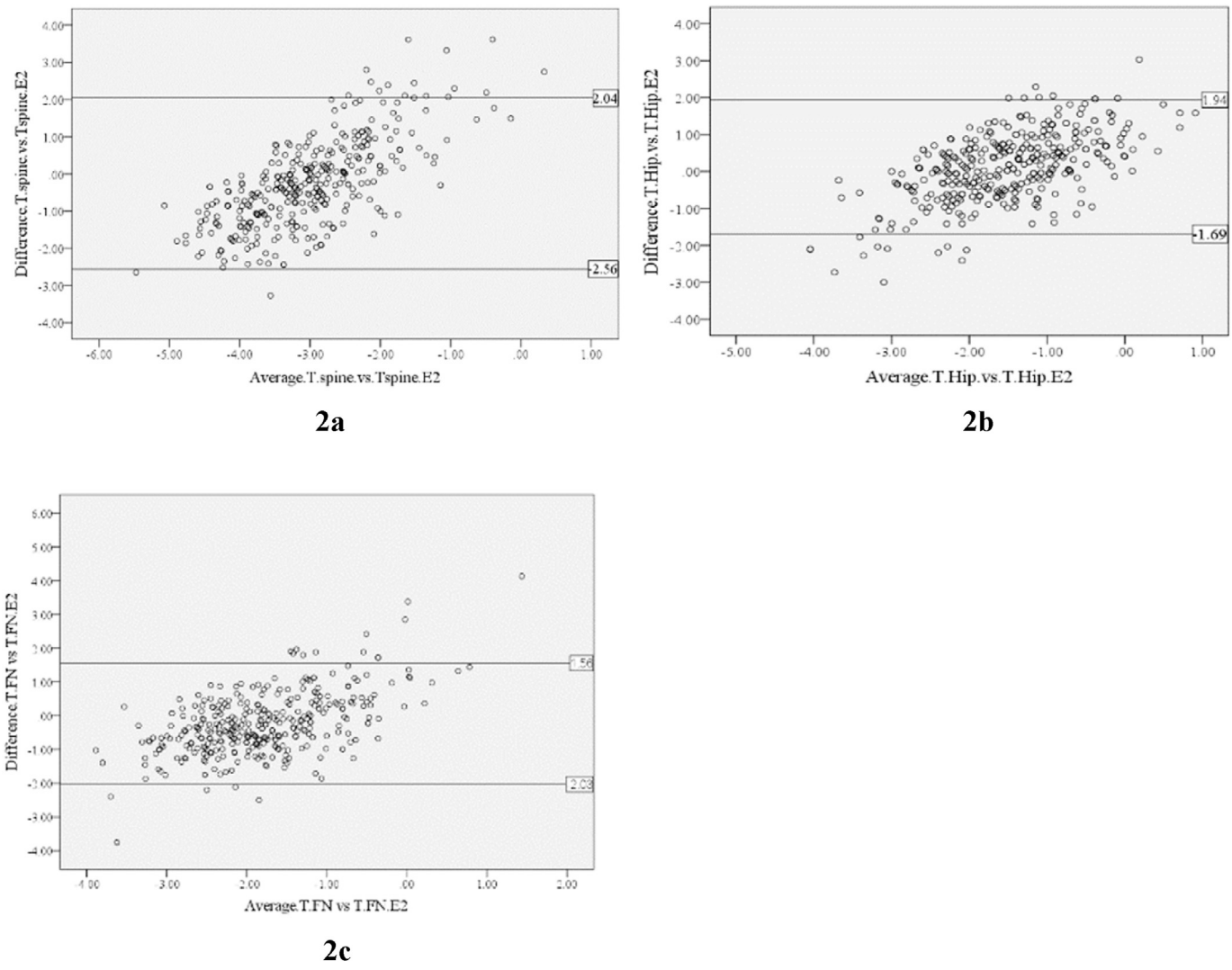

Fig. 2. Bland-Altman plots of actual and OPRAT-2 estimated regional T-scores. 2a-actual T-spine and OPRAT-2 estimated T.spine.E2, 2b-actual T-Hip and OPRAT-2 estimated T.Hip.E.2, 2c-actual T-FN and OPRAT-2 estimated T.FN.E2.

Table 5
Regression analyses comparing actual and estimated T-scores in the validation sample.

Tool	Variable	r	R^2	SEE	P-value
OPRAT-1	T.Hip.E1	0.63	0.40	0.92	<0.001
	T.Spine.E1	0.56	0.31	1.12	<0.001
	T.FN.E1	0.61	0.38	0.94	<0.001
OPRAT-2	T.Hip.E2	0.64	0.41	0.93	<0.001
	T.Spine.E2	0.53	0.28	1.17	<0.001
	T.FN.E2	0.61	0.37	0.92	<0.001

R^2, coefficient of determination; r, correlation coefficient; SEE, standard error of the estimate; OPRAT, osteoporosis risk assessing tool; FN, femoral neck. This table shows the statistics of regression analysis that predicts the ability of new osteoporosis risk assessing tools to identify high risk patients.

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