Predicting Lumbar Vertebral Osteopenia Using LvOPI Scores and Logistic Regression Models in an Exploratory Study of Premenopausal Taiwanese Women

Chun-Wen Chen1,2,3 · Yi-Jui Liu4 · Shao-Chieh Lin5,6 · Chien-Yuan Wang7,8 · Wu-Chung Shen9,10 · Der-Yang Cho11 · Tung-Yang Lee12,13 · Cheng-Hsuan Juan6,12,13 · Cheng-En Juan4 · Kai-Yuan Cheng1 · Chun-Jung Juan6,9,10,14,15,16

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Abstract

Purpose To propose hybrid predicting models integrating clinical and magnetic resonance imaging (MRI) features to diagnose lumbar vertebral osteopenia (LvOPI) in premenopausal women.

Methods This prospective study enrolled 101 Taiwanese women, including 53 before and 48 women after menopause. Clinical information, including age, body height, body weight and body mass index (BMI), were recorded. Bone mineral density (BMD) was measured by the dual-energy X-ray absorptiometry. Lumbar vertebral fat fraction (LvFF) was measured by MRI. LvOPI scores (LvOPISs) comprising different clinical features and LvFF were constructed to diagnose LvOPI. Statistical analyses included normality tests, linear regression analyses, logistic regression analyses, group comparisons, and diagnostic performance. A P value less than 0.05 was considered as statistically significant.

Results The post-menopausal women had higher age, body weight, BMI, LvFF and lower BMD than the pre-menopausal women (all P < 0.05). The lumbar vertebral osteoporosis group had significantly higher age, longer MMI, and higher LvFF than the LvOPI group (all P < 0.05) and normal group (all P < 0.005). LvOPISs (AUC, 0.843 to 0.864) outperformed body weight (0.747; P = 0.0566), BMI (0.737; P < 0.05), age (0.649; P < 0.05), and body height (0.5; P < 0.05) in diagnosing LvOPI in the premenopausal women. Hybrid predicting models using logistic regression analysis (0.894 to 0.9) further outperformed all single predictors in diagnosing LvOPI in the premenopausal women (P < 0.05).

Conclusion The diagnostic accuracy of the LvOPI can be improved by using our proposed hybrid predicting models in Taiwanese premenopausal women.

Keywords Osteoporosis · Osteopenia · Magnetic resonance imaging · Lumbar vertebral fat fraction · Menopause-MR interval

Abbreviations

AUC Area under curve
BMD Bone mineral density
BMI Body mass index
DeXA Dual-energy X-ray absorptiometry
IDEAL Iterative decomposition of water and fat with echo asymmetry and least-squares estimation
LvFF Lumbar vertebral fat fraction
LvOPI Lumbar vertebral osteopenia
LvOPIS Lumbar vertebral osteopenia score
LvOPIS3 LvOPI using 3 selected predictors
LvOPIS6 LvOPI using all 6 predictors
LvOPI_Logi3 LvOPI model predicted by logistic regression analysis using 3 selected predictors
LvOPI_Logi4 LvOPI model predicted by logistic regression analysis using 4 selected predictors
LvOPI_Logi5 LvOPI model predicted by logistic regression analysis using 5 selected predictors
LvOPI_Logi6 LvOPI model predicted by logistic regression analysis using all 6 predictors
LvOPO Lumbar vertebral osteoporosis

* Kai-Yuan Cheng
kycheng@ctust.edu.tw
* Chun-Jung Juan
peterjuancj@yahoo.com.tw

Extended author information available on the last page of the article

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LvOPPOS  Lumbar vertebral osteoporosis score
LvOPPOS3  LvOPPOS using 3 selected predictors
LvOPPOS6  LvOPPOS using all 6 predictors
LvOPPO_Logi2  LvOPPO model predicted by logistic regression analysis using 2 selected predictors
LvOPPO_Logi3  LvOPPO model predicted by logistic regression analysis using 3 selected predictors
LvOPPO_Logi6  LvOPPO model predicted by logistic regression analysis using all 6 predictors
MMI  Menopause-to-magnetic resonance imaging interval
MRI  Magnetic resonance imaging
ROC  Receiver operating characteristic

1 Introduction

Lumbar vertebral osteoporosis (LvOPO) and lumbar vertebral osteopenia (LvOPI) are determined by dual-energy X-ray absorptiometry (DEXA). Alternatively, they can also be evaluated by quantitative ultrasound [1], quantitative computed tomography (CT) [2, 3], and quantitative magnetic resonance imaging (MRI) [4, 5].

In LvOPO and LvOPI, the reduced bone mineral density (BMD) is usually accompanied by increase of marrow fat deposition in the lumbar vertebrae. Therefore, evaluation of lumbar vertebral fat fraction (LvFF) plays a role in better understanding LvOPO and LvOPI conceptually. It has been recently shown that patients with LvOPO have higher LvFF than those with LvOPI and healthy participants [6]. Patients with LvOPO are also older than those in the control group [7]. Whether the LvFF serves as an independent predictor in diagnosing LvOPI is clinically important. However, it has not yet been investigated until 2016 when Zhang et al. diagnosed LvOPO by the LvFF with a criterion of 0.674, achieving an area under curve (AUC), sensitivity, and specificity of 0.740, 79.2%, and 72.4%, respectively [7].

A hybrid scoring system integrating clinical information and MRI features for diagnosing a certain disease is rapidly emerging. For example, our prior study has shown that the Warthin tumor score outperforms any independent predictors in diagnosing parotid Warthin tumors [11]. We hypothesized that hybrid scores integrating clinical and MRI features also improve the diagnosis of LvOPI and LvOPO. The aim of our study was to propose a LvOPI score (LvOPIS) and a LvOPO score (LvOPOS) to diagnose female LvOPI and LvOPO, respectively.

2 Materials and Methods

This prospective study was approved by the Institutional Review Board of Tri-Service General Hospital with written informed consent obtained from each participant.

2.1 Patient Cohorts

A total of 101 female patients, including 53 patients before menopause and 48 patients after menopause, were recruited. All participants received BMD measures using DeXA as well as LvFF quantification. Clinical information, including age, menopause-to-magnetic resonance imaging interval (MMI), body height, body weight, body mass index (BMI), were recorded.

2.2 Measurements of Bone Mineral Density Using DeXA

BMD of the lumbar spine, including L1 to L4 vertebrae, was measured by DeXA using a Hologic QDR-4500 W (SN 47,125) model (Hologic Inc., Bedford, MA, USA). BMD data were acquired, processed, and calculated based on the International Society for Clinical Densitometry (ISCD) guidelines [12]. To represent the overall status of the BMD of each participant, the averaged BMD was calculated by the Eq. 1:

\[
BMD_m = \frac{1}{4} \sum_{i=1}^{4} BMD_i,
\]

where \(BMD_m\) denotes the averaged fat fraction of L1 to L4 vertebral bodies, \(BMD_i\) denotes the fat fraction of the \(i^{th}\) lumbar vertebral body with \(i\) ranging from 1 to 4.

2.3 MRI Protocols

MRI study was performed using a 1.5 T clinical scanner (Signa HDxt, GE Healthcare, Milwaukee, WI). LvFF was measured by quantitative MRI using the iterative decomposition of water and fat with echo asymmetry and least-squares
for the whole population, four predictors (age, LvFF, body weight, and BMI) were selected for hybrid models in diagnosing the LvOPI for the premenopausal women; and two predictors (body height and body weight) were selected for hybrid models in diagnosing the LvOPO for the postmenopausal women.

2.6 Statistical Analysis

Statistical analyses were performed using MATLAB, SPSS Version 16.0 software (SPSS Inc, Chicago, III), SAS 9.4 (SAS Institute Inc., Cary, NC), and MedCalc Version 13.0 (MedCalc Software Inc, Ostend, Belgium). The relationships between two continuous parameters were evaluated by linear regression analyses. Comparisons between two groups were performed by Mann Whitney test. Comparisons among the three groups classified based on the BMD were performed by nonparametric Kruskal–Wallis test with post hoc analysis with correction for multiple comparisons. The nonparametric receiver operating characteristics (ROC) curves were used to distinguish the LvOPO group from non-LvOPO groups and distinguishing the normal group from abnormal groups. Comparison of areas under multiple ROC curves was performed by a nonparametric test using DeLong method [14]. A P value less than 0.05 was considered as statistically significant.

3 Results

Patient characteristics classified by the menopausal statuses are shown in Table 1.

3.1 Scatter Plots and Linear Regression Analyses Between the BMD and Other Parameters

Scatter plots of different clinical and MRI parameters vs. BMD in whole population (Fig. 1), premenopausal group (Fig. 2), and postmenopausal group (Fig. 3) were shown. Linear regression analyses showed that the BMD was negatively associated with the age, LvFF, and BMI significantly (all $P < 0.005$) and positively associated with the body height and body weight significantly (all $P < 0.05$) in the whole population. In the premenopausal group, the BMD was positively associated with the age and the body height significantly (both $P < 0.05$).
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Table 1 Patient characteristics classified by the menopausal statuses

|                      | All (n = 101) | Pre-menopausal (n = 53) | Post-menopausal (n = 48) | P value | Statistical significance |
|----------------------|--------------|-------------------------|--------------------------|---------|-------------------------|
| Age (years)          | 54.8 ± 9.6   | 47.4 ± 4.1              | 62.9 ± 7.1               | .000    | ***                     |
| Body height (cm)     | 157.5 ± 5.1  | 158.6 ± 5.1             | 156.3 ± 4.8              | .052    | –                       |
| Body weight (Kg)     | 61.0 ± 11.0  | 59.2 ± 10.5             | 62.9 ± 11.3              | .031    | *                       |
| BMI (Kg/m²)          | 24.6 ± 4.3   | 23.6 ± 4.1              | 25.7 ± 4.2               | .003    | **                      |
| LvFF                 | 0.65 ± 0.11  | 0.57 ± 0.09             | 0.74 ± 0.05              | .000    | ***                     |
| BMD (T-score)        | −0.78 ± 1.48 | −0.08 ± 1.23            | −1.54 ± 1.37             | .000    | ***                     |

Diagnostic distribution

|                  | All (n = 101) | Pre-menopausal (n = 53) | Post-menopausal (n = 48) |
|------------------|--------------|-------------------------|--------------------------|
| Normal           | 57           | 75.5% (40/53)           | 35.4% (17/48)            |
| LvOPI            | 29           | 22.6% (12/53)           | 35.4% (17/48)            |
| LvOPO            | 15           | 1.9% (1/53)             | 29.2% (14/48)            |

Data are shown as mean ± standard deviation. Body weight and BMI was analyzed by Mann–Whitney U-test. *, **, *** denotes a P value less than 0.05, 0.01, and 0.001, respectively.

Fig. 1 Scatter plots of clinical and MRI parameters, including a age, b LvFF, c MMI, d body height, e body weight, and f BMI, vs. lumbar vertebral BMD in the whole population, showing that the BMD is negatively associated with age, LvFF, plus MMI and that the BMD is positively associated with the body height and body weight.

3.2 Comparisons of Parameters Among the LvOPO, LvOPI, and Normal Groups

Box and Whisker plots of the patient characteristics classified by the BMD were shown in Fig. 4. The LvOPO group was significantly older than the LvOPI group (P < 0.01) and normal group (P < 0.001), had significantly longer MMI than the LvOPI group (P < 0.01) and normal group (P < 0.001), was significantly shorter than the normal group (P < 0.05), and had significantly higher LvFF than the LvOPI group (P < 0.05) and normal group (P < 0.005). The LvOPI group was significantly older (P < 0.05) and had significantly longer MMI (P < 0.05) as well as higher LvFF (P < 0.001) than the normal group.

3.3 ROC Curves of Independent Predictors and Hybrid Scores in Predicting LvOPI and LvOPO in Whole Population

ROC curves of the six independent predictors and two hybrid predicting models, including hybrid scores and logistic regression models, in diagnosing the LvOPI and the LvOPO in whole population were plotted in Fig. 5. The AUC of the age, LvFF, MMI, body height, body weight, and BMI in diagnosing the LvOPI was 0.691, 0.758, 0.67, 0.618, 0.576, and 0.536, respectively. The AUC of the LvOPIIS and logistic regression models using all six predictors were 0.746 and 0.804, respectively. The AUC of the age, LvFF, MMI, body height, body weight, and BMI in diagnosing the
LvOPO was 0.794, 0.802, 0.788, 0.687, 0.617, and 0.545, respectively. The AUC of the LvOPOS and logistic regression models using all six predictors were 0.833 and 0.85, respectively.

### 3.4 ROC Curves of Independent Predictors and Hybrid Scores in Predicting LvOPI in Pre-Menopausal Women and Predicting LvOPO in Post-Menopausal Women

ROC curves of the five independent predictors and two hybrid predicting models, including hybrid scores and logistic regression models, in diagnosing the LvOPI in pre-menopausal women were plotted in Fig. 6 (left). The AUC of the age, LvFF, body height, body weight, and BMI in diagnosing the LvOPI was 0.649, 0.788, 0.5, 0.747, and 0.7737, respectively. The AUC of the LvOPOS and logistic regression models using five predictors were 0.868 and 0.898, respectively. ROC curves of the six independent predictors and two hybrid predicting models, including hybrid scores and logistic regression models, in diagnosing the LvOPO in post-menopausal women were plotted in Fig. 6 (right). The AUC of the age, LvFF, MMI, body height, body weight, and BMI in diagnosing...
Fig. 4 Box and Whisker plots of the a age, b LvFF, c MMI, d body height, e body weight, and f BMI in different patient groups classified by the lumbar vertebral BMD, showing significant difference of age, LvFF, and MMI among normal, LvOPI, and LvOPO groups and significant difference of body height between normal and LvOPO groups. Note: *, **, and *** denotes a P value less than 0.05, 0.01, and 0.005.

Fig. 5 ROC curves of the clinical and MRI predictors in diagnosing the LvOPI and the LvOPO in the whole female population.
the LvOPO was 0.546, 0.607, 0.551, 0.707, 0.708, and 0.665, respectively. The AUC of the LvOPOS and logistic regression models using 6 predictors were 0.713 and 0.767, respectively.

3.5 ROC Curves of Hybrid Scores Using Selected Predictors Based on AUC Criteria

Table 2 shows the sensitivity and specificity of each single predictor selected for LvOPIS and LvOPOS in diagnosing

| Scores | Predictors | Criteria         | Sensitivity | Specificity | TP  | TN  | FP  | FN  |
|--------|------------|------------------|--------------|-------------|-----|-----|-----|-----|
| Total  | LvOPIS     | Age (years) ≥ 54 | 70% (0.55 ~ 0.83) | 68% (0.55 ~ 0.80) | 31  | 39  | 18  | 13  |
|        | MMI (years) ≥ 1 | 70% (0.55 ~ 0.83) | 72% (0.58 ~ 0.83) |             | 31  | 41  | 16  | 13  |
|        | LvFF       ≥ 0.676 | 70% (0.50 ~ 0.81) | 65% (0.51 ~ 0.77) |             | 30  | 37  | 16  | 13  |
| LvOPOS | Age (years) ≥ 59 | 80% (0.51 ~ 0.95) | 77% (0.66 ~ 0.85) |             | 12  | 66  | 20  | 13  |
|        | MMI (years) ≥ 4 | 87% (0.58 ~ 0.98) | 69% (0.58 ~ 0.78) |             | 13  | 59  | 27  | 13  |
|        | LvFF       ≥ 0.71 | 80% (0.51 ~ 0.94) | 70% (0.59 ~ 0.79) |             | 12  | 60  | 27  | 13  |
| Pre-M  | LvOPIS     | Age (years) ≥ 46 | 85% (0.54 ~ 0.97) | 40% (0.25 ~ 0.57) | 11  | 16  | 24  | 2   |
|        | LvFF       ≥ 0.589 | 77% (0.46 ~ 0.94) | 70% (0.53 ~ 0.83) |             | 10  | 28  | 12  | 3   |
|        | BW (kg) ≤ 55 | 69% (0.39 ~ 0.90) | 68% (0.51 ~ 0.81) |             | 9   | 27  | 13  | 4   |
|        | BMI (kg/m²) ≤ 21.88 | 85% (0.54 ~ 0.97) | 73% (0.56 ~ 0.85) |             | 11  | 29  | 11  | 2   |
| Post-M | LvOPOS     | BH (cm) ≤ 157 | 86% (0.56 ~ 0.97) | 59% (0.41 ~ 0.75) | 12  | 20  | 14  | 2   |
|        | BW (kg) ≤ 65 | 79% (0.49 ~ 0.94) | 50% (0.33 ~ 0.67) |             | 11  | 17  | 17  | 3   |

BH denotes body height, BW denotes body weight, Post-M denotes post-menopausal group, Pre-M denotes pre-menopausal group, TN denotes true negative, and TP denotes true positive. The 95% confidence interval of sensitivity and specificity are shown within the parentheses.
LvOPI and LvOPO in the whole population, pre-menopausal group and post-menopausal group. For the whole population, parameters including age, BMI and LVFF were qualified for the LvOPIS and the LvOPOS. For the premenopausal group, parameters including age, LVFF, body weight, and BMI were qualified for the LvOPIS. For the postmenopausal group, parameters including body height and body weight were qualified for the LvOPOS. ROC curves of the LvOPIS and LvOPOS and logistic regression models in diagnosing LvOPI and LvOPO in whole population with 3 selected predictors were plotted in Fig. 5A and Fig. 5B, respectively. ROC curves of the LvOPIS and LvOPOS and logistic regression models in diagnosing LvOPI in premenopausal women using four selected predictors and LvOPO in in post-menopausal women using two selected predictors were plotted in Fig. 6A and Fig. 6B, respectively.

3.6 Analysis of Reliability of Single Predictor and Hybrid Predicting Models

Table 3 shows the sensitivity, specificity, positive predictive value, negative predictive value, accuracy and f1 score for each single predictor and hybrid predicting methods in diagnosing LvOPI and LvOPO in whole population, premenopausal group, and postmenopausal group.

3.7 Comparisons of AUC Among Single Predictors and Hybrid Predicting Models

In the whole population, the LvOPI_Logi6 model achieved the highest AUC in diagnosing LvOPI, followed by the LvOPIS6 model, LvOPI_Logi3 model, LVFF, and LvOPIS6 mode3 in a decreasing order (Fig. 5). For the diagnosis of LvOPO, the LvOPO_Logi6 model achieved the highest AUC, followed by the LvOPOS6 model, LvOPS3 mode, LvOPO_Logi3 model, and LVFF in a decreasing order (Fig. 5). Nevertheless, there was no difference between any of hybrid predicting model and the best single predictor LVFF in diagnosing either LvOPI or LvOPO (P = 0.1322 to 0.7151).

In the premenopausal group, the LvOPI_Logi4 model achieved the highest AUC in diagnosing LvOPI, followed by the LvOPI_Logi5 model, LvOPIS5 model, LvOPIS4 model, and LVFF in a decreasing order (Fig. 5). Both hybrid models using logistic regression analysis significantly outperformed the best single predictor LVFF (P < 0.05). LvOPISs signignificantly outperformed BMI, age, and body height (all P < 0.05) but not LVFF (P = 0.2736) or body weight (P = 0.0566), in diagnosing LvOPI.

In the postmenopausal group, the LvOPO_Logi6 model achieved the highest AUC, followed by the LvOPO_Logi2 model, LvPOS6 model, LVFF, and LvOPS2 model in a decreasing order but without significant difference between hybrid models and the best single predictor (P = 0.14 to 0.9323) (Fig. 6).

4 Discussion

Our study showed significantly higher LVFF in the postmenopausal women than the premenopausal women by a difference of 17% in average, consistent with studies performed by Burian et al. (21%) [13] and Sollmann et al. (18%) [15]. It can be attributed to the compound effects of the aging. The postmenopausal women in our study were older than the premenopausal women by an average of 15.5 years. Our observation is consistent with Schellinger’s study [16] and Baum’s study [17], showing increase of LVFF along with increase of age. On the other hand, estrogen has been found to have an inverse effect on the vertebral marrow fat fraction during the menstrual cycle, i.e., increase during the follicular phase and decrease during the luteal phase, and, reduction of rapid vertebral marrow fat fraction in postmenopausal women rapidly after 17-ß estradiol administration [18].

Our study showed significantly lower BMD in the postmenopausal women than the premenopausal women by a difference of – 1.46 on T-score. The difference of BMD can be attributed to the aging, which has an effect on bone loss via suppressing osteogenic programs in the bone marrow [19–21]. It can also be ascribed to the depletion of estrogen, which reduces bone resorption by inhibiting osteoclast formation and enhancing osteoclast apoptosis [22, 23], in postmenopausal women. Our study showed higher ratio (64.5%) of LVPO plus LVPI in the postmenopausal women than that (34.5%) in the premenopausal women. Our results can be explained by the mixed effects of estrogen deficiency related bone resorption acceleration and the aging related bone formation deceleration [24, 25].

Our study showed a general trend of an inverse association between the BMD and LVFF as well as an inverse association between the BMD and age in the women. Our results could be explained by the aging factor. A recent review focusing on cell autonomous changes in hematopoietic and skeletal systems showed reduced osteogenesis and increased adipogenesis in aging bone [26]. In addition to the aging factor, marrow adipose tissue itself has been recognized as an active endocrine organ [27]. Bone marrow adipocytes have been reported to be inversely associated with the BMD [28]. Verma et al. provided histological evidence by examining the adipocytic to haemopoietic tissue ratio in iliac crest biopsies [29]. Their results indicated increased volume of adipose tissue and reduced bone formation in osteoporosis. Yeung et al. examined the LVFF and fat unsaturation index using MR spectroscopy, showing that osteoporosis is associated with increased marrow fat and, especially, saturated lipids rather than unsaturated lipids [30].
Clinical information, including but not limited to age, body weight, BMI, and post-menopausal years, has been used to construct clinical decision rules such as SCORE, ORAI, OSA, OSIRIS, and ABONE to predict osteoporosis [8]. Our results showed that the age, MMI and LvFF allowed prediction of LvOPO with an AUC ranging from 0.788 to 0.802 in whole female population. By integrating these predictors, our results showed that the hybrid predicting models achieved AUC ranging from 0.81 to 0.85 higher than the single predictors.

By excluding the postmenopausal women, the influence of estrogen depletion due to ovary failure on the LvOPI can be omitted in the premenopausal women theoretically. Prior studies show that BMD is inversely associated with age [31]

| Group  | Diagnosis | Predictors | Criteria          | Sn (%) | Sp (%) | PP (%) | NPV (%) | Ac (%) | F1 score (%) |
|--------|-----------|------------|-------------------|--------|--------|--------|---------|--------|--------------|
| Total  | LvOPI     | Age ≥ 54   | 70 68 63          | 75     | 69     | 67     |         |        |              |
|        |           | MMI ≥ 1    | 70 72 66          | 76     | 71     | 68     |         |        |              |
|        |           | LvFF ≥ 0.676 | 70 65 61         | 74     | 67     | 65     |         |        |              |
|        |           | BH ≤ 155   | 75 23 43          | 54     | 46     | 55     |         |        |              |
|        |           | BW ≤ 51    | 77 11 40          | 38     | 40     | 53     |         |        |              |
|        |           | BMI ≤ 20.9 | 75 18 41          | 48     | 43     | 53     |         |        |              |
|        |           | LvOPOS3 ≥ 1 | 80 63 63        | 80     | 70     | 70     |         |        |              |
|        |           | LvOPOS6 ≥ 3 | 68 74 67        | 75     | 71     | 67     |         |        |              |
|        |           | LvOPO_Logi3 ≥ 44% | 82 70 68  | 83     | 75     | 74     |         |        |              |
|        |           | LvOPO_Logi6 ≥ 37% | 93 63 66  | 92     | 76     | 77     |         |        |              |
| LvOPO  | Age ≥ 59  | 70 77 38 | 96 77 51 |         |        |        |        |        |              |
|        | MMI ≥ 4   | 87 69 33 | 97 71 47 |         |        |        |        |        |              |
|        | LvFF ≥ 0.71 | 80 70 32 | 95 71 45 |         |        |        |        |        |              |
|        | BH ≤ 155  | 67 22 13 | 79 29 22 |         |        |        |        |        |              |
|        | BW ≤ 52  | 67 17 12 | 75 25 21 |         |        |        |        |        |              |
|        | BMI ≤ 21.1 | 80 26 16 | 88 34 26 |         |        |        |        |        |              |
|        | LvOPOS3 ≥ 2 | 87 71 34 | 97 73 49 |         |        |        |        |        |              |
|        | LvOPOS6 ≥ 3 | 73 79 38 | 94 78 50 |         |        |        |        |        |              |
|        | LvOPO_Logi3 ≥ 19% | 80 70 32 | 95 71 45 |         |        |        |        |        |              |
|        | LvOPO_Logi6 ≥ 15% | 80 77 38 | 96 77 51 |         |        |        |        |        |              |
| Pre-M  | LvOPI     | Age ≥ 46 | 85 40 31 | 89 51 46 |         |        |        |        |              |
|        | LvFF ≥ 0.589 | 85 70 48 | 93 74 61 |         |        |        |        |        |              |
|        | BH ≤ 163  | 92 23 28 | 90 40 43 |         |        |        |        |        |              |
|        | BW ≤ 55  | 69 68 41 | 87 68 51 |         |        |        |        |        |              |
|        | BMI ≤ 21.88 | 85 73 50 | 94 75 63 |         |        |        |        |        |              |
|        | LvOPOS4 ≥ 3 | 69 83 56 | 89 79 62 |         |        |        |        |        |              |
|        | LvOPO5 ≥ 3 | 100 63 46 | 100 72 63 |         |        |        |        |        |              |
|        | LvOPO_Logi3 ≥ 35% | 85 88 69 | 95 87 76 |         |        |        |        |        |              |
|        | LvOPO_Logi6 ≥ 35% | 85 88 69 | 95 87 76 |         |        |        |        |        |              |
| Post-M | LvOPO    | Age ≥ 61  | 71 50 37 | 81 56 49 |         |        |        |        |              |
|        | MMI ≥ 9   | 79 41 35 | 82 52 49 |         |        |        |        |        |              |
|        | LvFF ≥ 0.729 | 79 44 37 | 83 54 50 |         |        |        |        |        |              |
|        | BH ≤ 157 | 86 59 46 | 91 67 60 |         |        |        |        |        |              |
|        | BW ≤ 65 | 79 50 39 | 85 58 52 |         |        |        |        |        |              |
|        | BMI ≤ 26.37 | 79 53 41 | 86 60 54 |         |        |        |        |        |              |
|        | LvOPOS2 ≥ 1 | 79 44 37 | 83 54 50 |         |        |        |        |        |              |
|        | LvOPO6 ≥ 3 | 86 47 40 | 89 58 55 |         |        |        |        |        |              |
|        | LvOPO_Logi2 ≥ 22% | 93 50 43 | 94 63 59 |         |        |        |        |        |              |
|        | LvOPO_Logi6 ≥ 17% | 93 53 45 | 95 65 60 |         |        |        |        |        |              |

Ac denotes accuracy, BH denotes body height, BW denotes body weight, NPV denotes negative predictive value, PPV denotes positive predictive value, Sn denotes sensitivity, and Sp denotes specificity. The unit of age, MMI, BH, BW, and BMI is years, years, cm, kg, and kg/m², respectively.
and LvFF [32] but positively associated with BMI [33] in premenopausal women. Our study showed that the age, body weight, BMI, and LvFF allowed prediction of premenopausal LvOPI with an AUC ranging from 0.649 to 0.788. LvFF has been used to predict LvOPO in general population containing both women and men, achieving an AUC of 0.896 [34]. By integrating these predictors, our results show that the LvOPIS achieved an AUC significantly higher than age and BMI with statistical significance, and higher than body weight with marginal significance. Showing similar AUC with LvOPIS, a hybrid predicting model using logistic regression model outperformed all single predictors, including LvFF, with statistical significance.

In the postmenopausal women, however, the age, LvFF, and MMI did not predict LvOPO as well as they did in the whole female population, neither did the LvOPOS. The poor diagnostic performance of these predictors and the LvOPO- POS might be attributed to the potential drawback of DeXA, which has been reported to overestimate the BMD by mistaking the osteophytes as lumbar vertebral bony structures [2, 35].

Our study has several limitations. First, the potential osteophyte-related overestimation of BMD using DeXA was not evaluated in our study. We suggest not to overemphasize our observation in postmenopausal women. Second, our study only enrolled patients older than 40 years of age in the premenopausal women. Our results should not be generalized to those younger than 40 years of ages. To better understand the performance of the aforementioned clinical and MR features in diagnosing LvOPI or LvOPO, further study enrolling a wider age range is warranted. Third, our study only enrolled Taiwanese patients from a single hospital. A multicenter study enrolling different racial patients is warranted to evaluate the generalization of our results. Finally, with the similar age distribution in the postmenopausal women, the LvFF in our study (0.74 ± 0.05; 63 ± 7 years) was apparently higher than Burian’s study (0.49 ± 0.08; 65 ± 7 years) [13] and Sollmann’s study (0.47 ± 0.09; 63 ± 6 years) [15]. The discrepancy of postmenopausal female LvFF might be attributed to either population variation or sampling bias. In 2019, Burian et al. documented that the heterogeneity of the lumbar vertebral bone marrow increased in the postmenopausal women than the premenopausal women [13]. To eliminate the potential sampling bias related to the lumbar vertebral bone marrow heterogeneity, the signal intensity averaged from the ROIs contouring the entire vertebra on three sagittal slices was intentionally used for calculation of LvFF in our study.

In conclusion, by integrating the LvFF derived from MR images and the clinical data, our proposed hybrid predicting models improve the diagnostic accuracy of the LvOPI in premenopausal Taiwanese women. Our study suggests that premenopausal LvOPI could be accurately diagnosed while receiving MR study incidentally so that patients might have a better chance to prevent further progression toward LvOPO.

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Declarations

Competing interest The authors declare no competing interest.

Additional information Correspondence and requests for materials should be addressed to CJJ or K.Y.C.

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Predicting Lumbar Vertebral Osteopenia Using LvOPI Scores and Logistic Regression Models in an Exploratory Study of Premenopausal Taiwanese Women

Authors and Affiliations

Chun-Wen Chen1,2,3 · Yi-Jui Liu4 · Shao-Chieh Lin5,6 · Chien-Yuan Wang7,8 · Wu-Chung Shen9,10 · Der-Yang Cho11 · Tung-Yang Lee12,13 · Cheng-Hsuan Juan6,12,13 · Cheng-En Juan4 · Kai-Yuan Cheng1 · Chun-Jung Juan6,9,10,14,15,16

1 Department of Medical Imaging and Radiological Sciences, Central Taiwan University of Science and Technology, No.666, Buzih Road, Beitun District, Taichung City 406, Taiwan, Republic of China
2 Department of Radiology, Taichung Armed Forces General Hospital, Taichung, Taiwan, Republic of China
3 Department of Radiology, School of Medicine, National Defense Medical Center, Taipei, Taiwan, Republic of China
4 Department of Automatic Control Engineering, Feng Chia University, Taichung, Taiwan, Republic of China
5 Ph.D. program in Electrical and Communication Engineering in Feng Chia University, Taichung, Taiwan, Republic of China
6 Department of Medical Imaging, China Medical University Hsinchu Hospital, 199, Sec. 1, Xinglong Rd, Zhubei City, Hsinchu 302, Taiwan, Republic of China
7 Department of Orthopedics, China Medical University Hsinchu Hospital, Zhubei City, Hsinchu 302, Taiwan
8 Department of Orthopedics, College of Medicine, China Medical University, Taichung 400, Taiwan
9 Department of Radiology, School of Medicine, College of Medicine, China Medical University, Taichung, Taiwan, Republic of China
10 Department of Medical Imaging, China Medical University Hospital, Taichung, Taiwan, Republic of China
11 Department of Neurosurgery, China Medical University Hospital, Taichung, Taiwan, Republic of China
12 Cheng Ching Hospital, Taichung, Taiwan, Republic of China
13 Master’s Program of Biomedical Informatics and Biomedical Engineering, Feng Chia University, Taichung, Taiwan, Republic of China
14 Department of Computer Science and Information Engineering, National Taiwan University, Taipei, Taiwan, Republic of China
15 Department of Biomedical Engineering and Environmental Sciences, National Tsing Hua University, Hsinchu, Taiwan, Republic of China
16 Department of Biomedical Engineering, National Defense Medical Center, Taipei, Taiwan, Republic of China