Purpose:
The purpose of this study was to clarify whether some radiographic features observed on foot X-rays can be used to identify patients with skeletal osteoporosis. To that end, we prospectively examined several commonly described pedal radiographic features of low bone mineral density (e.g., cortical thinning, presence of prominent primary trabeculae, etc. [Figure 1]) with clinically established risk factors for osteoporosis in 80 women using multivariable (MV) analyses and bone densitometry (i.e., DEXA scan) as the reference standard.

Methodology:

Summary:
This was a prospective, matched case-control (1:1) study. Data was collected from 40 patients with osteoporosis and 40 age-matched (<3 y) control subjects. Adult female participants were recruited at the time of their DEXA scan while attending the Advocate Illinois Masonic Medical Center (AIMMC) outpatient radiology department from Jan. 2013 to Jan 2016. Enrolled subjects also had weight-bearing X-rays (2 views) taken of their dominant foot, a brief foot exam, and were queried regarding their medication and social history. All participants provided written research informed consent. This study was reviewed and approved by Advocate Health Care’s Institutional Review Board.

Inclusion/Exclusion Criteria:

Inclusion Criteria:
- Adult women between the ages of 45 and 75 years who underwent a DEXA scan for any reason.
- Eligible women must have received either an ‘osteoporosis’ determination in either the hip or lumbar spine region (i.e., case subject) OR a ‘normal’ determination in both lumbar spine and femoral head regions (i.e., control subject).

Exclusion Criteria:
- Patients with DEXA scan results read as ‘osteopenia’ or ‘osteopenia-1’.
- Patients with local causes of abnormal bone mineral density within their dominant foot (e.g., previous foot surgery, history of foot fracture or other serious foot deformity)
- Patients who were on hormone replacement therapy for >5 years
- Women who were pregnant at the time of the study.

Definition of Cases/Controls:
Cases were defined as having osteoporosis determined by DEXA scan in accordance with WHO criteria (less than 2.5 standard deviations below the mean for young adults) (Table 1). Patients with normal DEXA scans were recruited as age-matched control subjects. 50 of these patients were randomly selected from a pool of 400 patients who had undergone DEXA scans at AIMMC between January 2013 and January 2016.

Literature Review:

Osteoporosis is a systemic skeletal disease characterized by low bone mass and a consequent increase in bone fragility, susceptibility to fracture, and poor bone healing. Approximately 8 million women in the United States have osteoporosis, and another 34 million people are classified as having osteopenia and are at imminent risk of developing osteoporosis.1 Foot and ankle surgeons can play an important role in detection of this insidious disease by helping to identify patients with osteoporosis early in the disease process. After all, it has been estimated that nearly forty percent of older adult women seek medical consultation regarding a foot problem each year. Moreover, three out of four older adults admit to suffering from foot pain at some time and as many as 90% admit to a foot problem that impacts on their quality of life at some point during their aging years.2,3

The World Health Organization (WHO) has recommended that all evaluations of fracture risk include assessment of what are widely considered to be the most important clinical predictors of fracture risk: age, tobacco use, family history of osteoporosis, low bone mass (BMD) BMD <2.5 kGm2, chronic estrogen deprivation (or hypogonadism in men), rheumatoid arthritis, more than four alcohol-containing drinks per day, and glucocorticoid therapy.4,5 However, findings on plain film radiographs can also be useful in estimating bone mineral density and help to assess fracture risk. The principle radiographic findings of osteoporosis are: (1) increased radiolucency, (2) cortical thinning, (3) altered trabecular pattern, and (4) fractures and deformities. Early on in osteoporosis the primary trabeculae are accentuated on a radiograph, while later on in the disease process they begin to disappear, resulting in a “washed-out” appearance.6,7 These findings are best described in the spine and proximal femur,8,9 but may also be true in the calcaneus, as well.10 Several studies have also indicated that cortical bone provides a sensitive index for changes in bone metabolism.11,12 Radiographs from several peripheral sites in the body have already been found to aid in the detection of low skeletal bone mineral density. These sites include the calcaneus,13,14 metatarsal shaft,15 and mandible16; however, similar studies to validate the use of foot X-rays for this purpose are lacking.

Results:

Radiographic Features of Diminished Bone Density on Foot X-rays

The radiographic indices of bone mineral density which we assessed have previously been found to be responsive the effects of aging.1 Additionally, all indices have been found to be consistent with similar indices in hip studies.14,15,16,17,18 AP radiographs were evaluated for percent cortical area (PCA) within the 2nd metatarsal as originally described by Meema (1977).19 AP films were also assessed for the presence of prominent primary trabeculae (PTT) and intracortical tunneling (IT) within the lesser metatarsals (scored as either ‘present’ or ‘clearly not present’). Finally, lateral radiographs were used to obtain values independently of Damra’s calcaneal index (grades 1-5) and the modified calcaneal index1 (grades 1-3) as described previously. All radiographic assessments were performed by a single experienced rater (AA).

Other Study Covariates:
Enrolled participants were queried as to their clinical risk factors for developing osteoporosis by a member of the research team. Clinical covariates also examined in this analysis included diabetes mellitus (y/n), rheumatoid arthritis (y/n), hypertension (y/n), menopause age, smoking history, oral steroid use (y/n), family history of osteoporosis (y/n), body mass index (BMI), alcohol use, and presence of renal failure (y/n). Participants were also examined by an experienced clinician for limited motion within the first MTP joint, excessive motion at the 1st MTP, tenderness within the 2nd MTP joint, and the 1st metatarsal cuneiform angle (an indirect measurement of 1st ray hypermobility).

Statistical Analysis:
Conditional logistic regression was used to predict the presence or absence of osteoporosis based on values of a set of predictor variables. Only variables with p<0.25 in the univariate analysis were considered in the MV analysis.

Analysis & Discussion:
This study, the first of its kind, demonstrated that certain radiographic findings sometimes seen on foot X-rays correlate quite well with skeletal osteoporosis. Specifically, we found that when AP foot X-rays show:

- diminished cortical thickness in the 2nd metatarsal (i.e., less than 50% of the 2nd metatarsal consists of cortical bone), or
- intracortical tunneling in one or more lesser metatarsals, patients are at significantly increased risk for having skeletal osteoporosis. These radiographic findings are also effective in predicting osteoporosis that the only other variable to make it into the final model was BMI— all other clinical predictors were not significant in the final model. We conclude that when cortical thinning or tunneling is present, surgeons may want to consider further workup with formal bone densitometry prior to elective foot or ankle surgery where osteoporosis, arthrodesis and internal fixation is planned.

References:
8. Kandel M, Schaffner A, Herweg R. density on foot x-rays: Look Before You Cut: Thirty-five patients with osteoporosis determined by DEXA scan were entered into this study, and were evaluated for various radiographic indices of bone mineral density. These were then compared to a group of age-matched control subjects. The radiographic findings which were found to be most responsive to changes in bone density were:

- Diminished cortical thickness in the 2nd metatarsal (i.e., less than 50% of the 2nd metatarsal consists of cortical bone), or
- Intracortical tunneling in one or more metatarsals.

These radiographic findings were also found to be effective in predicting osteoporosis in the foot and ankle region. The only other variable to make it into the final model was BMI— all other clinical predictors were not significant in the final model. We conclude that when cortical thinning or tunneling is present, surgeons may want to consider further workup with formal bone densitometry prior to elective foot or ankle surgery where osteoporosis, arthrodesis and internal fixation is planned.

Acknowledgements:
This study was graciously funded by Advocate’s Presidents Fund.

Table 1. Final multivariable model for predicting patients with skeletal osteoporosis.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Odds Ratio</th>
<th>95% Confidence Interval</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body Mass Index</td>
<td>0.84</td>
<td>0.74 - 0.95</td>
<td>0.005</td>
</tr>
<tr>
<td>Less Than 50 Percent</td>
<td>14</td>
<td>3.7 - 55</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Intracortical Tunneling</td>
<td>5.0</td>
<td>1.2 - 29</td>
<td>0.029</td>
</tr>
</tbody>
</table>

Eighty subjects (40 cases and 40 age-matched controls) with a mean age of 64.6 ± 6.2 years (range 49 to 75 years) were enrolled. Percent cortical area of the 2nd metatarsal (measured at the mid-diaphysis posterior cortex) was used as a discriminating test for osteoporosis (area under the curve = 0.878, p<0.001, Figure 2). The optimal cut-point was <50% cortical area which correlated with a sensitivity and specificity of 0.90 and 0.70, respectively. The final multivariable model (Table 1) included body mass index (odds ratio 0.84 [95% CI 0.74-0.95]), <50% cortical area in the 2nd metatarsal (odds ratio 14.45 [95% CI 3.7-55]) and cortical tunneling of the lesser metatarsals (odds ratio 5.0 [95% CI 1.2-19]).