Original article

Hip-spine syndrome: A cadaveric analysis between osteoarthritis of the lumbar spine and hip joints

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ABSTRACT

Background: Authors have recently proposed the concept of “hip-spine syndrome”, however there exists limited evidence available to differentiate whether these concomitant arthritides are due to anatomic/structural causes, or systemic/metabolic effects. Exploring this relationship has important implications during the evaluation and treatment of both spine and hip disorders—a common clinical presentation of many patients. The purpose of this experiment was to investigate the individual contribution of hip arthritis towards the development of spine arthritis, with knee arthritis also being analyzed as a negative (systemic) control.

Hypothesis: Hip and spine arthritis are caused by both metabolic and anatomic causes.

Methods: A large, well-organized osteological database was queried, and osteoarthritis of the spine, hip, and knee joints was quantified using a validated scoring criteria. Six hundred and twenty-five specimens were chosen for analysis. Multivariate linear regression models were created to quantify the independent contributions of age, gender, race, height, and arthritis of the spine and hip joints.

Results: Age was the strongest predictor of arthritis at each site (standardized betas > 0.281, P < 0.001 for all). Hip arthritis was a stronger predictor of spine arthritis than was knee arthritis (standardized betas 0.215 and 0.155, respectively, P < 0.001 for both). Spine arthritis was also a stronger predictor of hip arthritis than was knee arthritis (standardized betas 0.232 and 0.173, P < 0.001 for both).

Conclusions: Anatomic/structural influences about the lumbosacral-pelvic junction contribute towards the development of arthritis that is separate from any systemic/metabolic effects. Surgeons performing total hip arthroplasty should remain aware of these relationships, although future research is necessary regarding optimal surgical treatment of these patients.

Level of evidence: N/A (cadaveric study).

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1. Introduction

Degenerative joint disease of the lumbar spine and hip joints are among the most common reasons for a visit to a physician [1]. These disorders often coexist, and patients may present with a spectrum of disabilities from overlapping pathologies. Consequently, this “hip-spine syndrome” has been used to describe individuals with corresponding lumbar spine and hip arthrosis disorders [2]. Its implications are especially relevant during the management of patients with concomitant spine and hip pain—where providers are faced with a diagnostic challenge of determining the predominant pain generator. A number of different treatment algorithms have recently been proposed to help answer these questions, although details regarding the pathogenesis of hip-spine syndrome remain unclear [3–5].

Recently, there has been considerable interest in differentiating the anatomic versus systemic contributions of hip-spine syndrome. While there exists a growing body of evidence associating these arthritis patterns together, authors have debated whether these effects are due to structural considerations, such sagittal balance, femoracetabular impingement, and acetabular orientation, or merely simply a consequence of the systemic and biochemical processes that lead to the formation of degenerative joint disease elsewhere in the body [5–8]. Proponents of the later theory would point to the well-established data confirming that individuals with arthritis of one joint are more likely to have other arthritic joints [9]. However, advocates of the former have presented compelling evidence that a complex biomechanical load-sharing interaction takes place at the lumbosacral-pelvic junction, and may be directly

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2. Methods

2.1. Cadaveric specimens

Cadaveric skeletons were acquired from the Hamann-Todd Osteological Collection (Cleveland, Ohio, United States). This collection contains over 3000 disarticulated human skeletons catalogued for age, sex, and ethnicity in a large database utilized for the present study. We included 625 specimens that were randomly selected from the database whose age at the time of death were between 40 to 79 years old. Exclusion criteria included any obvious fractures of the spine, femur or tibia, rheumatologic diseases, slipped capital femoral epiphysis, suspected metabolic disease, evidence of infection affecting the joint surfaces, and incomplete skeletons leaving a total of 579 skeletons available for primary study (579 lumbar spines, 1158 femora and tibiae).

2.2. Arthritis grading

Arthritis grading was performed by two study authors using a previously described system for spine, hip and knee degenerative joint disease [16,17]. The two authors, both with significant experience studying orthopaedic osteopathy, examined a large number of specimens together to establish a grading system; osteoarthritis of the spine, hips, and knees were graded by quantifying known macroscopic signs of degenerative joint disease [18,19].

Arthritis of the proximal right and left femurs and acetabuli were graded from 0–3, as follows: grade 0: less than 15% osteophyte reaction affecting the joint surface, grade 1: between 15–49% mild osteophyte reaction affecting the joint surface, grade 2: between 50–100% mild osteophyte reaction, or any moderate osteophyte formation, grade 3: greater than 50% moderate osteophyte formation or any severe osteophyte formation. They were then averaged to form a composite hip joint score from 0–3 (Fig. 1) [20].

The right and left patellae, patellofemoral articulations of the femur, medial femoral condyles, medial tibial joint surfaces, lateral femoral condyles and lateral tibial joint surface were also graded from 0–3, using the above criteria, and these measurements were averaged to form a composite knee joint score from 0–3 (Fig. 2) [16,17].

Osteoarthritis at each lumbar vertebral joint was measured from 0–4, as follows: grade 0: no evidence of lipping or osteophytes on endplates or facets, grade 1: mild arthrosis with osteophyte reaction involving ≤ 50% of the facet joint or vertebral endplates, grade 2: moderate arthrosis with osteophyte reaction involving > 50% of vertebral endplates but without bridging osteophytes, or mild changes greater than 50%, grade 3: severe lipping or osteophytes encompassing 100% of the endplate or facet joint, but with bridging osteophytes on less than 50% of joint surface, and grade 4: ankylosed segment or osteophyte bridging between two spinal levels occupying over 50% of joint surface. Measurements at each joint level were subsequently averaged to form a composite spine arthritis grade, measured from 0–4 (Fig. 3) [16,17].

Twenty specimens were measured independently by two authors to establish inter-rater reliability. Intra-rater reliability was assessed by one of the study authors with a four-week interval between grading.

2.3. Statistical methods

All statistics were performed with the SPSS 23 software package (IBM Corporation, Armonk, NY). Inter-relator reliability for arthritis grading at each articulation was compared with the Cohen’s Kappa statistic. Multivariate linear regression analysis was used to predict the effects of age, race, gender, and height, on osteoarthritis. Separate analyses were run with the dependent variable set as degenerative arthritis of the spine, hips, and knees. In the

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Fig. 1. Osteoarthritis at the hip joint was measured using previously published grading criteria to account for lipping and osteophytes. Reproduced with permission, Weinberg et al. Femoral version and tibial torsion are not associated with hip or knee arthritis in a large osteological collection. J Pediatr Orthop 2017 [16].

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Fig. 2. Osteoarthritis at the knee joint was measured using previously published grading criteria to account for liping and osteophytes. Reproduced with permission, Weinberg et al. A cadaveric investigation into the demographic and bony alignment properties associated with osteoarthritis of the patellofemoral joint. Knee.

Fig. 3. Osteoarthritis at the spine was measured using previously published grading criteria to account for liping and osteophytes. Reproduced with permission, Weinberg et al. Increased and decreased pelvic incidence, sagittal facet joint orientations are associated with lumbar spine osteoarthritis in a large cadaveric collection. Int Orthop.
regression analyses, multicollinearity was assessed as negative based on VIF < 5 and coefficient tolerance > 0.1. Normal probability plots of the regression standardized residual were inspected for normality, scatterplots of the standardized residuals were inspected for homoscedasticity, and the lack of any undue influence from outliers was confirmed with a Cook’s distance < 1. Significance was set at \( P < 0.05 \).

3. Results

The average age and standard deviation of specimens was 55 ± 10 years. There were 79 females (14%) and 500 males. There were 298 Caucasians (69%), 179 African-Americans (31%), and 2 other ethnicities. The mean height was 1709 ± 22 mm.

For specimen grading, reliability analyses was considered “good” (0.60–0.79) or “excellent” (0.81–0.99) for all categorical variables [20,21]. Average grades for spine, hip and knee osteoarthritis were 2.3 ± 1.0, 3.1 ± 1.4, and 2.7 ± 1.4, respectively. Arthritis increased linearly with age at each joint (Fig. 4).

Multivariate linear regression analysis was performed to determine independent predictors of ipsilateral spine, hip and knee arthritis (Tables 1 and 2). Age was the strongest predictor of arthritis at each site (standardized beta > 0.281, \( P < 0.001 \) for all). Hip arthritis was a stronger predictor for spine arthritis than knee arthritis (standardized betas 0.215 and 0.155, respectively, \( P < 0.001 \) for both). Spine arthritis was a stronger predictor for hip arthritis than was knee arthritis (standardized betas 0.232 and 0.173, respectively, \( P < 0.001 \) for both). The relationship between spine and hip arthritis is plotted on Fig. 5. Male gender was an independent predictor of spine arthritis (standardized beta = −0.086, \( P = 0.028 \)), and knee arthritis (standardized beta = −0.053, \( P = 0.002 \)).

4. Discussion

Patients presenting with pathologic lumbar spine and hip disorders have proven to be a challenge to diagnose and treat [3–5]. Offierski and MacNab proposed the term “hip-spine syndrome” in 1983 to account for these patients with coexisting arthritic pathologies [2]. Devin et al. recently discussed the many difficulties associated with the diagnosis and management of these complicated cases, which has become increasingly relevant in preoperative planning for total hip arthroplasty [5,22]. However, one of the essential questions asked by those authors was whether hip-spine syndrome exists as a consequence of anatomic/structural biomechanics, such as sagittal balance, or merely a result of the systemic and metabolic alterations that predispose to arthritis in the first place. To our knowledge, there exists limited data available to differentiate between the two. The purpose of this study was to

![Arthritis Increases With Age](image)

**Fig. 4.** Mean and standard deviations for spine, hip, and knee arthritis plotted by decade. Arthritis increased with age at each joint.

**Table 1**

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>Unstandardized coefficient</th>
<th>Standardized beta coefficient</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>0.032</td>
<td>0.363</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Gender</td>
<td>−0.225</td>
<td>−0.086</td>
<td>0.028</td>
</tr>
<tr>
<td>Race</td>
<td>−0.124</td>
<td>−0.064</td>
<td>0.073</td>
</tr>
<tr>
<td>Height</td>
<td>−0.001</td>
<td>−0.035</td>
<td>0.383</td>
</tr>
<tr>
<td>Hip arthritis</td>
<td>0.096</td>
<td>0.215</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Knee arthritis</td>
<td>0.053</td>
<td>0.155</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

A negative value for gender indicates that males are more likely to have arthritis than females.

A negative value for race indicates that African-Americans are less likely to have arthritis than Caucasians.

**Table 2**

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>Unstandardized coefficient</th>
<th>Standardized beta coefficient</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>0.072</td>
<td>0.281</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Gender</td>
<td>−0.401</td>
<td>−0.53</td>
<td>0.203</td>
</tr>
<tr>
<td>Race</td>
<td>−0.010</td>
<td>−0.002</td>
<td>0.964</td>
</tr>
<tr>
<td>Height</td>
<td>−0.002</td>
<td>−0.062</td>
<td>0.138</td>
</tr>
<tr>
<td>Spine arthritis</td>
<td>0.103</td>
<td>0.232</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Knee arthritis</td>
<td>0.077</td>
<td>0.173</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

A negative value for gender indicates that males are more likely to have arthritis than females.

A negative value for race indicates that African-Americans are less likely to have arthritis than Caucasians.
try to segregate the independent structural and metabolic contributions of arthritis seen in patients with hip and spine arthritis. We designed an experiment to test the hypothesis that biomechanical interactions occurring at the level of the hip joints would result in greater contributions to spine arthritis than from those “downstream” effects of knee arthritis, which was employed as a negative (systemic) control.

The results of this study suggest that hip arthritis is a stronger predictor of spine arthritis than knee arthritis is, and conversely, that spine arthritis is a stronger predictor of hip arthritis than knee arthritis is. This data would therefore support the hypothesis that anatomic/structural influences should be considered separately from metabolic effects. If one is to square the standardized beta coefficients (Tables 1 and 2), the resulting percentages of each independent variable can be interpreted as the relative contributions to the overall effect size, or variance, seen in the dependent variable [23]. In this case, hip arthritis had a larger associated effect size than did knee arthritis towards the development of spine arthritis (5% versus 2%).

The downstream negative control, knee arthritis, had a smaller contribution to the overall variance seen in the development of spine arthritis than was caused by hip arthritis. This adds validity to the argument proposed by Saunders et al. who suggested that anatomic disequilibrium across the lumbosacral-pelvic junction may lead to increased osteophyte formation in both the hip and lumbar spine. Saunders et al. showed that radiographic evidence of spine arthritis was more commonly seen in those patients with hip arthritis, and postulated that alterations of joint reactive forces may be mediated by sagittal alignment of the lumbar spine, sacrum, pelvis, and hip joints [24].

The lumbosacral-pelvic complex works in such a way that the body transmits stresses from a two-part structure—the hip joint axis—to a one-part column—the spine, and vice-versa. The semi-rigid structure of the sacropelvis rotates and translates with locomotion to maintain the necessary balance around the hip joint axis [25,26]. Consequently, perturbations of this sagittal alignment may result in a misallocation of load absorption at the respective joints in question. Data from this experiment would support the emerging theory of a hip-spine syndrome. While we would agree with the conclusions of most earlier authors that systemic, rheumatic, and metabolic inflammatory phenomenon play a large role in the development of spine and hip osteoarthritis; sagittal alignment, and the mechanical influences of spine and hip biomechanics should not be ignored, along with the important effects of acetabular version and dysplasia [27,28].

These conclusions would be in accord with the latest reports of numerous related clinical analyses [29]. Parvizi et al. recently administered a survey to 344 patients undergoing total hip arthroplasty (THA), and found that 170 patients reported low-back pain preoperatively, with 66% of patients reporting some resolution of symptoms postoperatively [7]. Ben-Galim et al. conducted a prospective analysis of low-back pain following THA [6]. These authors found that both hip and back pain improved postoperatively, with Harris Hip Scores increasing from 46 preoperatively to an average of 86 at two years postoperatively. Likewise, Oswestry Disability Index scores for back pain decreased from 37 preoperatively, to 20 at two years postoperatively (P<0.05 for both) [6]. Similarly, Prather et al. analyzed a billing database and concluded that presence of coexisting hip and spine arthritis is higher than previously thought [30]. These authors also showed that patients undergoing THA who had concomitant lumbar spine arthritis reported increased pain postoperatively, and had longer hospital courses with more expensive medical care.

Not surprisingly, our study showed that age was the strongest predictor of spine and hip arthritis, which supports the validity of our grading system. The high-standarized beta values suggests that 14% of the overall variance in spine arthritis scores can be attributed to age, which is similar to previously published studies [17]. This data also confirms that men are more likely to have spine arthritis than women, as has been shown previously [31,32]. Similarly, men were more likely to have knee arthritis, as were Caucasians [33,34]. This study was not without limitations. While the use of an osteological collection allowed for us to establish a random sample population, it lacked a great deal of corresponding objective clinical information and we were unable to assess patient reported symptomatic hip and low-back pain. Similarly, this study did not assess osteoarthritis at the sacroiliac joint, which should be an important area of future research. While this data shows a moderate link between osteoarthritis of the spine and hip, it is based on osteopathologic findings, which may not have correlated with functional patient disability [35,36]. This has presented a similar problem found in the radiographic experiments comparing these entities. However, the studies that relied on subjectively administered patient-surveys were created with inherent selection-bias; where only those individuals whom presented for treatment were included, and therefore more likely to report negative symptoms [3–5]. Other limitations of this osteological collection have been described previously. Although skeletons with traumatic, metabolic, and infectious entities were excluded from study, it is possible that the specimens analyzed may not have been representative of modern individuals. Within these limitations, the reliability suggests that the measurements taken were both accurate and reproducible. Moreover, the use of an osteological collection avoided many selection-bias’ seen in previous clinical studies; where it has not been possible to provide a negative control as the only individuals included were those symptomatic enough to present for treatment. This study did not evaluate pelvic tilt or disc heights, as this was not possible on cadaveric specimens.

In summary, this large anatomic study of a random population provides further evidence to support the hypothesis of a structural hip–spine syndrome. This data confirms the anecdotal observations of many arthroplasty surgeons who have noticed a strong association between these two pathologies. When a downstream control (knee arthritis) was used to account for the metabolic influences of arthritis, the independent associations were still significantly higher between spine arthritis and hip arthritis. While this study cannot show cause and effect, these results lend credence to earlier authors who have suggested that coexisting hip and spine arthritis

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**Fig. 5**. Scatter bubble plot showing the correlation between spine and hip arthritis.
may be largely mediated by sagittal balance across the lumbar spine, sacrum, pelvis, and hip joints. Further biomechanical investigation regarding the exact relationship between the hip and spine, especially their interactions through the pelvis in the sagittal plane, and a more thorough appreciation for the etiology of hip-squint syndrome, is warranted to assist in the appropriate management of the challenging population of patients with coexisting hip and back pain. Going forward, future research should focus on the clinical outcomes of these patients and strategies for best optimizing component sizing and orientation during total hip arthroplasty [37].

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Disclosure of interest

The authors declare that they have no competing interest.

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