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ORIGINAL PAPER

Influence of weather variables on pain severity in end-stage osteoarthritis

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Abstract
Purpose Patients often attribute increasing pain in an arthritic joint to changing weather patterns. Studies examining the impact of weather on pain severity have yielded equivocal and sometimes contradictory results. The relationship between subchondral pseudocysts and the role they play in this phenomenon has not been explored.
Methods Fifty-three patients with end-stage osteoarthritis of the hip completed daily pain severity visual analogue scale (VAS) scores over a one month period. Radiographs were reviewed to determine the presence of pseudocysts. Data pertaining to precipitation, atmospheric pressure and temperature were collected from the nearest weather station. A generalised linear mixed model was used to explore the relationship between weather variables, cysts and pain severity.
Results Pain levels increased as a function of absolute change in atmospheric pressure from one day to the next. Precipitation, temperature and the presence of subchondral pseudocysts were not shown to influence pain severity.
Conclusions This data supports the belief held by many osteoarthritic patients that changing weather patterns influence their pain severity.

Level of Evidence: 2 Prospective comparative study

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Introduction

Many patients with arthritic conditions believe that the weather influences their pain severity [1]. Previous studies investigating this proposed relationship have been inconclusive and contradictory [2, 3]. A recent study asserted that pain severity in individuals with knee osteoarthritis is modestly influenced by weather and that both a decrease in ambient temperature and an increase in barometric pressure are associated with greater pain [4]. The mechanism by which changes in weather pattern influence joint pain has not been elucidated. Subchondral osteolytic lesions or pseudocysts are commonly found in association with osteoarthritis and rheumatoid arthritis. Subchondral pseudocysts are also known as geodes. In geology, the term geode refers to a rounded pocket of gas in a mineral specimen. Some deem this description more appropriate, as there is often an absence of fluid within these lesions [5]. When examined histologically, communication between the pseudocyst and the joint space is always found [6]. As atmospheric pressure changes, so too should the pressure within these geodes. This may induce a pain response in the highly innervated subchondral bone or alternately cause a fluid shift between the joint and the communicating cyst, which may lead to impairment of lubrication. The aim of this study was thus to examine the relationship between weather variables in patients with end-stage osteoarthritis and to ascertain whether any correlation was more pronounced in those with subchondral pseudocysts compared to those without.

Methods

One hundred and ten patients with Tonnis grade 3 or 4 osteoarthritis awaiting total hip arthroplasty were assessed in this prospective study. Visual analogue pain severity scoring systems (VAS) were completed by participants, each of whom was blinded to the hypothesis of the study. Pain severity in the joint awaiting surgery was rated between 0 (no pain) and 10 (worst imaginable pain) on a daily basis over a 28-day period. Pain scores were recorded each morning prior to analgesic medication and before significant exercise. Meteorological data pertaining to barometric pressure (mmHg), precipitation (mm) and temperature (degrees Celsius) were obtained from the nearest data-collecting weather station. Additionally, the difference in temperature (DiffTemp) and the absolute difference in temperature (AbsDiffTemp) between each day and the previous day were considered. Similarly, the difference and the absolute difference in atmospheric pressure (DiffAP and AbdDiffAP) between days were examined.

Statistical analysis

A generalised linear mixed model (GLMM) was used to explore the relationship between response data and weather conditions [7]. Let y_{it} denote the pain level on day t for patient i where $t=1, \ldots, 28$. Let $\mathbf{x}_{it}$ be a column vector of explanatory variables on day t for patient i; in the context of this study $\mathbf{x}_{it}$ denotes the weather conditions on day t and/or the presence or absence of a cyst for patient i. The set of explanatory variables has an associated fixed-effect parameter vector β. Finally, let u_i denote the random effect value for patient i. This value is common to all 28 observations on patient i. It is assumed that the random effects follow a zero mean normal distribution with variance σ^2. Conditional on the random effects, a GLMM resembles a GLM, i.e. for $J=11$ possible (ordered) pain levels

$$\log\left[\frac{P(Y_{it}\le j|u_i)}{P(Y_{it}>j|u_i)}\right]=\alpha_j+x_{it}^{'}\beta+u_i \qquad (1)$$

for $j=1, \ldots$ J-1. Equation 1 models the log odds of having pain less than level j compared with pain greater than level j, conditional on the value of the random effect, as a linear function of the explanatory variables (i.e. weather conditions and/or cyst presence). Conditional on the random effects, the model treats all observations as independent, both within and between patients. This model is known as a cumulative logit model with random intercept t [8].

Interest focuses on estimating the parameters β and σ^2; the β parameter values provide insight on the influence of the explanatory variables on log odds of pain levels, whereas the σ^2 value gives an indication of the level of correlation between observations within each patient. For example, a β parameter value that is not significantly different from zero suggests that the associated explanatory variable has no influence on pain levels. A large value of the variance σ^2 of the random effects indicates that patient responses are positively correlated, i.e. pain scores of individual patients are typically at the same level across the observation period.

A wide range of models of the form of (1) are possible given the range of weather conditions recorded and the interest in the presence of cysts on pain levels. Initially, models involving only one of the explanatory variables were fitted to the observed data, then models involving several explanatory variables were fitted and finally models involving several weather conditions and interaction terms were examined. Optimal models were selected using the well-established model selection criterion, Akaike Information Criterion (AIC) [9]. This criterion rewards model fit but penalises lack of parsimony.

Results

Fifty-three patients completed the study questionnaires. Of these, 27 exhibited radiographic evidence of subchondral pseudocysts. The mean precipitation level was 3.6 mm (0–16.7 mm). The mean barometric pressure was 1114 mmHg (992-1,032 mmHg). The maximum and minimum temperatures recorded were 13.3 and -1° Celsius respectively. The top five models according to the AIC criterion are listed in Table 1 below. Lower values of the AIC indicate preferable models.

From Table 1, it is clear that atmospheric pressure appears to be an influential variable given its prevalence in the optimal models. According to the AIC, the optimal model (A) only involves a single explanatory variable – the absolute difference in atmospheric pressure between day t and day $t-1$. Table 2 provides details of parameter estimates obtained in model A and their associated standard errors (SE).

Table 1 The optimal five models fitted according to the Akaike Information Criterion (AIC) criterion

Model	Linear component $(a_{\mathrm{j}}+\mathbf{x}_{it}^{'}\beta+u_i)$	AIC
A	$\alpha_j+\beta_1$ *AbsDiffAp+u_i	4,285.9
B	$\alpha_j+\beta_1$*AbsDiffAp+β_2 *Cyst+β_3 *AbsDiffAP*Cyst+u_i	4,288.8
C	$\alpha_j+\beta_1$*DiffAp+u_i	4,290.2
D	$\alpha_j+\beta_1$*Rain+u_i	4,292.3
E	$\alpha_j+\beta_1$*Cyst+u_i	4,293.7

Table 2 Parameter estimates and standard errors (SE) in the optimal model A

Parameter	Estimate	Standard error	*P* value
β_1	−0.024	0.008	0.005
σ^2	4.373	0.474	<0.0001

Estimates in Table 2 show evidence of the effect of the absolute difference in atmospheric pressure on pain levels in that the associated parameter ($\beta_1 = -0.024$) is significantly different from zero. Essentially, the odds of having a higher than lower pain level increase by 1.02 [=exp(0.024)] with every 1-U change in the absolute difference in atmospheric pressure. In other words, fluctuating atmospheric pressure alters pain levels experienced by osteoarthritic patients. The large σ^2(= 4.373) value in model A also indicates that there is high correlation among pain-level scores within each patient. This suggests that patients' pain levels did not fluctuate wildly through the 11-point scale but tended to remain around the same level throughout the observation period. An initial interest of the study was in pain levels of patients with cysts relative to those without. Whereas models B and E from the list of optimal models in Table 1 include the explanatory variable cyst, neither were selected as the optimal model and, as indicated in Tables 3 and 4, estimated parameter values were not significantly different from zero. Thus, the presence of cysts does not appear to influence their pain levels.

Discussion

A recent systematic review of the relationship between joint pain and weather found no consensus on the issue [10]. Our study of patients with end-stage hip osteoarthritis suggests a relationship between fluctuating atmospheric pressure and increasing pain severity. This is consistent with the findings of Wilder, who demonstrated a significant relationship between pain severity and days of rising barometric pressure in women with hand osteoarthritis [11]. McAlindon studied 200 patients with knee osteoarthritis and found that changes in barometric pressure and ambient temperature influenced pain [4]. In an early work, Hollander and Yeostros using a controlled climate chamber claimed that arthritic pain worsened within a few hours of the onset of a combined rise in humidity and fall of barometric pressure. However, his work involved only a few patients over a short observation period [12].

Table 3 Parameter estimates and standard errors in model B

Parameter	Estimate	Standard error	*P* value
β_1	-0.028	0.0114	0.020
β_2	-1.168	1.209	0.339
β_3	0.007	0.016	0.669
σ^2	4.341	0.470	<0.0001

Table 4 Parameter estimates and standard errors in model E

Parameter	Estimate	Standard error	*P* value
β_1	-1.119	1.201	0.356
σ^2	4.325	0.469	<0.0001

Severe deterioration in weather is associated with marked fluctuations in atmospheric pressure. Although patients are not aware of the pressure differential, they will associate their increasing pain with any precipitation that may take place in association with this weather front, and hence believe they can predict changes in weather patterns. The underlying mechanism as to why changes in atmospheric pressure affect pain severity is not well understood. One of the aims of this study was to examine the role that subchondral pseudocysts may play in this phenomenon. The pathological description of a cyst implies a synovial lining; however, this is not true of these cavitary defects [13]. Two theories have been proposed for their development in osteoarthritis. The synovial fluid intrusion theory proposes that high intra-articular pressure leads to extrusion of synovial fluid through articular defects into the subchondral bone with secondary resorption of bony trabeculae [14]. The bony contusion theory proposes that cystic lesions are foci of bone necrosis caused by violent impact of opposing surfaces of the joint, which had been denuded of healthy cartilage [15]. Human studies have shown that an increase in intra-articular pressure is directly transmitted to the adjacent pseudocyst, confirming hydrostatic continuity with the joint space. In addition, persistent elevation of pseudocyst pressures is seen postexercise, which may be related to blocking of the channel between geode and joint space by a plug of geodal contents [5].

The hypothesis that fluctuations in atmospheric pressure leads to synovial fluid being forced into the richly innervated subchondral bone and also decreasing joint lubrication is not supported by the findings of our study. Our failure to display a difference between patients with and without radiographic evidence of cysts may relate to limitations of the imaging modality. Further studies using magnetic resonance imaging (MRI) or pathological examination of specimens are needed to confirm or refute this theory. Another theory proposes that hip joint stability is contributed to by atmospheric pressure. Cadaveric studies carried out by Wingstrand showed that atmospheric pressure was primarily responsible for stabilising the hip joint within the normal range of rotation around the axis of the femoral neck. The hip-joint capsule did not contribute to stability except in the positions of extreme rotation around this axis. In addition to this, he showed that following the elimination of the effect of atmospheric pressure (via capsulotomy), the hip joint could be subluxed 8 mm without any significant traction force until the joint capsule tightened and resisted further distraction. In the presence of significant pathology. there may be an effusion. This will counteract the stabilising effect of atmospheric pressure by replacing the volume of the femur in the acetabulum. This will result in microinstability and unfavourable loading [16]. Alternately, the effect of atmospheric pressure on pain may be related to pressure-induced changes in cytokine pathways. Hydrostatic pressure applied to chondrocytes in culture induces high expression levels of interleukin (IL)6 and tumour necrosis factor (TNF)-alpha, with changes in cell morphology [17]. This modification in cytokine pathways may explain alterations in pain perception.

It is possible that psychological mechanisms triggered by observable weather conditions may affect a patient's perceived pain. There was, however, no relationship displayed between these observable weather variables, such as precipitation and temperature, and pain severity. In contrast, the nonobservable atmospheric pressure variability displayed an association with pain severity, thus implicating a physiological process as opposed to a psychological mechanism. Whereas the physiological process remains unclear, the relationship between weather and pain severity appears real for those suffering from osteoarthritis. A better understanding could help alleviate pain flareups pain through manipulation of the microclimate.

Conflict of interest The authors declare that they have no conflict of interest.

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