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Increased Occupational Hip Joint Stress Predicts Earlier Hip Arthroplasty

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Abstract

Background: Higher non-occupational contact stress in the hip joint has been implicated in idiopathic osteoarthritis development. The aim of our study was to explore, whether additional increase in contact hip stress during lifting of heavy objects might contribute to earlier hip arthroplasty.

Methods: Fifty female subjects with suitable standard pelvic radiographs made years prior to surgery were carefully selected from a list of consecutive recipients of hip endoprosthesis due to idiopathic osteoarthritis. Mass of the lifted loads (Mload) and body weight were obtained through an interview for each subject. Maximum loads lifted more than 5 times a day, more than 3 times a week and for more than 10 years were recorded. Peak contact hip stress in the one-legged stance (pmax) was calculated for sixty-five hips from body weight and parameters of the pelvic-hip contours with the HIPSTRESS method. Regression analysis was used to correlate non-occupational (pmax) and occupational (Mload) load on the hip joint with age at hip arthroplasty. In addition, a univariate model with natural logarithm of occupational contact hip stress (pocc), acting as an independent variable, was constructed.

Results: An increase in pmax by 1.00 MPa (non-occupational load) was associated with hip arthroplasty 7.3 years earlier (R2=0.137; P-value<0.001) and an increase in Mload by 10 kg (occupational load) with 1.3 years earlier hip arthroplasty (R2=0.107; P-value=0.014). A bivariate regression analysis incorporating pmax as well as Mload was also performed (adjusted R2=0.214, P-value< 0.001).With the univariate model, addressing pocc, we were able to explain 22.8 % of variability in age at hip arthroplasty (adjusted R2=0.228, P-value<0.001).

Conclusions: In our study, work-related lifting of heavy objects with increase in occupational contact hip stress has been associated with earlier hip arthroplasty.

Keywords: Occupational lifting; Contact stress; Hip Arthroplasty; Hipstress

Introduction

Traditionally, research of idiopathic osteoarthritis of the hip has been the domain of occupational epidemiologists, who were trying to identify professions at risk [1,2]. Case-control studies and population surveys have been performed in order to identify common exposure patterns that might lead to cartilage degeneration. As work-related body posture and strenuous activities have been proposed as having a possible causative role [3], up to 40 % of idiopathic hip osteoarthritis was suggested to be related to physically demanding tasks [4].

Prolonged and frequent lifting of significant loads has been most consistently [5], but in no way universally, implicated in hip osteoarthritis development. A systematic review of appropriate studies has revealed moderate to strong evidence for a positive relationship between heavy-lifting and hip osteoarthritis, when loads heavier than 10 kilograms were lifted for at least 10 years [6]. The relationship seemed to be less pronounced in women, presumably due to less exposure to frequent lifting as part of their daily professional and domestic work requirements [7,8].

Attention of many scientists has shifted away from environmental influences, toward intrinsic structural properties of the hip joint. Molecular-based research of joint cartilage turnover has given us insight into the age-related senescence of chondrocyte function [9], which was suggested to be accelerated by focal contact joint stress gradients [10]. Increased non-occupational as well as frequent occupational mechanical loading within the hip joint could therefore both lead to early chondrocyte dysfunction, faster osteoarthritis onset and sooner hip arthroplasty.

A biomechanical model, called HIPSTRESS, has been developed for calculating peak contact hip stress in the one-legged stance from pelvic radiographs [11]. Similar stresses compared to those obtained by experimental studies constitute a sort of consensual validity for the HIPSTRESS method, even though no reciprocal validation was ever performed [12]. As one-legged stance is the most strenuous phase of the most common activity in everyday life – walking, peak contact hip stress obtained in this way can be used to explain maximal non-occupational loading. By using the three-dimensional model it has been suggested that elevated contact hip stress might be responsible for increased incidence of osteoarthritis in females [13]; higher hip stresses were observed in hips with subsequent earlier hip arthroplasty compared to the contralateral hips in the same subjects [14]. In addition, higher non-occupational peak contact hip stress has been associated with younger age at hip arthroplasty, with both increased body weight and unfavorable biomechanical constitution of the pelvis contributing [15].

The model has been used in analyzing various hip disorders with

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high prevalence of secondary osteoarthritis. Higher mean cumulative and higher mean peak contact hip stresses were found in dysplastic compared to healthy hips [16]. As the operative procedures aimed at delaying the onset of osteoarthritis in developmental dysplasia were found to act through decreasing peak contact hip stress [17], it has been suggested that elevated contact stress might be implicated in osteoarthritis development. Similarly, decreased weight-bearing surface in avascular necrosis and consequently enlarged hip stress were indicated to be responsible for early progression of the degenerative process [18]. While the importance of shear stress in slipping of capital femoral epiphysis has been well documented [19], no evidence of contact stress role in degeneration of the cartilage has been provided.

Mathematically determined peak contact hip stress in the one-legged stance presumably reflects the most common basic mechanical load on the hip joint cartilage in a persons' lifetime. In contrast, heavy lifting is a highly strenuous occupational activity that exerts an additional burden on hip joint surface, but only for a limited amount of time. Since the relationship between prolonged and frequent lifting and the development of osteoarthritis has been well described in males, and because of higher prevalence of idiopathic disease in women [20], only female patients were considered for evaluation in our study.

The objective of our study is to further explore the role of occupational as well as non-occupational loading on progression of hip osteoarthritis in females. We pursued the idea by determining whether earlier hip arthroplasty might be related to occupational and/or non-occupational increase in contact hip stress. The question was addressed by studying their individual and synergistic effect.

Materials and Methods

Study sample

Subjects were recruited from a population of 431 female patients with consequently performed hip arthroplasties for osteoarthritis at the Department of Orthopedic Surgery in a two year period. Pelvic radiographs that were taken years before the operation for various reasons, including minor hip or back pain, were searched for in the central archives. Only complete anterior-posterior radiographs with both hips and pelvis clearly visible and with spherical femoral heads were considered appropriate for HIPSTRESS method implementation. Exclusion criteria for participation in the study consisted of secondary causes of hip osteoarthritis (rheumatoid or psoriatic arthritis, avascular necrosis, slipped capital femoral epiphysis, dysplasia of the hip, lower extremity fracture), inadequate radiological criteria (minimum joint space width less than 3 mm, center-edge angle less than 20°C, large osteophytes or acetabular protrusion) and subject-specific factors (unavailability, unreliability, failure to provide consent, over 10 % fluctuation in body weight over adulthood, a job with no load-lifting requirements). Maximum loads lifted at work more than 5 times a day, more than 3 times a week and for more than 10 years were recorded. No minimum weight of the lifted objects was set for inclusion in the study.

Most constant lifelong body mass and mass of the lifted loads (Mload) were assessed by a single health care professional in a telephone interview for fifty selected individuals. Corresponding weight measurements were addressed as BW (body weight) and LW (load weight). Thirty-five of the selected subjects had unilateral and 15 had bilateral arthroplasty. Our sample therefore consisted of 65 operated hips. Average age at the time of surgery was 67.6 years (standard deviation 8.4 years). Radiographs were taken on average at 62.5 years of age (standard deviation 8.5 years).

Peak contact hip stress (pmax) was evaluated from selected standard standing pelvic radiographs with the HIPSTRESS method. It is based on a three-dimensional biomechanical model of the resultant hip force in the one-legged stance [21] and a three dimensional mathematical model of the contact hip stress distribution [11]. The model requires as the input data BW and geometrical parameters of the pelvis and proximal femora. The pelvic height (H), the pelvic width laterally from the center of the articular sphere (C), the interhip distance (l) and the coordinates of the insertion of the gluteal muscles on the greater trochanter (x, z) in its respect to the centre of the articular sphere were measured from the pelvic contours and used to calculate the resultant hip force (Figure 1). Accounting for the 10 % magnification of the radiographs, the corrected values of all the parameters, except for the scale-independent centre-edge angle, were used. The equations for the equilibrium of forces and torques were solved to yield the magnitude of the resultant hip force (R) and its inclination with respect to the vertical axis (ϑR). These parameters were used together with the centre-edge angle (ϑCE) and the radius of the femoral head (r) to calculate the peak contact hip stress in the one-legged stance (pmax), which was considered non-occupational load on the hip joint. Its value normalized to the body weight (pmax/BW) was regarded as a biomechanical determinant of the geometrical constitution of the hip. All data was measured by one of the authors, acknowledging that the model has previously shown good repeatability when adjusted for pelvic/femoral inclination with intra-class correlation coefficient for pmax/BW being 0.94 [22].

Contact hip stress at the time of load lifting was estimated as additional stress on the hip joint exerted by enlarged weight (LW in addition to BW) times normalized peak contact hip stress (pmax/BW). It was referred to as occupational contact hip stress (pocc).

Data analysis and statistical methods

In the beginning, univariate and multivariate regression analysis

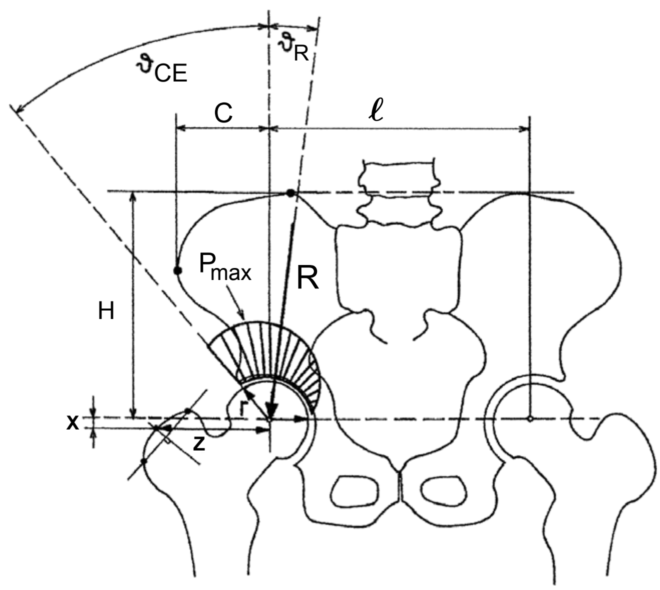

Figure 1: Radiological landmarks of the pelvis and the hips needed for determination of peak contact hip stress with HIPSTRESS method (l – the interhip distance, C – pelvic width laterally from the center of the articular sphere, H – pelvic height, r – radius of the femoral head, x, z – vertical and horizontal coordinates of the insertion of the effective muscle on the greater trochanter with respect to the center of the articular sphere, R – magnitude of the resultant hip force, ϑR – inclination of the resultant hip force with respect to the vertical axis, ϑCE – center-edge angle, pmax – peak contact hip stress).

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were performed using the SPSS 12.0 statistical package to correlate age at hip arthroplasty with peak contact hip stress (pmax) and mass of the lifted loads (Mload), with the first presenting non-occupational and the later occupational load on the hip joint. Both independent variables followed a normal distribution pattern. Statistical significance was determined at P<0.05 level.

Furthermore, an attempt has been made to create an explanatory model for younger age at hip arthroplasty, including both non-occupational (intrinsic pelvic geometry as well as BW) and occupational loads. A univariate model, using natural logarithm of occupational contact hip stress (pocc) as an independent variable and age at hip arthroplasty as a dependent variable was constructed. Statistical significance of the model was determined at P<0.001 level.

Results

Characteristics of subjects' exposure to body mass and mass of the lifted loads, as well as characteristics of hips' exposure to contact hip stress are presented in Table 1. Mean contact hip stress normalized to the body weight (pmax/Wb) equalled 2.45 kPa/N (std. dev.=0.52 kPa/N).

The relationship between peak contact hip stress in the one-legged stance (pmax) and mass of the lifted loads (Mload), and age at hip arthroplasty is presented in Table 2. An increase in pmax by 1.00 MPa was associated with hip arthroplasty 7.3 years earlier (R2=0.137; P-value=0.001). Similarly, lifting 10 kg heavier loads was related to 1.3 years sooner total hip arthroplasty (R2=0.107; P-value=0.014). A bivariate regression analysis model incorporating both non-occupational (pmax) as well as occupational loading on the hip joint (Mload) was constructed in order to try to explain variability of age at hip arthroplasty (adjusted R2=0.214, P-value<0.001).

By using natural logarithm of occupational contact hip stress (pocc) as an independent variable, we were able to explain 22.8 % of variability in age at hip arthroplasty with the constructed univariate model (adjusted R2=0.228, P-value<0.001). The relationship is depicted in Figure 2.

Discussion

Our study has shown that increased mass of the lifted loads might be associated with earlier hip arthroplasty. Such occupational increase in contact hip stress, when combined with non-occupational loading, was able to explain almost one quarter of variability in age at hip arthroplasty.

Biomechanical analysis of work-related activities has shown that individuals performing those activities, where highest compression is exerted on hip joint cartilage surface, are more prone to develop hip osteoarthritis [23]. As our results imply, periodical lifting of heavy objects could cause additional elevations of hip joint contact stress with presumptive faster degeneration of the hyaline cartilage. Although the relationship might be far from linear, it seems heavier loads could be associated with faster osteoarthritis development.

Variable (units)	No.	Minimum	Maximum	Mean	Std. Dev.
Body mass (kg)	50	50	100	70.6	9.5
M_{load} (kg)	50	2	60	19.7	15.4
p_{max} (MPa)	65	0.93	2.99	1.67	0.41
p_{occ} (MPa)	65	1.32	3.71	2.18	0.56

Table 1: Exposure of the study population to habitual (body mass, pmax – peak contact hip stress at one-legged stance) as well as occupational loads on the hip joint (Mload – mass of the lifted loads, pocc - occupational contact hip stress during heavy lifting).

	Univariate analysis		*Multivariate analysis*†††	
Independent variable	Regression coefficient (95% CI)	*P*-value	Regression coefficient (95% CI)	*P*-value
p_{max} (MPa)	–7.2*(–11.4, –3.1)	**0.001†**	–7.3*(–11.3, –3.3)	**0.001**
M_{load} (kg)	–0.13** (–0.24, –0.02)	**0.025††**	–0.13** (–0.24, –0.03)	**0.014**

Table 2: The relationship between a parameter of non-occupational (pmax – peak contact hip stress at one-legged stance) and occupational mechanical loading within the hip joint (Mload – mass of the lifted loads) and age at hip arthroplasty. The bold values signify that the findings were statistically significant.
*Change in years at hip arthroplasty per 1 MPa increase in pmax.
**Change in years at hip arthroplasty per 1 kg increase in Mload.
† Univariate model for pmax with adjusted R2 = 0.137.
†† Univariate model for Mload with adjusted R2 = 0.107.
†††Bivariate model summary: R2 = 0.239, adjusted R2 = 0.214, P-value < 0.001.

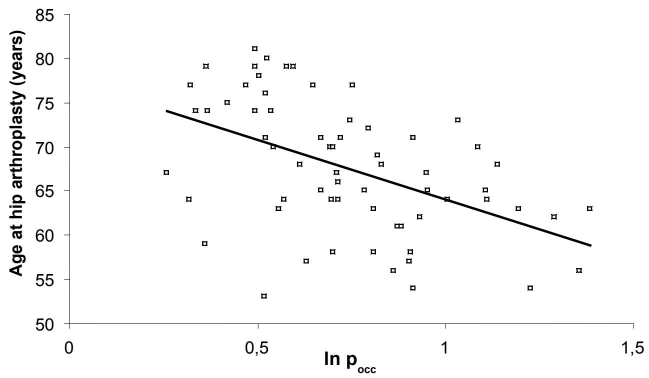

Figure 2: The relationship between age at hip arthroplasty and natural logarithm of occupational contact hip stress (pocc); the trend-line of the corresponding correlation is depicted (adjusted R2=0.228, P<0.001).

Non-occupational loading of the hip joint by unfavorable biomechanical constitution of the pelvis and by increase in body weight have been previously associated with idiopathic hip osteoarthritis. A 4.5 kg increase in BW was suggested to result in 1 year earlier hip arthroplasty. Furthermore, an increase in pmax/BW, which is individually-based biomechanical determinant of the geometrical constitution of the hip, by 0.263 kPa/N has been shown to be associated with 1 year earlier hip arthroplasty. The bivariate regression model, which was hence constructed, was found to explain 14.0% of variability in age at hip arthroplasty [15]. By including occupational loads we were able to upgrade the model and explain 22.8% of variability in age at hip arthroplasty. Although one would wish the model be even better, this would be hard to achieve. More independent variables and a much larger sample size would have to be considered. If such a model with 100% explanation of variability could be possible somewhere in the future, the term "idiopathic" might ideally become obsolete.

As the relationship between two time-related variables is not unidirectional, the duration of lifting heavy objects with regard to age at hip arthroplasty was not analyzed, which poses a limitation of our study. Since lifting heavy objects for more than 10 years was related to the development of hip osteoarthritis in previous studies [6], using mass of the loads lifted above that cut-off point was only reasonable. Self-assessment of load mass has been associated with good relative estimates and slight underestimation of its absolute values [24]. Such subjectivity bias might have been over-passed by decades-long measurements, which unfortunately few employers keep records of. Even though methodologically limited, self-assessment of lifted loads remains a valuable tool in retrospective research of occupational disorders [25].

The biomechanical model used has its shortcomings as well. It does not take into account the size of the fovea, the decrease of the joint contact surface during walking or the deformation qualities of the articular cartilage [11]. These might explain higher absolute values of peak contact hip stress obtained by discrete element analysis modeling [26] and by in vivo measurements with an experimentally implanted partial hip endoprosthesis [27]. However, even if the absolute values of peak contact hip stress presented in our paper would be corrected by adjusting the biomechanical model, no change in correlation with age at hip arthroplasty would be expected.

Our limited sample is nevertheless considered population-based. However, strict radiographic criteria might have biased the sample towards inclusion of subjects with fewer radiographic but more clinical signs of hip osteoarthritis. Since age at hip arthoplasty is not a validated surrogate for age at hip osteoarthritis onset and no consensus exists on objective criteria for timing of hip arthroplasty among orthopedic surgeons [28], speculating on the influence of the radiographic/clinical signs on timing of the operation would be far-fetched. As social and economic factors also have to be considered when making the decision whether to operate or not, some of the unaccounted variability in age at hip arthroplasty could be attributed to them.

Since the relationship between hip osteoarthritis and heavy lifting has first been established in male workers and the evidence lagged in females, physically less demanding jobs with smaller exposure contrasts and failure to address home-related lifting activities were believed to be responsible for the difference [5-8]. An alternative explanation might come from a population based study, which has shown a stronger association between occupational lifting and hip pain in women than in men [29]. Later studies have nevertheless shown no gender discrimination when influence of occupational lifting on hip osteoarthritis was in question [30]. By selecting only female subjects with frequent and prolonged lifting of loads during work we tried to overcome the mentioned drawbacks.

In conclusion, increased occupational loading of the hip joint, in addition to non-occupational loads, might be associated with earlier hip arthroplasty through an increase in contact hip stress. Our results support the idea that increment of contact hip stress in the workplace could be related to idiopathic hip osteoarthritis development and should therefore be ergonomically addressed.

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