CHECKing activity limitations in persons with early osteoarthritis of the knee or hip

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PART III

RANGE OF MOTION OF THE HIP AND KNEE


9

Chapter 9

Determinants of range of joint motion in patients with early symptomatic osteoarthritis of the hip and/or knee: an exploratory study in the CHECK cohort

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Abstract

Objective. Reduced range of motion (ROM) is supposed to be a characteristic feature of osteoarthritis (OA). Because little is known about determinants of ROM, the objective of the present study was to explore the association between demographic, articular, and clinical factors and ROM in patients with early symptomatic knee and/or hip OA.

Design. Baseline data of 598 participants of the Cohort Hip and Cohort Knee (CHECK) study were used in this cross-sectional study.

Methods. Separate analyses were performed for participants with knee and participants with hip symptoms. Active knee flexion, and hip internal rotation, external rotation, flexion, adduction and abduction were assessed using a goniometer. Participants underwent a standardized physical and radiographic examination, and completed a questionnaire. Exploratory regression analyses were performed to explore the association between ROM and demographic (i.e. age, gender, body-mass index [BMI]), articular (i.e. osteophytosis, joint space narrowing [JSN]), and clinical (i.e. pain, stiffness) factors.

Results. In patients with early symptomatic knee OA, osteophytosis, bony enlargement, crepitus, pain and higher BMI were associated with lower knee flexion. JSN was associated with lower ROM in all planes of motion. In addition, osteophytosis, flattening of the femoral head, femoral buttressing, pain, morning stiffness, male gender and higher BMI were found to be associated with lower hip ROM in two planes of motion.

Conclusion. Features of articular degeneration are associated with lower knee ROM and lower hip ROM in patients with early OA. Pain, stiffness, higher BMI and male gender are associated with lower ROM as well.

Introduction

Reduced range of motion (ROM) of the joint is supposed to be a characteristic feature of osteoarthritis (OA).[1] Reduced knee movement is part of two of the 10 European League Against Rheumatism (EULAR) recommendations for the diagnosis of knee OA.[2] The American College of Rheumatology (ACR) considered ROM as a clinical criterion for the classification of hip OA, resulting in the inclusion of reduced hip internal rotation ($< 15°$) and reduced hip flexion ($\leq 115°$) in the ACR classification tree for hip OA.[3] Furthermore, ROM measurements are often used to quantify limitations at the start of treatment, and as an outcome measure to evaluate the effectiveness of interventions.[4] Finally, there is increasing evidence that reduced ROM contributes to the development of activity limitations in knee and hip OA patients.[5-7] Because reduced ROM is a classification criterion to separate OA from other diseases associated with joint symptoms,[3] it is important to examine which factors are of influence on ROM. This is especially important in the early phase in which symptoms commence and the disease is diagnosed.

The cause of reduced ROM is not well understood. Several demographic factors, articular factors (radiographic features), and clinical factors (clinical signs and symptoms) have been associated with reduced ROM. With regard to demographic factors James and Parker[8] reported that knee and hip ROM declined consistently as age increased, with men having smaller ROM than women in a population of elderly people. Escalante et al.[9] found that lower hip flexion was significantly correlated with female gender and higher body-mass index (BMI) in community-dwelling elderly.

Although reduced ROM is a characteristic feature of OA, studies on the association between articular factors and ROM are scarce. To our knowledge two studies focused on this association in knee OA patients. Ersoz and Ergun[10] found significant negative correlations between knee ROM and the Kellgren and Lawrence radiographic scores[11] of knee joint compartments in 20 patients. Ozdemir et al.[12] found significant correlations between knee flexion and the size and location of osteophytes, and between knee flexion and joint space narrowing (JSN) in the lateral tibiofemoral (TF) compartment. In addition, only two studies examined the association between ROM and articular factors in hip OA patients. Birrell et al.[13] reported an association between reduced ROM and radiographic OA in 195 new presenters with hip pain. Bierma-Zeinstra et al.[14] found associations between decreased hip external rotation, internal rotation and adduction and JSN.

With regard to clinical factors, Escalante et al.[9] reported a negative association between knee pain and the knee flexion range in community-dwelling elderly. Bennett et al.[15] found that pain reduction led to increases in knee ROM in 141 OA patients referred for total knee arthroplasty.

Thus, demographic, articular, and clinical factors seem to be of influence on reduced ROM. However, the number of studies is limited and there is almost no information on the relative importance of these factors when compared to each other.

Therefore, the aim of the present study was to explore a broad range of possible determinants of ROM in patients with early symptomatic knee and/or hip OA. Exploratory regression analyses were used to investigate the associations between knee and hip ROM, and demographic factors (age, gender, BMI), articular factors (radiographic features) and clinical factors (e.g. warmth, pain, stiffness).

Methods

Study design and population

Data for the present cross-sectional study were obtained from the Cohort Hip & Cohort Knee (CHECK) study.[16] CHECK is a prospective cohort study of 1,002 individuals with early symptomatic OA of the knee or hip. On entry, all participants had pain or stiffness of the knee or hip, and were aged 45-65 years. They had not yet consulted their physician for these symptoms, or the first consultation was within six months before entry. Participants with any other pathological condition that could explain the existing symptoms were excluded (other rheumatic diseases, previous hip or knee joint replacement, congenital dysplasia, osteochondritis dissecans, intra-articular fractures, septic arthritis, Perthes' disease, ligament or meniscus damage, Plica syndrome, Bakers cyst, tendinitis quadriceps, adductor tendinitis, iliopectineal bursitis, trochanteric bursitis, radicular syndrome, ischemic bone necrosis, generalized pain syndromes, joint symptoms caused by malignant tumours, and cancer other than skin carcinoma during the past 5 years). Additional exclusion criteria were: comorbidity that did not allow physical evaluation and/or follow-up of at least 10 years, malignancy in the last 5 years, and inability to understand the Dutch language.

The CHECK cohort was formed from October 2002 till September 2005. At baseline, the majority of this cohort (83%) reported knee symptoms,[16] of whom 76% fulfilled the clinical ACR criteria for the classification of knee OA.[17] Hip symptoms were reported by 59% of the cohort,[16] of whom 24% fulfilled the clinical ACR criteria for the classification of hip OA.[3] Two-year follow-up data show an increase in these percentages, as well as an increase in radiological signs (manuscript in preparation). Therefore the CHECK cohort can be considered as an "early symptomatic OA cohort".

Nationwide, 10 general and academic hospitals in the Netherlands are participating, located in urbanized and semi-urbanized regions. General practitioners (GP) in the surroundings of the participating centres were invited to refer eligible persons. All patients that visited the GP on their own initiative, potentially fulfilling the inclusion criteria, were referred to one of the 10 participating centres. In addition, participants were recruited through advertisements and articles in local newspapers and on the Dutch Arthritis Association website. The physicians in the participating centres checked whether referred patients as well as patients from their outpatient clinics fulfilled the inclusion criteria.

In 5 of the 10 participating hospitals (Utrecht, Amsterdam, Nijmegen, Rotterdam & Maastricht) the ROM of knee flexion and ROMs of internal and external rotation, flexion and adduction and abduction of the hip were assessed by protocol. Data for the present study were obtained from the 598 participants assessed in these 5 CHECK-centres at baseline. Two strata were defined: a knee stratum, consisting of 497 participants with knee symptoms, and a hip stratum, consisting of 344 participants with hip symptoms. Patients with both knee and hip symptoms were included in both strata. The study was approved by the medical ethics committees of all participating centres, and all participants gave their written informed consent before entering the study.

Outcome variables

Assisted active ROM was measured bilaterally for the knee and hip, using a goniometer. Participants had to carry out the motion by themselves, using muscle strength to increase the angle, but did not have to use their muscle strength to keep their limb in position. The examiner provided support against the pull of gravity, but no support for the completion of the joint action. Measurements were taken according to Norkin and White.[18] The following joint actions were measured: knee flexion, hip internal and external rotation, hip flexion, and hip adduction and abduction. For each action, the protocol provided starting positions for both participant and examiner, and reference points for the pivot and distal points of the goniometer. For participants who were unable to adopt a prescribed starting position, the protocol provided an alternative starting position. Supplying a protocol for starting positions for the participant and examiner and the positioning of the goniometer increases the reliability of ROM measurements.[5] Measurements were carried out by a trained physiatrist, rheumatologist or orthopaedic surgeon, dependent on the CHECK-centre in which the participant was assessed. In the present study we used ROM of the "index knee" (most affected knee) or "index hip" (most affected hip) as the outcome measure. Most participants identified their affected knee and/or hip in a clinical interview. For participants with bilateral symptoms we defined an index knee or index hip based on the following decision tree: (1) highest Kellgren and Lawrence score, (2) lowest degree of active knee flexion (index knee) or degree of active hip internal rotation (index hip), (3) highest pain during active knee flexion (index knee) or highest pain during active hip internal rotation (index hip), and (4) crepitus during knee flexion (index knee) or highest pain during active hip flexion (index hip). In participants for whom we could not define an index knee or hip based on these signs, we randomly assigned an index joint.

Independent variables

Demographic variables, articular factors, and clinical factors were assessed during baseline measurements of the CHECK cohort.

Articular factors were measured using radiographs. Radiographs of tibiofemoral (TF) joints were made by a weight-bearing posterioanterior (PA) view, semi-flexed (7-10°) according to Buckland-Wright et al.[19-21] Radiographs of patellofemoral (PF) joints were made by a single standing mediolateral view in 30° flexion, and a skyline (inferior superior) view in 30° flexion.[22,23] For the hip, weight-bearing anterioposterior (AP) radiographs of the pelvis were made.[24,25] In addition, a weight-bearing single faux profile radiograph of both hips was obtained.[26]

Radiographic features were scored according to the paired reading procedure by 5 observers (four medical students and one medical doctor) independently. The knee and hip features in the anterior-posterior plane [knee: medial and lateral JSN, medial and lateral osteophytes (femoral and tibial), subchondral sclerosis, spiking of the tubercles of the intercondylar eminence of the tibial plateau; hip: superior and medial JSN, superior and inferior osteophytes (acetabular and femoral), femoral subchondral sclerosis, flattening of the femoral head, femoral buttressing (thickening of the medial femoral calcar)] were scored according to Altman and Gold.[27] The mediolateral and skyline radiographs of the knee (PF JSN, osteophytes and sclerosis) were scored according to Burnett et al.[28] On the faux profile radiographs of the hip superior JSN was scored according to Lequesne and Laredo.[26] Before scoring the features the examiners were extensively trained by an musculoskeletal radiologist and an experienced reader in four separate sessions with training radiographs. At the end of this course the readers' performance was assessed by scoring a new set of radiographs of 12 participants with differing OA severity. The trainers confirmed that all readers had scored the trainings set adequately. For the analyses some features were combined with each other (see **Tables 1** and **2**), and all non-dichotomous features were dichotomized into normal/mild vs. moderate/severe. A feature was scored as present if at least in one radiograph a 2 or 3 (0-3 scale) or a 1 (0-1 scale) was scored.

Clinical signs were assessed during the same physical examination as the ROM measurements. The knee examination consisted of measurements of the presence of pain on knee flexion (none/slight vs. severe/extreme), bony enlargement, intra-articular fluid (positive refill-test), warmth, crepitus, pain on palpation of the joint line, and pain on patellofemoral joint compression. In the hip examination the presence of pain on the hip ROM measurements was assessed. Clinical symptoms were assessed in the clinical interview (ipsilateral knee or hip pain and morning stiffness in the knee $<$ 30 minutes[17] or hip $\leq$ 60 minutes[3]) and with a questionnaire (0-10 numeric rating scale (NRS) for pain in the knee and/or hip during the past week).

Statistical analysis

Univariable linear regression analyses were performed to establish the crude associations between the independent variables and the outcome measures (ROMs of the knee and hip). Pearson correlation coefficients were calculated to establish the correlation between the ROM scores of the different hip joint actions.

In the existing literature on ROM in knee and hip OA no justification was found for considering one determinant of ROM more important than another. Therefore, we used an automatic procedure to assess the most important determinants of ROM: independent variables individually associated with the outcome with a p-value < 0.20 were entered into a multivariable regression model (method: backward stepwise, p-removal 0.05). Standardized regression coefficients (β) were presented to show the relative importance of the independent variables when compared to each other. As measure of the substantive importance of the factors in the multivariable models, the R-squared (R^2), the proportion of the variance in range of motion accounted for by the factors in the model, was presented.[29] The assumptions of normal distribution and constant variance of residuals were assessed by visual inspection of residual plots.[29] We controlled for co linearity by examining tolerance and the variance inflation factor.[29] All analyses were performed using SPSS version 15.0.

Table 1. Baseline characteristics, and results of the univariable analyses of the association between factors and the range of knee flexion (degrees) for the knee stratum (n = 497)

Characteristic / factor	Value	B (95% CI)	β	P
Demographics				
Age (years)	55.9 ± 5.2	-0.09 (-0.26, 0.08)	-0.05	0.29
Male	107 (21.5)	2.05 (-0.10, 4.20)	0.08	0.06
BMI (kg/m²)	26.2 ± 4.1	-0.82 (-1.04, -0.61)	-0.33	<0.0001
Articular factors				
Moderate or severe JSN				
Tibiofemoral medial	41 (8.2)	-5.19 (-8.36, -2.02)	-0.15	0.001
Tibiofemoral lateral	10 (2.0)	0.67 (-5.59, 6.94)	0.01	0.83
Patellofemoral	31 (6.2)	-0.09 (-3.82, 3.65)	-0.00	0.96
Moderate or severe osteophytes				
Tibiofemoral medial	33 (6.6)	-9.11 (-12.61, -5.62)	-0.23	<0.0001
Tibiofemoral lateral	56 (11.3)	-3.69 (-6.46, -0.93)	-0.12	0.01
Patellofemoral	95 (19.1)	-4.50 (-6.73, -2.27)	-0.18	<0.0001
Subchondral sclerosis	45 (9.1)	-3.82 (-6.89, -0.76)	-0.11	0.02
Spiking of the tibial tubercles	226 (45.5)	-1.68 (-3.47, 0.11)	-0.08	0.07
Clinical factors (signs and symptoms)				
Knee pain				
Unilateral	215 (43.3)			
Bilateral	282 (56.7)			
Duration of pain (months)	18 (9-36)			
Clinical knee OA*	391 (78.7)			
Severe pain on knee flexion	41 (8.2)	-10.72(-13.79, -7.66)	-0.30	<0.0001
Bony enlargement	19 (3.8)	-9.61 (-14.12, -5.09)	-0.19	<0.0001
Positive refill-test	45 (9.1)	0.48 (-2.59, 3.54)	0.01	0.76
Palpable warmth	31 (6.2)	-4.92 (-8.53, -1.30)	-0.12	0.01
Crepitus during knee flexion	238 (47.9)	-4.61 (-6.33, -2.88)	-0.23	<0.0001
Pain on palpation of the joint line	212 (42.7)	-0.64 (-2.43, 1.16)	-0.03	0.49
Pain on patella fem. joint compression	121 (24.3)	-1.97 (-3.91, 0.03)	-0.10	0.05
Ipsilateral hip pain	191 (38.4)	0.68 (-1.14, 2.50)	0.03	0.46
NRS pain intensity (0-10)	3.7 ± 2.2	-0.72 (-1.13, -0.32)	-0.16	0.0005
Morning stiffness knee < 30 minutes†	331 (66.6)	-2.22 (-4.10, -0.35)	-0.11	0.02

Values are presented as the number (percentage), the mean ± standard deviation or the median (interquartile range). B = regression coefficient: the change in knee flexion associated with a unit change in the factor. 95% CI = 95% confidence interval of B. β = standardized regression coefficient: the number of standard deviations that the range of knee flexion will change as a result of one standard deviation change in the factor. JSN = joint space narrowing. NRS pain intensity = numeric rating scale for pain in the knee and/or hip during the past week. * Knee osteoarthritis according to the American College of Rheumatology clinical classification criteria. † Reference category = no morning stiffness at all.

Table 2. Baseline characteristics, and results of the univariable analyses of the association between factors and the ranges of hip internal and external rotation for the hip stratum (n = 344)

		Internal rotation hip (degrees)			External rotation hip (degrees)		
Characteristic / factor	**Value**	**B (95% CI)**	**β**	**p**	**B (95% CI)**	**β**	**p**
Demographics							
Age (years)	55.9 ± 5.4	-0.27 (-0.45, -0.08)	-0.15	0.01	-0.10 (-0.27, 0.07)	-0.06	0.25
Male	75 (21.8)	-6.71 (-9.07, -4.35)	-0.29	<0.0001	-0.68 (-2.91, 1.54)	-0a.03	0.55
BMI (kg/m²)	25.9 ± 3.9	-0.07 (-0.34, 0.20)	-0.03	0.62	-0.08 (-0.33, 0.16)	-0.04	0.51
Articular factors							
Moderate or severe JSN							
Superior	23 (6.7)	-12.20 (-16.00, -8.40)	-0.33	<0.0001	-5.39 (-9.00, -1.78)	-0.16	0.004
Medial	29 (8.4)	-3.47 (-7.08, 0.14)	-0.11	0.14	-3.49 (-6.60, -0.37)	-0.13	0.03
Moderate or severe osteophytes							
Superior acetabular or femoral	56 (16.3)	-6.48 (-9.13, -3.84)	-0.26	<0.0001	-1.22 (-3.67, 1.23)	-0.05	0.33
Inferior acetabular or femoral	12 (3.5)	-16.54 (-21.93, -11.15)	-0.32	<0.0001	-4.95 (-9.83, -0.07)	-0.11	0.05
Subchondral sclerosis	19 (5.5)	-6.71 (-11.04, -2.38)	-0.17	0.002	-3.36 (-7.27, 0.56)	-0.09	0.09
Flattening femoral head	48 (14.0)	-0.69 (-3.60, 2.23)	-0.03	0.64	-4.52 (-7.07, -1.96)	-0.19	0.001
Femoral buttressing	93 (27.0)	-1.46 (-3.75, 0.82)	-0.07	0.21	-4.41 (-6.44, -2.39)	-0.23	<0.0001
Clinical factors (signs and symptoms)							
Unilateral hip pain	222 (64.5)						
Bilateral hip pain	122 (35.5)						
Duration of pain (months)	18 (10-36)						
Clinical hip OA*	97 (28.2)						
Severe pain on hip internal rotation	88 (25.6)	-3.97 (-6.26, -1.67)	-0.18	0.001			
Severe pain on hip external rotation	29 (8.4)				-2.44 (-5.75, 0.86)	-0.08	0.15
Severe pain on hip flexion	58 (16.9)						
Severe pain on adduction	40 (11.6)						
Severe pain on abduction	62. (18.0)						
Ipsilateral knee pain	212 (61.6)	0.00 (-2.09, 2.09)	0.00	1.00	-0.07 (-1.96, 1.83)	-0.00	0.95
NRS pain intensity (0-10)	3.9 ± 2.2	-0.17 (-0.64, 0.29)	-0.04	0.46	-0.10 (-0.52, 0.32)	-0.03	0.63
Morning stiffness hip†	214 (62.2)	-1.88 (-3.96, 0.21)	-0.10	0.08	1.51 (-0.39, 3.40)	0.09	0.12

Values are presented as the number (percentage), the mean ± standard deviation or the median (interquartile range). B = regression coefficient: the change in the range of hip motion associated with a unit change in the factor. 95% CI = 95% confidence interval of B. β = standardized regression coefficient: the number of standard deviations that the range of hip motion will change as a result of one standard deviation change in the factor. JSN = joint space narrowing. NRS pain intensity = numeric rating scale for pain in the knee and/or hip during the past week. * Hip osteoarthritis according to the American College of Rheumatology clinical classification criteria. † Morning stiffness hip ≤ 60 minutes, reference category = no morning stiffness at all.

Results

Study population

The baseline characteristics of the knee (*n* = 497) and hip stratum (*n* = 344) are presented in **Tables 1** and **2**. The mean ROM values for the knee and hip stratum, and the correlations between the ROM of different joint actions of the hip are given in **Table 3**.

Determinants of knee flexion

Crude associations between the range of knee flexion and demographic, articular, and clinical factors are given in **Table 1.** Lower knee flexion was individually associated with higher BMI, medial TF JSN, TF and PF osteophytes, subchondral sclerosis, severe pain on knee flexion, bony enlargement, palpable warmth, crepitus during knee flexion, pain on patellofemoral joint compression, a higher score on the NRS for joint pain intensity, and morning stiffness of the knee. The results of the adjusted analysis are presented in **Table 4.** Lower knee flexion was associated with higher BMI, medial TF osteophytes, severe pain on knee flexion, bony enlargement, and crepitus during knee flexion. The R^2 of the multivariable model for knee flexion was 0.26.

Determinants of hip internal and external rotation

Lower hip internal rotation was individually associated with age, male gender, superior JSN, superior and inferior osteophytes, subchondral sclerosis, and severe pain on hip internal rotation (**Table 2**). Adjusted analysis revealed that lower hip internal rotation was associated with male gender, superior JSN, inferior osteophytes, and morning stiffness of the hip (**Table 5**).

Table 3. Mean range of motion (ROM) values of the knee and hip, and correlations between the ROM scores of the different hip joint actions

		Joint actions of the hip							
		Hip internal rotation (degrees)		Hip external rotation (degrees)		Hip flexion (degrees)		Hip adduction (degrees)	
	Value	r	p	r	p	r	p	r	p
Knee stratum (n = 497)									
Knee flexion (degrees)	132.2 ± 10.0								
Hip stratum (n = 344)									
Hip internal rotation (degrees)	28.2 ± 9.5								
Hip external rotation (degrees)	27.3 ± 8.6	0.13	0.01						
Hip flexion (degrees)	115.3 ± 12.2	0.35	<0.0001	0.10	0.06				
Hip adduction (degrees)	19.9 ± 8.3	0.19	0.001	0.39	<0.0001	0.19	0.0005		
Hip abduction (degrees)	30.9 ± 11.1	0.21	0.0001	0.57	<0.0001	0.19	0.0004	0.52	<0.0001

Values are presented as mean ± standard deviation. r = Pearson correlation coefficient (range: -1, +1): a coefficient of +1 indicates that the ROM scores of two joint actions are perfectly positively correlated (as the ROM of one joint action increases the ROM of the other joint action increases by a proportionate amount), a coefficient of -1 indicates a perfect negative relationship.

Lower hip external rotation was individually associated with superior and medial JSN, inferior osteophytes, flattening of the femoral head, and femoral buttressing (**Table 2**). Adjusted analysis revealed that lower hip external rotation was associated with medial JSN, flattening of the femoral head, and femoral buttressing (**Table 5**). The R^2 of the multivariable model for hip external rotation was 0.06.

Determinants of hip flexion

Lower hip flexion was individually associated with male gender, higher BMI, superior JSN, superior and inferior osteophytes, femoral buttressing, severe pain on hip flexion, a higher score on the NRS for joint pain intensity, and morning stiffness of the hip (**Table 6**). Adjusted analysis revealed that lower hip flexion was associated with male gender, higher BMI, superior JSN, a higher score on the NRS for joint pain intensity and morning stiffness of the hip (**Table 7**). The R^2 of the multivariable model for hip flexion was 0.26.

Determinants of hip adduction and abduction

Lower hip adduction was individually associated with superior JSN, superior osteophytes, femoral buttressing, and severe pain on hip adduction (**Table 6**). Adjusted analysis revealed that lower hip adduction was associated with superior osteophytes, femoral buttressing, severe pain on hip adduction and the absence of morning stiffness of the hip (**Table 7**). The R^2 of the multivariable model for hip adduction was 0.09.

Lower hip abduction was individually associated with superior JSN, flattening of the femoral head, femoral buttressing, severe pain on hip abduction, ipsilateral knee pain, and a higher score on the NRS for joint pain intensity (**Table 6**). Adjusted analysis revealed

Table 4. Results of the multivariable analysis of the association between factors and the range of knee flexion (degrees) for the knee stratum (n = 497)

Factor	B (95% CI)	β	P
Demographics			
BMI (kg/m²)	-0.68 (-0.89, -0.47)	-0.29	<0.0001
Articular factors			
Moderate or severe tibiofemoral medial osteophytes	-5.77 (-9.10, -2.44)	-0.16	0.001
Clinical factors (signs and symptoms)			
Severe pain on knee flexion	-5.29 (-8.47, -2.10)	-0.15	0.001
Bony enlargement	-7.36 (-12.03, -2.68)	-0.14	0.002
Crepitus during knee flexion	-3.71 (-5.38, -2.04)	-0.20	<0.0001
R^2	0.26		

B = regression coefficient: the change in knee flexion associated with a unit change in the factor if the effects of all other factors in the model are held constant. 95% CI = 95% confidence interval of B. β = standardized regression coefficient: the number of standard deviations that the range of knee flexion will change as a result of one standard deviation change in the factor if the effects of all other factors in the model are held constant. R^2 = R-squared.

that lower hip abduction was associated with higher BMI, superior JSN, flattening of the femoral head, femoral buttressing, severe pain on hip abduction and ipsilateral knee pain (**Table 7**). The R^2 of the multivariable model for hip abduction was 0.19.

Discussion

The aim of the present study was to assess the association between ROM, and demographic, articular and clinical factors in patients with early symptomatic OA of the knee and/or hip.

The study provided evidence that lower ROM in early symptomatic knee and hip OA is related to articular deformation. In the knee, moderate or severe TF medial osteophytes were associated with lower knee flexion. This finding is in accordance with results of Ersoz and Ergun.[10] Osteophytes may decrease ROM directly by causing a mechanical block.[30] However, in our study population severe osteophytes are observed in only 12.9% of participants. Moderate or severe osteophytes were more often observed TF lateral (11.3%) and PF (19.1%) than TF medial (6.6%) in the joint. In respectively 33.3% and 69.7% of participants with TF medial osteophytes also TF lateral or PF osteophytes were observed. This finding supports the idea that reduction of ROM due to incongruity of the joint surfaces occurs

Table 5. Results of the multivariable analyses of the association between factors and the ranges of hip internal and external rotation for the hip stratum (n = 344)

	Hip internal rotation (degrees)			Hip external rotation (degrees)		
Factor	**B (95% CI)**	**β**	**P**	**B (95% CI)**	**β**	**P**
Demographics						
Male	-5.26 (-7.55, -2.97)	-0.24	<0.0001			
Articular factors						
Moderate or severe superior JSN	-8.00 (-11.89, -4.11)	-0.22	<0.0001			
Moderate or severe medial JSN				-3.16 (-6.24, -0.08)	-0.12	0.05
Moderate or severe inferior acetabular or femoral osteophytes	-11.17 (-16.37, -5.96)	-0.23	<0.0001			
Flattening femoral head				-2.68 (-5.40, 0.03)	-0.12	0.05
Femoral buttressing				-2.74 (-4.82, -0.65)	-0.16	0.01
Clinical factors (signs and symptoms)						
Morning stiffness hip†	-2.34 (-4.27, -0.42)	-0.12	0.02			
R^2	0.25			0.06		

B = regression coefficient: the change in the range of hip motion associated with a unit change in the factor if the effects of all other factors in the model are held constant. 95% CI = 95% confidence interval of B. β = standardized regression coefficient: the number of standard deviations that the range of hip motion will change as a result of one standard deviation change in the factor if the effects of all other factors in the model are held constant. JSN = joint space narrowing. R^2 = R-squared. † Morning stiffness hip ≤ 60 minutes, reference category = no morning stiffness at all.

when a large part of the joint is affected.[30] There is, however, an alternative explanation for the association between osteophytosis and lower ROM. When OA progresses, the capsule will be more and more affected (thickened and rigid) which possibly lowers the ROM. Osteophytosis is a sign of disease progression. Progression of OA may cause both osteophytosis and rigidity of the capsule and thereby lower ROM.

In the hip lower ROM was associated with superior and medial JSN, inferior and superior osteophytes, flattening of the femoral head and femoral buttressing. The association between lower ROM and articular factors may be explained by the same mechanisms as in knee OA (i.e. osteophytes may lower ROM by forming a mechanical block; or disease progression may cause both osteophytosis and rigidity of the capsule and thereby lower ROM).

The correlations between the ROM scores of the different joint actions ranged from 0.10 to 0.57. Most of the correlations were small to medium.[29] This finding confirms the conclusion of Steultjens et al.[5] that joint ROM cannot be regarded as a one-dimensional

Table 6. Results of the univariable analyses of the association between factors and the ranges of hip flexion, adduction and abduction for the hip stratum (n = 344)

	Hip flexion (degrees)		
Factor	**B (95% CI)**	**β**	**P**
Demographics			
Age (years)	0.01 (-0.24, 0.25)	0.00	0.97
Male	-4.71 (-7.81, -1.60)	-0.16	0.003
BMI (kg/m²)	-1.01 (-1.34, -0.67)	-0.31	<0.0001
Articular factors			
Moderate or severe JSN			
Superior	-15.00 (-19.96, -10.05)	-0.31	<0.0001
Medial	-4.07 (-8.61, 0.48)	-0.10	0.08
Moderate or severe osteophytes			
Superior acetabular or femoral	-7.50 (-10.95, -4.06)	-0.23	<0.0001
Inferior acetabular or femoral	-10.97 (-17.95, -3.98)	-0.17	0.002
Subchondral sclerosis	-3.12 (-8.82, 2.60)	-0.06	0.28
Flattening femoral head	0.09 (-3.67, 3.86)	0.00	0.96
Femoral buttressing	-2.94 (-5.86, -0.02)	-0.11	0.05
Clinical factors (signs and symptoms)			
Severe pain on hip flexion	-7.18 (-10.54, -3.81)	-0.22	<0.0001
Severe pain on adduction			
Severe pain on abduction			
Ipsilateral knee pain	-1.19 (-3.86, 1.48)	-0.05	0.38
NRS pain intensity (0-10)	-1.31 (-1.89, -0.72)	-0.24	<0.0001
Morning stiffness hip*	-3.48 (-6.14, -0.82)	-0.14	0.01

B = regression coefficient: the change in the range of hip motion associated with a unit change in the factor. 95% CI = 95% confidence interval of B. β = standardized regression coefficient: the number of standard deviations that the range of hip motion will change as a result of one standard deviation change in the factor. JSN = joint space narrowing. NRS pain intensity = numeric rating scale for pain in the knee and/or hip during the past week. * Morning stiffness hip ≤ 60 minutes, reference category = no morning stiffness at all.

physical characteristic of OA patients. Therefore, separate analyses were performed to identify determinants of ROM for all different joint actions.

Dependent on the plane of motion ROM was found to be associated with different radiographic features. Hip internal rotation, flexion and abduction were found to be associated with superior JSN, and hip external rotation was found to be associated with medial JSN. This is a notable finding because superior and medial OA are classified as different subsets of hip OA.[31] Possibly different subsets of OA lead to reductions in ROM in different planes of motion.

Furthermore, hip internal rotation was found to be associated with inferior osteophytes, hip adduction was found to be associated with superior osteophytes and femoral buttressing, and hip external rotation and abduction were found to be associated with femoral buttressing and flattening of the femoral head. Osteophytes are formed already in early stage OA and can be seen prior to JSN.[32] Flattening of the femoral head and femoral but-

Hip adduction (degrees)			Hip abduction (degrees)		
B (95% CI)	β	P	B (95% CI)	β	P
0.02 (-0.15, 0.18)	0.01	0.86	-0.16 (-0.38, 0.06)	-0.08	0.15
-1.54 (-3.67, 0.60)	-0.08	0.16	-1.31 (-4.17, 1.55)	-0.05	0.37
-0.23 (-0.46, 0.01)	-0.10	0.06	-0.31 (-0.62, 0.01)	-0.10	0.06
-5.63 (-9.16, -2.10)	-0.17	0.002	-7.48 (-12.17, -2.80)	-0.17	0.002
0.26 (-2.70, 3.21)	0.01	0.87	-0.81 (-4.82, 3.21)	-0.02	0.69
-3.41 (-5.81, -1.01)	-0.15	0.005	-1.53 (-4.76, 1.69)	-0.05	0.35
-4.79 (-9.62, 0.05)	-0.11	0.05	-5.85 (-12.29, 0.59)	-0.10	0.08
-3.32 (-7.21, 0.57)	-0.09	0.09	-3.93 (-9.10, 1.24)	-0.08	0.14
-1.43 (-4.00, 1.14)	-0.06	0.28	-5.17 (-8.55, -1.79)	-0.16	0.003
-2.11 (-4.11, -0.11)	-0.11	0.04	-6.75 (-9.32, -4.16)	-0.27	<0.0001
-4.87 (-7.56, -2.17)	-0.19	0.0004			
			-7.14 (-10.13, -4.16)	-0.25	<0.0001
-0.92 (-2.74, 0.90)	-0.05	0.32	-3.22 (-5.63, -0.81)	-0.14	0.01
-0.38 (-0.78, 0.03)	-0.10	0.07	-0.55 (-1.10, -0.01)	-0.11	0.05
1.69 (-0.13, 3.51)	0.10	0.07	1.48 (-0.96, 3.92)	0.07	0.23

tressing are assumed to mostly occur in a later stage of OA.[30] It is notable that we observed these features in already 14% and 27% of participants of our early symptomatic OA cohort.

Of the examined clinical factors severe pain on knee flexion, bony enlargement, and crepitus were associated with lower knee flexion. Painful movement is described in one of the 10 EULAR recommendations for the diagnosis of knee OA,[2] and a relation between pain and knee flexion has been shown earlier.[9,15] Bony enlargement is caused by large osteophytes and widening of the subchondral bone leading to remodelling of the joint. It is considered to be a late stage sign of OA and was observed in only 3.8% of our participants. However, bony enlargement seems an important determinant of lower knee ROM: the mean knee ROM of participants with bony enlargements was -7.36 lower than in participants without bony enlargements if all other factors in the model were held constant. The finding that bony enlargement is related to lower knee flexion in the multivariable analysis suggests that palpable deformities of the joint add clinically important information to what is seen on radiographs. Crepitus in the knee is a sign of irregularities of opposing cartilage surfaces within the joint.[33] Therefore, these clinical findings together support the assumption that articular deformation has a great impact on knee ROM.

Table 7. Results of the multivariable analyses of the association between factors and the ranges of hip flexion, adduction and abduction for the hip stratum (n = 344)

	Hip flexion (degrees)		
Factor	**B (95% CI)**	**β**	**P**
Demographics			
Male	-3.54 (-6.56, -0.52)	-0.13	0.02
BMI (kg/m²)	-0.99 (-1.31, -0.67)	-0.31	<0.0001
Articular factors			
Moderate or severe superior JSN	-11.29 (-16.35, -6.23)	-0.24	<0.0001
Moderate or severe superior osteophytes acetabular or femoral			
Flattening femoral head			
Femoral buttressing			
Clinical factors (signs and symptoms)			
Severe pain on adduction			
Severe pain on abduction			
Ipsilateral knee pain			
NRS pain intensity (0-10)	-1.06 (-1.63, -0.48)	-0.19	0.0004
Morning stiffness hip*	-3.95 (-6.52, -1.38)	-0.16	0.003
R^2	0.26		

B = regression coefficient: the change in the range of hip motion associated with a unit change in the factor if the effects of all other factors in the model are held constant. 95% CI = 95% confidence interval of B. β = standardized regression coefficient: the number of standard deviations that the range of hip motion will change as a result of one standard deviation change in the factor if the effects of all other factors in the model are held constant. JSN = joint space narrowing. R^2 = R-squared. * Morning stiffness hip ≤ 60 minutes, reference category = no morning stiffness at all.

In the hip stratum severe pain on hip adduction and abduction were found to be associated with lower hip ROM. No significant association between pain on hip internal rotation and lower hip internal rotation was found in the adjusted model, whereas pain on hip internal rotation is included in the ACR classification criteria for hip OA.[3] Little is known about the relation between pain during hip adduction and abduction and lower ROM. Possibly the pain is caused by stretching and compression of joint structures leading to activation of pain receptors. Furthermore, we found that morning stiffness in the hip was associated with lower hip ROM. Morning stiffness is considered to be a clinical parameter for inflammation.[34] When the joint is inflamed, the synovial membrane can also be thickened,[34] which may in turn lower ROM.

Regarding demographic factors, male gender was found to be associated with lower hip internal rotation and flexion. Although conflicting results are reported on gender and ROM,[8,9,15,35] it is assumed that women have in general greater ROM than men.[36] This difference may be explained by joint geometry (the pelvic region of the female body allows a greater ROM), smaller muscle mass, and gender specific collagenous muscle structure.[36] Our study results support greater ROM in women than in men. It is remarkable that Escalante et al.[9] reported an association between female gender and lower passive hip flexion. In the latter study participants were older, and particularly women had a higher BMI in com-

Hip adduction (degrees)			Hip abduction (degrees)		
B (95% CI)	β	P	B (95% CI)	β	P
			-0.32 (-0.63, -0.02)	-0.11	0.04
			-5.29 (-9.86, -0.72)	-0.12	0.02
-3.16 (-5.62, -0.71)	-0.14	0.01			
			-4.13 (-7.71, -0.56)	-0.13	0.02
-2.24 (-4.27, -0.21)	-0.12	0.03	-4.98 (-7.77, -2.19)	-0.20	0.001
-4.94 (-7.76, -2.13)	-0.19	0.001			
			-6.08 (-9.06, -3.09)	-0.21	<0.0001
			-4.17 (-6.59, -1.75)	-0.18	0.001
2.39 (0.50, 4.28)	0.14	0.01			
0.09			0.19		

parison to our study population. In women fat is often stored around the hips and thighs where it can limit the available range of hip motion. This might explain these conflicting results. In addition we found that BMI was associated with lower knee and hip flexion, which is in agreement with earlier studies.[9,35]

There are some limitations to this study. First, no causal conclusions can be inferred because the study was cross-sectional in design. Second, the intra- and inter-observer reliability of the ROM measurements were not tested. Therefore we have no indication if and to what extent measurements were biased. However, to minimize bias all measurements were taken according to a strict protocol.[5] Third, the inter-rater reliability of the x-ray readings could not yet be reported, because radiographs will be read again with 5-year follow-up (which is ongoing). After this re-reading we can report inter-rater reliability. Although we have as yet no exact figure on the reading reliability, readings with similar training show in general intra-class correlation coefficients of 0.5 to 0.9 depending on the type of feature.[37] Because the x-ray readers were blinded for the results of the ROM measurements, it is unlikely that there is a bias in the readings. Based on possible variability in the readings there might be an underestimation of the association between radiographic features and ROM.

The explained variances for the regression models for hip external rotation, adduction and abduction were relatively low. Apparently, other factors which we did not examine in the present study, have impact on these joint actions. Other factors which potentially have impact on ROM include capsular contracture, muscle spasm, contracture of muscles and their overlying fascia, and the shape of the hip joint (acetabulum, femoral neck and head).[30] Furthermore, we did not measure biomechanical factors including muscle strength and joint laxity: both muscle strength and laxity might influence ROM.[5,38,39] Another explanation for the low explained variances of these models might be the accuracy of the measurements of external rotation, adduction and abduction. Particularly hip adduction and abduction are difficult to measure,[13,40] which may lead to measurement error.

Given the currently available evidence on ROM in OA, the present study was explorative rather than hypothesis driven. Backward stepwise regression was used to identify factors independently associated with ROM. This method uses significance-testing criteria to decide which factors should be included in the model. However, statistical differences may contrast with the clinical importance of a factor to the model, and the use of stepwise regression increases the risk for biased regression coefficients and *p*-values.[29,41,42] Therefore, additional hypothesis driven studies are required. The present study provides a stepping stone towards more focussed studies in the future.

In summary, in patients with early symptomatic knee OA, osteophytosis, bony enlargement of the knee joint, crepitus during knee flexion, pain and higher BMI were associated with lower knee flexion. JSN was associated with lower ROM in all planes of motion. In addition, osteophytosis, flattening of the femoral head, femoral buttressing, pain, morning stiffness, male gender and higher BMI were found to be associated with lower hip ROM in two planes of motion.

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