Towards sex-specific osteoarthritis risk models

Towards sex-specific osteoarthritis risk models: evaluation of risk factors for knee osteoarthritis in males and females

Ingrid A. Szilagyi1*, Jan H. Waarsing2, Dieuwke Schiphof3, Joyce B.J. van Meurs4, Sita M.A. Bierma-Zeinstra2,5

1Department of General Practice, Erasmus MC, University Medical Center Rotterdam, The Netherlands; e-mail: i.szilagyi@erasmusmc.nl

2Department of Orthopedics, Erasmus MC, University Medical Center Rotterdam, The Netherlands; e-mail: e.waarsing@erasmusmc.nl

3Department of General Practice, Erasmus MC, University Medical Center Rotterdam, The Netherlands; e-mail: d.schiphof@erasmusmc.nl

4Department of Internal Medicine and Department of Epidemiology, Erasmus MC, University Medical Center Rotterdam, The Netherlands; e-mail: j.vanmeurs@erasmusmc.nl

5Department of General Practice, Erasmus MC, University Medical Center Rotterdam, The Netherlands; e-mail: s.bierma-zeinstra@erasmusmc.nl

* Corresponding author. Erasmus MC, University Medical Center Rotterdam, Room NC-428, PO Box 2040, 3000 CA, Rotterdam, The Netherlands

Running headline: Towards sex-specific osteoarthritis risk models

© The Author(s) 2021. Published by Oxford University Press on behalf of the British Society for Rheumatology. This is an Open Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (http://creativecommons.org/licenses/by-nc/4.0/), which permits non-commercial re-use, distribution, and reproduction in any medium, provided the original work is properly cited. For commercial re-use, please contact journals.permissions@oup.com
Abstract

Objectives
The aim of this study was to identify sex-specific prevalence and strength of risk factors for the incidence of radiographic knee osteoarthritis (incRKOA).

Methods
Our study population consisted of 10,958 Rotterdam Study participants free of knee OA in one/both knees at baseline. 1064 participants developed RKOA after a median follow-up time of 9.6 years. We estimated the association between each available risk factor and incRKOA using sex stratified multivariate regression models with generalized estimating equations. Subsequently, we statistically tested sex differences between risk estimates and calculated the population attributable fractions (PAFs) for modifiable risk factors.

Results
The prevalence of the investigated risk factors was, in general, higher in women compared to men, except alcohol intake and smoking was higher in men and high BMI showed equal prevalence. We found significantly different risk estimates between men and women: high level of PA (RR 1.76, 95% CI 1.29-2.40) or a KL-score 1 at baseline (RR 5.48, 95% CI 4.51-6.65) was higher in men. Among borderline significantly different risk estimates was BMI ≥27, associated with higher risk for incRKOA in women (RR 2.00, 95% CI 1.74-2.31). The PAF for higher BMI was 25.6% in women and 19.3% in men.

Conclusion
We found sex-specific differences in both presence and relative risks of several risk factors for incRKOA. Especially BMI, a modifiable risk factor, impacts women more strongly than men. These risk factors can be used in the development of personalized prevention strategies and in building sex-specific prediction tools to identify high-risk profile patients.
Towards sex-specific osteoarthritis risk models

Keywords: sex difference, risk factors, knee osteoarthritis, epidemiology, GEE

Key messages

- Studies on risk factors and designing prediction models have largely ignored sex differences in osteoarthritis.
- Physical activity and KL1 showed sex differences in their relationship with incidence of knee OA.
- In women 1/4 and in men 1/5 new knee cases is attributable to a BMI≥27.
Towards sex-specific osteoarthritis risk models

Introduction

Men and women are similar in many ways, but when it comes to health the differences matter. Sex and gender influence our risk of developing certain diseases[1], their clinical manifestation, how well we respond to treatment[2] and how often we seek health care[3]. Knee osteoarthritis (KOA) is one of the diseases that affect females and males differently. After the age of 50, there is a steep increase in incidence of KOA in women compared to men[4], leading to a higher prevalence in women[5]. Also, KOA in women is more often accompanied by pain and disability compared to men[6, 7]. Sex is a strong risk factor for KOA[8] and it is thought that different etiology can underlie the disease in the different sexes[9]. Despite this knowledge, studies on risk factors and designing prediction models have largely ignored sex differences.

There are several reasons why certain risk factors might display different risk in men and women. First, a large number of factors have different distribution depending on gender and socio-cultural influence (ethnicity, socio-economic status) visible in the study characteristics of various population-based studies. Moreover, behavior connected to lifestyle factors might be different depending on gender. For instance physical activity in women, while similar in amount, might still be composed of different types of activity than in men, leading to differences in strength of association.

Second, several studies have indicated that certain etiological pathways might be more predominant in one of the sexes [9]. For example, the metabolic OA-type is thought to be female-specific. Not only the prevalence of metabolic syndrome (MetS) differs between the sexes, but also its clinical representation with sex differences in fat distribution and adipocyte function[10]. The association of OA with MetS is not completely explained by an obesity-
induced increased biomechanical load and obese people have also an increased risk for hand OA, a non-weight bearing joint[11]. This suggests that the relationship between MetS and OA is through altered metabolism and inflammation. Due to its modifiable nature, obesity has already been the target in a randomized controlled trial to prevent KOA[12].

Third, women not only have different morphology of the knee joint[13] but also differ in neuromuscular control and gait kinematics[14]. In addition, the relation between hip-shape differences (dysplasia and CAM-impingement) and OA has been shown to be sex-specific[15]. This evidence suggests that other joint- and OA-related risk factors constitute a valuable set to further investigate for sex-differences.

In order to provide better healthcare for both men and women, the differences and similarities in the manifestation, etiology and pathophysiology of KOA should be considered in health research and subsequently translated to clinical practice. The more we understand how sex and gender affect health, the more we can improve health and quality of life for everyone. With the study of sex differences we get closer to obtaining a more efficient and personalized health care, as sex- and gender-based prevention strategies or therapies are probably more effective than the usual ‘one-size-fits all’ approach and would benefit patients of both sex.

It is high time to overcome this lack of knowledge and shed more light on the role sex differences play in osteoarthritis. Therefore, the aim of the present study was to identify sex-specific prevalence and strength first of the usual person-related risk factors and then OA related
risk factors for the development of radiographic KOA (RKO) in a large population-based prospective study.

Materials and Methods

Participants

We selected our study population from the Rotterdam Study cohort, a population-based prospective study ongoing since 1990 in the city of Rotterdam in the Netherlands. Baseline measurements were collected from 1990 to 1993 for 7983 participants (RS-I). Two additional sub-cohorts were recruited from 2000 to 2001 including 3011 participants (RS-II) and 2006 to 2008 comprising of 3932 participants (RS-III). In this study we used visits 1, 3, 4 of RS-I (1990-2004), visits 1, 2 and 3 of RS-II (2000-2012) and visits 1 and 2 of RS-III (2006-2014) where the radiographic measurements of the knees were available. As of 2008, 14,926 participants aged 45 years and over comprise the Rotterdam Study. The participants are followed for a variety of diseases that are frequent in the elderly with the aim to investigate determinants of disease occurrence and progression. The Rotterdam study is approved by the medical ethics committee of the Erasmus University Medical Centre and the review board of the Ministry of Health, Welfare and Sports of the Netherlands. Written informed consent was obtained from all participants in the study[16].

Incidence of RKO

Knee radiographs were taken with the knee and patella in an extended and central position respectively[17]. Knee radiographs were available for 4874 men and 6084 women at baseline, and for 3187 men and 3948 women(Figure 1) after a median follow-up time of 9.56 years (IQR=5.65-10.60 years). We defined RKO according to the original Kellgren and Lawrence (KL) scoring system[18, 19]. Incidence of RKO (incRKO) was defined for each knee as a
Towards sex-specific osteoarthritis risk models

KL-score of 0 or 1 at baseline and a KL-score 2-4 or a total joint replacement at the second or third visit during the total follow-up time of 10 years.

Person-related risk factors

We selected the studied risk factors for KOA from the latest systematic review[8] that were also available in the three cohorts of the Rotterdam Study. Baseline information on the following characteristics were collected from participants using questionnaires, structured home interviews and visits to the research centre: age, highest level of education according to the UNESCO classification (primary education, lower=lower/intermediate general education or lower vocational education, intermediate=intermediate vocational education or higher general education, higher=higher vocational education or university)[20], body mass index (BMI, kg/m2), waist and hip circumference (cm) used to calculate waist-to-hip ratio(WHR), femoral neck-bone mineral density(FN-BMD) derived from DEXA scans, alcohol consumption (yes/no) and cigarette smoking status (never/ever smoker) recorded during home interviews and total physical activity(PA) assessed in RS-I and RS-II using a validated adapted version of Zutphen Physical Activity Questionnaire[21] and in RS-III cohort using the LASA Physical Activity questionnaire(LAPAQ)[22]. In both questionnaires, total PA was expressed in Metabolic Equivalent of Task in hours per week (MET hours/week)[23]. Total PA is composed of all physical activity types and thus, of different METs.

OA related risk factors

Information on hip OA, as well as on hand OA was assessed at baseline during the visits at the research center where X-ray photos were made and graded by two independent researchers according to the KL grading system[18, 19]. OA was defined as having a KL grade of 2 or higher. Hand OA was divided into bilateral finger OA (KL 2 or higher in at least one distal
Towards sex-specific osteoarthritis risk models

interphalangeal joint (DIP) or proximal interphalangeal (PIP) joint on both hands) and bilateral thumb OA (defined as OA in carpometacarpal joint or scaphotrapeziotrapezoidal joint; CMC/TS)[24].

The Stanford Health Assessment Questionnaire (HAQ) was used to assess disability[25]. A comprehensive description of the way the HAQ was assessed during the home interview carried out by one of nine extensively trained interviewers has been presented earlier[26]. Locomotor disability of the lower-limb was defined as the mean of the scores (with zero indicating no impairment and three indicating unable to perform) on the six questions related to lower limb functions. Disability was defined as a lower limb disability index of 0.5 or over. Upper-limb disability and an overall disability index were computed in a similar way.

Baseline KL score of 1 in the knee was also included as a risk factor in the analysis as it is widely known that it increases the risk of developing RKOA in the future.

Statistical analysis

We reported the prevalence (or mean or median) of each of the available risk factors. We estimated the association between each available risk factor measurement and the incRKOa using sex-stratified multivariate regression models with generalized estimating equations (GEE models) that takes into account the correlation between the two knees in an individual. We report a relative risk (RR) per 1 standard deviation (SD) with 95% confidence interval (CI), where SD was based on the whole study population, for continuous variables and per presence of risk factors in case of dichotomous variables. FN-BMD and total PA were analyzed per sex-specific tertile and the lowest tertile used as reference. P-values <0.05 were considered to be statistically significant. In the basic model we adjusted for age, months between radiographs and sub-cohort. Further, in the second model we additionally adjusted for BMI to verify if the associations are independent of this well-known modifiable risk factor. We used Z-test statistic
Towards sex-specific osteoarthritis risk models

to test if the RR estimates were statistically significantly different between men and women[27].
We decided to use Z-test because the interpretation of the interaction term would only be valid
when the other variables in the regression model are the same between the men and women.
This is a method often used in similar settings, i.e. work of Schiphof et al., 2013 [28]. For the
calculation, we needed \( d = E_1 - E_2 \) which is the difference of estimates from 2 groups and has
standard error \( SE(d) = \sqrt{SE(E_1)^2 + SE(E_2)^2} \). The ratio \( z = d / SE(d) \) gives a test of the null
hypothesis that there is no difference between the 2 groups, by comparing the value of \( z \) to the
standard normal distribution. A 2-sided test with a significance level of 0.05 was used. There is
a significant difference in the factor for the specific grade if \( z \) is less than -1.96 or if \( z \) is >1.96.
The 95% CI for the difference is \( d - 1.96 * SE(d) \) to \( d + 1.96 * SE(d) \)[29]. We defined a risk factor
as being sex-specific if the RR estimates were statistically significantly different between men
and women according to the Z-test, when the p-value was 0.05 and borderline significant when
this was <0.1.

Finally, we built sex-specific multivariable models where we included all factors that showed
a p-value ≤0.1 in the second, BMI adjusted, model. This model, conditioning on the other risk
factors, was ran to get an estimation of the net effect of a risk factor on the outcome accounting
for the effects of other risk factors. Subsequently, to illustrate the contribution of the risk factors
to the incRKOA, we estimated the sex-specific population attributable fractions (PAFs) for the
modifiable factors that showed a significant association in the multivariable model. PAF is an
impact measure that allows estimation of the proportion of new cases of KOA in the population
that could be avoided if the risk factor was removed. We used the following formula for
calculating sex-specific PAFs in our study sample: \( (Pe * adjRR) / [(Pe * adjRR) + 1] \), where \( Pe \)
is the proportion of exposed male/female knees, and \( adjRR \) is the adjusted RR from the sex-
specific multivariable GEE model. All statistical analyses were performed using R version
3.5.2[30].
Results

11,730 participants underwent longitudinal radiographic measurements of the knee and baseline measurements of several person- and OA-related factors. Our study population included 10,958 participants at baseline who did not have KOA in at least one knee at the first visit (Figure 1). Subsequently, we excluded participants without follow-up data on radiographic measurements. The lost to follow-up group (35% out of 10,958) is older on average, suffering from disabilities and other comorbidities, reasons why these participants were not able to participate in any of the follow-up measurements taken place at the research center. In contrast, the participants included in our analysis are younger and healthier on average, with less hypertension and diabetes cases, less OA in other joints and less disability (Supplementary Table S1b).

A total number of 1064 participants, 713 women and 351 men, developed uni-/bi-lateral RKOA during follow-up. The proportion of women developing RKOA during follow-up is 17.3% and 10.7% in men. The median follow-up time is 9.7 years (interquartile range [IQR] 4.9 years / 5.7-10.6 years). We included 13,586 knees with KL-score <2 in our analysis. During the follow-up 1303 incident knee cases (9.6%) developed, 884 in women and 419 in men.

We compared the baseline characteristics between men and women in our study population and we observed that they differed significantly in almost every aspect (Table 1) except age, BMI and Hip OA status. Women had on average lower FN-BMD, consumed significantly less alcohol and a larger proportion has never smoked compared to men. Women were, on average, more physically active than the male population and were lower educated indicated by a higher proportion with primary and lower education (66%) compared to the men (37.4%) in our study population. Moreover, finger OA and thumb OA were more frequently present in women, with 26.2% and 16.1%, respectively, which is almost twice the proportion in men.
Person-related risk factors and KOA

Figure 2 shows the results obtained for the person-related risk factors in the two models tested. Well-known risk factors such as age, BMI, weight and height, were associated with the development of RKOA in both sexes. Additionally, we found that 1 SD increase in FN-BMD resulted in higher risk of developing knee KOA irrespective of sex with RR=1.29, 95%CI=1.15-1.43 in men, RR=1.16, 95%CI=1.07-1.25 in women, independently from BMI(Supplementary Table S2). Although associated in both sexes, the risk of both age and BMI was significantly different between the sexes, with age being stronger in men and BMI stronger in women (Figure 2 and Supplementary Table S2 and S4).

Total PA, alcohol intake and ever smoking were significantly associated with the incRKOA in only one of the sexes. Using the same model adjusted for age, BMI and time of follow-up, we found that higher level of total PA, RR=1.76, 95%CI=1.29-2.40 was associated with increased risk of developing KOA in our male population and this estimate was significantly higher compared to women (p-value=0.01). In women, we found that any alcohol intake RR=1.23, 95%CI=1.01-1.51 was associated with a higher risk of RKOA at follow-up. In addition, female ever smokers showed a near significant association with developing RKOA, RR=1.19, 95%CI=0.99-1.43 compared to female never smokers during follow-up independently from BMI(Supplementary Table S2). The RR of these latter two risk-factors did, however, not differ significantly between the sexes.

Although having a higher waist-hip ratio (WHR) was associated with higher risk of RKOA in women, this association disappeared when we adjusted for BMI.
OA related risk factors and KOA

Having OA at other joints showed some sex-specific associations with incRKOA as illustrated in Figure 3. In both men and women, having bilateral finger OA increases the risks of developing RKOA with RR=1.29, 95%CI=1.00-1.66 in men, and RR=1.44, 95%CI=1.22-1.70 in women. Also, a KL-score of 1, the strongest OA related factor has strong associations in both sexes, but with slightly higher risk in men, RR=5.48, 95%CI=4.51-6.65, than in women, RR=3.89, 95%CI=3.41-4.43 (Supplementary Table S3). These differences in risk estimates between men and women were significant (p-value=0.002), however, we did not include it in our multivariable model because it is arguably more likely a sign of early OA than a risk factor.

In women, we found a few additional risk factors. Having bilateral thumb OA increased the risk in women with RR=1.63, 95%CI=1.37-1.95, which was borderline significantly different from the risk in men (p-value=0.07, Supplementary Table S4). Having upper-limb disability increased the risk of developing KOA in 10 years only in women and the association remained after adjustment for BMI (RR=1.50, 95%CI=1.10-2.05). Similarly, lower-limb disability and general disability showed an association with KOA in women only. However, the risk estimates were reduced significantly and the associations attenuated after BMI adjustment. Also, the RRs of the disability related risk-factors did not differ significantly between the sexes. Having hip OA was not associated with the onset of KOA.

Population attributable fractions (PAFs)

For the modifiable factors BMI and total PA we estimated the PAFs using the adjusted risk estimates from the multivariable sex-specific models (Supplementary Table S5 and S6).

In women, the estimated PAF for having a BMI of 27 or higher was 25.6% indicating that 25.6% of new knee cases are attributable to being overweight or obese in our female study.
Towards sex-specific osteoarthritis risk models

population. In men, this proportion was significantly lower, with 19.3% of new knee cases attributable to a BMI $\geq 27$.

The PAF for total PA was only estimated in men because in women it was not associated with the incRKOA. The estimated PAF in men for values of total PA in the highest male-specific tertile (median=107 MET hours/week, range 78-1005 MET hours/week), was 11.5%.

Discussion

In this population-based study of adults aged 45 years or older, we found sex differences in the relationship between risk factors and incKOA. We detected significantly different risk estimates between men and women according to the Z-test: high level of total PA or a KL score of 1 at baseline was associated with significantly higher risk in men. Other sex-related risk factors showed a borderline significant difference: higher age, a BMI of 27 or higher, lower WHR and lower education level suggest a tendency of higher risk in men, while having bilateral thumb OA suggests a significantly higher risk in women. The associations remained in the sex-specific conditional multivariable models. We further focused on discussing our main findings while also touching upon a much-debated risk factor – smoking.

Our findings show evidence that obesity has a higher impact on KOA in women compared to men. Although the association is present in both sexes, the risk for RKOA was borderline significantly different between the sexes ($p=0.056$), stronger in women (RR=2, 95%CI=1.74 – 2.31) compared to men (RR=1.58, 95%CI=1.28 - 1.94). Using BMI as continuous variable provided similar results (data not shown). Despite the almost equal percentage of men and women with a BMI above 27 in our study population[31], a significantly higher proportion of new knee cases is attributable to a BMI of 27 or higher in women compared to men, with 25.6% and 19.3% respectively. This suggests that obesity, indicated by higher BMI, acts in a different
Towards sex-specific osteoarthritis risk models

way in women compared to men in the context of RKOAn. Obesity, is one of the MetS components and is known to be connected to low-grade systemic inflammation[32]. In previous work from Visser and co-authors[33] has been shown that the skeletal muscle mass (SMM) to fat mass (FM) ratio is important in knee OA and that the underlying mechanisms differ between men and women. More specifically, they found that FM was most strongly associated in women, whereas in men SMM was the most important factor. Future research is needed to disentangle this difference. Thus, our results support the hypothesis of the female-specific metabolic OA-type.

The sex-specific effect of smoking on the risk of KOA suggests the influence of gender roles in this case. We observed a higher proportion of male ever smokers at baseline, which may reflect the fact that three decades ago it was more acceptable for a man to smoke compared to women. Still, in our study, ever smoking showed a nearly significant positive association in women (RR=1.19, 95%CI=0.99-1.43) while there was no effect in men (RR=0.92, 95%CI=0.72-1.18). The association increased in the female-specific multivariable model conditional on other risk factors, adjRR=1.29, 95%CI=1.1-1.49(Supplementary Table S6). Smoking is a known risk factor for hypertension[34] and we therefore performed a sensitivity analysis where we also adjusted for systolic blood pressure, a reported causal factor for clinical KOA[35], which did not change the association(Supplementary Table S7). In previous studies, contrary to our findings, a protective effect of smoking on KOA was detected in diverse cohorts worldwide[36-38]. Still, the overall conclusion is that it has no effect[8]. Different study populations, study designs and different categorization of exposure levels are the main reasons for the inconsistent and sometimes intriguing results. Smoking remains a controversial topic in KOA and given the contradicting results with previous research, further large prospective
Towards sex-specific osteoarthritis risk models

studies should employ sex-stratified analysis in order to replicate and contribute to this evidence.

In the case of PA, we observe a sex difference in the total PA amount in baseline characteristics with higher values in women. This difference may partly be due to differences in the intensity and types of PA in which men and women engage[23]. Women more often performed low or moderate intensity PA comprised of walking or domestic work, while men performed on average more high intensity activities, like sports. Important to note is that these characteristics are from a previous generation and may not reflect the current trend. We show that higher total PA is associated with higher risk of RKO only in men, which might indicate that men were indeed engaged in different activities than women. Mainly high intensity PA has been shown to be detrimental to the knee joints and has been linked to the development or progression of OA in the future[39, 40]. The association remained but reduced in effect size in the multivariable model conditioning on other risk factors in men (RR=1.38, 95%CI=1.14-1.61). History of knee injury is a major risk factor for the development of KOA[41, 42], and may be responsible for a part of the association we found with higher levels of total PA.

Strengths and limitations

We acknowledge that our study has limitations. Firstly, due to the long follow-up period and the requirement for the participants to visit the research center, there is a high percentage of participants lost to follow-up. As a consequence, the participants included in the analysis are, on average, healthier than the participants lost to follow-up. This could have led to underestimation of the risk of KOA in this population[43]. A second limitation, the lack of data on injury history and surgery in the whole study population hindered us to investigate its sex-specific impact for KOA[41] and disentangle the attribution of PA alone to the risk of KOA.
Towards sex-specific osteoarthritis risk models

Furthermore, the PAF calculation was based on the knee cases of incKOA, meaning that for some participants we included two knees, therefore the PAF estimates reported may be overestimated due to the correlation between the knees. Finally, the observed sex-specific effects are the result of both biological sex effects (i.e. BMI) and sociological gender effects (i.e. smoking, PA) and it is difficult to disentangle the two. The first measurements in the Rotterdam Study took place more than three decades ago. Thus, distributions of the aforementioned risk factors might have changed among the two sexes and might not be representative for the present generation at risk for KOA. This study focuses on radiographic knee OA and did not consider symptomatic knee OA. Sex-specific risk factors may be very different for symptomatic knee OA. But this was out of the scope of this paper and subject to future research.

Conclusion

In conclusion, our findings provide evidence for sex-specific differences in both presence and relative risks of several risk factors for incRKOEA. BMI remains, however, the most important modifiable risk factor that impacts women to a larger extent than men. The new evidence we present should raise awareness of the sex differences that exist in the relationship between risk factors and KOA. The identified sex-specific risk factors can be used in the development of prevention strategies and in building sex-specific prediction tools to identify high-risk profile patients.
Data Availability Statement

Rotterdam Study data can be made available to interested researchers upon request. Requests can be directed to data manager Frank J.A. van Rooij (ln.cmsumsare@jioornav.f) or visit the following website for more information http://www.ergo-onderzoek.nl/wp/contact. We are unable to place data in a public repository due to legal and ethical restraints. Sharing of individual participant data was not included in the informed consent of the study, and there is potential risk of revealing participants’ identities as it is not possible to completely anonymize the data.

Acknowledgements

This research was funded by The Netherlands Organisation for Health Research and Development (ZonMw), project number 849200003. The Rotterdam Study is funded by Erasmus Medical Center and Erasmus University, Rotterdam, Netherlands Organization for the Health Research and Development (ZonMw), the Research Institute for Diseases in the Elderly (RIDE), the Ministry of Education, Culture and Science, the Ministry for Health, Welfare and Sports, the European Commission (DG XII), and the Municipality of Rotterdam. The authors are grateful to the study participants, the staff from the Rotterdam Study and the participating general practitioners and pharmacists.

Contributions

All authors contributed substantially to the conception and design of the article. IS performed the analysis and drafted the initial manuscript. All authors critically revised it for interpretation of results and important intellectual content. All authors approved the final version of the manuscript.
Role of the funding source

The funding source did not have any influence on study design, collection, analysis and interpretation of data; in the writing of the manuscript; and in the decision to submit the manuscript for publication.

Competing interests

S.M.A. Bierma-Zeinstra declares doing consultancy for Pfizer (tanezumab) and reports grants from The Netherlands Organisation for Health Research and Development (ZonMw), Dutch Arthritis Association, Foreum. The remaining authors declare no competing financial interests. All authors declare no nonfinancial conflicts of interest.
References

1 Berkley KJ. Sex differences in pain. Behav Brain Sci 1997;20(3):371-80; discussion 435-513.
2 Nechas E, Foley D. Unequal Treatment: What You Don’t Know about how Women are Mistreated by the Medical Community: Simon & Schuster; 1994.
3 Courtenay WH. Constructions of masculinity and their influence on men’s well-being: a theory of gender and health. Soc Sci Med 2000;50(10):1385-401.
4 Prieto-Alhambra D, Judge A, Javaid MK, Cooper C, Diez-Perez A, Arden NK. Incidence and risk factors for clinically diagnosed knee, hip and hand osteoarthritis: influences of age, gender and osteoarthritis affecting other joints. Ann Rheum Dis 2014;73(9):1659-64.
5 Srikanth VK, Fryer JL, Zhai G, Winzenberg TM, Hosmer D, Jones G. A meta-analysis of sex differences prevalence, incidence and severity of osteoarthritis. Osteoarthritis Cartilage 2005;13(9):769-81.
6 de Kruijf M, Stolk L, Zillikens MC, et al. Lower sex hormone levels are associated with more chronic musculoskeletal pain in community-dwelling elderly women. Pain 2016;157(7):1425-31.
7 Odding E, Valkenburg HA, Algra D, Vandenouweland FA, Grobbee DE, Hofman A. Associations of radiological osteoarthritis of the hip and knee with locomotor disability in the Rotterdam Study. Ann Rheum Dis 1998;57(4):203-8.
8 Silverwood V, Blagojevic-Bucknall M, Jinks C, Jordan JL, Protheroe J, Jordan KP. Current evidence on risk factors for knee osteoarthritis in older adults: a systematic review and meta-analysis. Osteoarthritis Cartilage 2015;23(4):507-15.
9 Huffman KM, Kraus WE. Osteoarthritis and the metabolic syndrome: more evidence that the etiology of OA is different in men and women. Osteoarthritis Cartilage 2012;20(7):603-4.
10 Pradhan AD. Sex differences in the metabolic syndrome: implications for cardiovascular health in women. Clin Chem 2014;60(1):44-52.
11 Strand MP, Neogi T, Niu J, Felson DT, Haugen IK. Association Between Metabolic Syndrome and Radiographic Hand Osteoarthritis: Data From a Community-Based Longitudinal Cohort Study. Arthritis Care Res (Hoboken) 2018;70(3):498-503.
12 Runhaar J, van Middelkoop M, Reijman M, et al. Prevention of knee osteoarthritis in overweight females: the first preventive randomized controlled trial in osteoarthritis. Am J Med 2015;128(8):888-95 e4.
13 Mahfouz MR, Merkl BC, Fatah EE, Booth R, Jr., Argenson JN. Automatic methods for characterization of sexual dimorphism of adult femora: distal femur. Comput Methods Biomech Biomed Engin 2007;10(6):447-56.
14 McKean KA, Landry SC, Hubley-Kozey CL, Dunbar MJ, Stanish WD, Deluzio KJ. Gender differences exist in osteoarthritic gait. Clin Biomech (Bristol, Avon) 2007;22(4):400-9.
15 Saberi Hosnijeh F, Zuidervijk ME, Versteeg M, et al. Cam Deformity and Acetabular Dysplasia as Risk Factors for Hip Osteoarthritis. Arthritis Rheumatol 2017;69(1):86-93.
16 Ikram MA, Brusselle G, Ghanbari M, et al. Objectives, design and main findings until 2020 from the Rotterdam Study. Eur J Epidemiol 2020;35(5):483-517.
17 Hoeven TA, Kavousi M, Clockaerts S, et al. Association of atherosclerosis with presence and progression of osteoarthritis: the Rotterdam Study. Annals of the Rheumatic Diseases 2013;72(5):646-51.
18 Kellgren JH, Lawrence JS. Radiological assessment of osteo-arthritis. Ann Rheum Dis 1957;16(4):494-502.
19 Schiphof D, Boers M, Bierma-Zeinstra SM. Differences in descriptions of Kellgren and Lawrence grades of knee osteoarthritis. Ann Rheum Dis 2008;67(7):1034-6.
20 United Nations Educational S, and Cultural Organization, Paris . Div. of Statistics on Education. International Standard Classification of Education (ISCED): ERIC Clearinghouse; 1976.
Towards sex-specific osteoarthritis risk models

21 Caspersen CJ, Bloemberg BP, Saris WH, Merritt RK, Kromhout D. The prevalence of selected physical activities and their relation with coronary heart disease risk factors in elderly men: the Zutphen Study, 1985. Am J Epidemiol 1991;133(11):1078-92.

22 Stel VS, Smit JH, Pluijm SM, Visser M, Deeg DJ, Lips P. Comparison of the LASA Physical Activity Questionnaire with a 7-day diary and pedometer. J Clin Epidemiol 2004;57(3):252-8.

23 Koolhaas CM, Dhana K, Golubic R, et al. Physical Activity Types and Coronary Heart Disease Risk in Middle-Aged and Elderly Persons: The Rotterdam Study. Am J Epidemiol 2016;183(8):729-38.

24 Dahaghin S, Birma- Zeinstra SM, Reijman M, Pols HA, Hazes JM, Koes BW. Does hand osteoarthritis predict future hip or knee osteoarthritis? Arthritis Rheum 2005;52(11):3520-7.

25 Fries JF, Spitz PW, Young DY. The dimensions of health outcomes: the health assessment questionnaire, disability and pain scales. J Rheumatol 1982;9(5):789-93.

26 Oding E, Valkenburg HA, Algra D, Vandenouweland FA, Grobbee DE, Hofman A. Association of locomotor complaints and disability in the Rotterdam study. Ann Rheum Dis 1995;54(9):721-5.

27 Altman DG, Bland JM. Interaction revisited: the difference between two estimates. BMJ 2003;326(7382):219.

28 Schiphof D, Kerkhof HJ, Damen J, et al. Factors for pain in patients with different grades of knee osteoarthritis. Arthritis Care Res (Hoboken) 2013;65(5):695-702.

29 Altman DG, Bland JM. Statistics Notes - Interaction revisited: the difference between two estimates. Bmj-Brit Med J 2003;326(7382):219-.

30 Team RC. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. 2016. In; 2017.

31 Reijman M, Pols HA, Bergink AP, et al. Body mass index associated with onset and progression of osteoarthritis of the knee but not of the hip: the Rotterdam Study. Ann Rheum Dis 2007;66(2):158-62.

32 Visser M, Bouter LM, McQuillan GM, Wener MH, Harris TB. Elevated C-reactive protein levels in overweight and obese adults. JAMA 1999;282(22):2131-5.

33 Visser AW, de Mutsert R, Loef M, et al. The role of fat mass and skeletal muscle mass in knee osteoarthritis is different for men and women: the NEO study. Osteoarthr Cartilage 2014;22(2):197-202.

34 Mills KT, Stefanescu A, He J. The global epidemiology of hypertension. Nat Rev Nephrol 2020;16(4):223-37.

35 Funck-Brentano T, Nethander M, Moverare-Skrtic S, Richette P, Ohlsson C. Causal factors for knee, hip and hand osteoarthritis: a Mendelian randomization study in the UK Biobank. Arthritis Rheumatol 2019.

36 Felson DT, Zhang Y, Hannan MT, et al. Risk factors for incident radiographic knee osteoarthritis in the elderly: the Framingham Study. Arthritis Rheum 1997;40(4):728-33.

37 Felson DT, Anderson JJ, Naimark A, Hannan MT, Kannel WB, Meenan RF. Does smoking protect against osteoarthritis? Arthritis Rheum 1989;32(2):166-72.

38 Samanta A, Jones A, Regan M, Wilson S, Doherty M. Is osteoarthritis in women affected by hormonal changes or smoking? Br J Rheumatol 1993;32(5):366-70.

39 D’Souza JC, Werner RA, Keyserling WM, et al. Analysis of the Third National Health and Nutrition Examination Survey (NHANES III) using expert ratings of job categories. Am J Ind Med 2008;51(1):37-46.

40 Driban JB, Hootman JM, Sitler MR, Harris KP, Cattano NM. Is Participation in Certain Sports Associated With Knee Osteoarthritis? A Systematic Review. J Athl Train 2017;52(6):497-506.

41 Muthuri SG, McWilliams DF, Doherty M, Zhang W. History of knee injuries and knee osteoarthritis: a meta-analysis of observational studies. Osteoarthritis Cartilage 2011;19(11):1286-93.

42 Richmond SA, Fukuchi RK, Ezzat A, Schneider K, Schneider G, Emery CA. Are joint injury, sport activity, physical activity, obesity, or occupational activities predictors for osteoarthritis? A systematic review. J Orthop Sports Phys Ther 2013;43(8):515-819.

43 Zhang Y, Niu J, Felson DT, Choi HK, Nevitt M, Neogi T. Methodologic challenges in studying risk factors for progression of knee osteoarthritis. Arthritis Care Res (Hoboken) 2010;62(11):1527-32.
Towards sex-specific osteoarthritis risk models

Tables and figure legends

Table 1. Baseline characteristics of the study population

* for Total Physical Activity we used the measurements from third visit (RS-I-3) as the measurement was not available at the first visit (RS-I-1). All the other measurements were available at the first visit of RS-I cohort.

Figure 1. Flow chart of study participants from the Rotterdam Study cohorts

* The lost to follow-up percentages are also due to missing data on time between radiographs and other covariates (age, BMI)

Figure 2. Forest plot of the associations between incident RKOA and person-related risk factors

Figure 3. Forest plot of the associations between incident RKOA and OA-related risk factors
### Table 1.

| Characteristics | Overall (N = 7135) | Men (N = 3187, 44.7%) | Women (N = 3948, 55.3%) | p-value |
|-----------------|--------------------|-----------------------|-------------------------|---------|
| Age, years, mean (sd) | 62.18 (7.08) | 62.12 (6.96) | 62.22 (7.19) | 0.557 |
| BMI ≥ 27, n (%) | 3014 (42.2) | 1353 (42.5) | 1661 (42.1) | 0.764 |
| Height, cm, mean (sd) | 169.10 (9.23) | 176.45 (6.74) | 163.17 (6.21) | <0.001 |
| Weight, kg, mean (sd) | 76.66 (13.49) | 83.21 (12.23) | 71.38 (12.06) | <0.001 |
| Waist-to-Hip Ratio (WHR), mean (sd) | 0.89 (0.09) | 0.95 (0.07) | 0.85 (0.08) | <0.001 |
| Femoral-neck Bone Mineral Density (FN-BMD), mean (sd) | 0.90 (0.14) | 0.94 (0.13) | 0.87 (0.14) | <0.001 |
| Alcohol intake (g/day), median [IQR] | 6.43 [0.54, 15.00] | 8.57 [1.85, 20.75] | 2.50 [0.25, 8.57] | <0.001 |
| Any alcohol consumption status, n (%) | 4651 (84.0) | 2162 (90.5) | 2489 (79.1) | <0.001 |
| Ever smoking, n (%) | 5143 (72.6) | 2357 (74.4) | 2786 (71.2) | <0.001 |
| Total Physical Activity* (Total PA), MET hours/week, median [IQR] | 73.10 [45.41, 106.32] | 61.33 [35.11, 93.10] | 81.62 [55.85, 115.88] | <0.001 |
| Total Physical Activity* (Total PA), sex-specific tertiles, n (%) | (N = 6106)* | (N = 2714)* | (N = 3392)* | 0.363 |
| Low (tertile 1) | 1950 (30.1) | 884 (30.4) | 1066 (29.9) | |
| Moderate (tertile 2) | 2252 (34.8) | 1009 (34.7) | 1243 (34.9) | |
| High (tertile 3) | 2267 (35.0) | 1012 (34.8) | 1255 (35.2) | |
| Education level (UNESCO), n (%) | <0.001 |
| primary | 802 (11.3) | 263 (8.3) | 539 (13.8) | |
| lower | 2964 (41.9) | 920 (29.1) | 2044 (52.2) | |
| intermediate | 2088 (29.5) | 1193 (37.7) | 895 (22.8) | |
| higher | 1228 (17.3) | 789 (24.9) | 439 (11.2) | |
| Disability, n (%) | 786 (12.1) | 209 (7.2) | 577 (16.0) | <0.001 |
| Lower-limb disability, n (%) | 679 (10.4) | 196 (6.7) | 483 (13.4) | <0.001 |
| Upper-limb disability, n (%) | 147 (2.3) | 26 (0.9) | 121 (3.4) | <0.001 |
| Hip OA at baseline, n (%) | 364 (5.2) | 154 (4.9) | 210 (5.4) | 0.393 |
| Finger OA at baseline, n (%) | 1308 (21.9) | 447 (16.6) | 861 (26.2) | <0.001 |
| Thumb OA at baseline, n (%) | 761 (12.7) | 234 (8.6) | 527 (16.1) | <0.001 |
Towards sex-specific osteoarthritis risk models

Figure 1.
## Sex-stratified results for the association between incidence of RKOa and person-related risk factors

| Person-related risk factors | N.obs.knees | N.inc.knees | adj. RR |
|-----------------------------|-------------|-------------|---------|
| **Age, SD**                 |             |             |         |
| Age - Women                 | 7477        | 884         | 1.24    |
| Age - Man                   | 6109        | 419         | 1.38    |
| BMI >= 27. yes              |             |             |         |
| BMI - Women                 | 7477        | 884         | 2       |
| BMI - Man                   | 6109        | 419         | 1.58    |
| **Height, SD**              |             |             |         |
| Height - Women              | 7477        | 884         | 0.87    |
| Height - Man                | 6109        | 419         | 0.77    |
| **Weight, SD**              |             |             |         |
| Weight - Women              | 7477        | 884         | 1.61    |
| Weight - Men                | 6109        | 419         | 1.49    |
| **Waist-Hip Ratio, SD**     |             |             |         |
| Waist-Hip Ratio - Women     | 7114        | 848         | 1       |
| Waist-Hip Ratio - Men       | 5796        | 398         | 0.96    |
| **FN-BMD, SD**              |             |             |         |
| FN-BMD - Women              | 6757        | 814         | 1.16    |
| FN-BMD - Man                | 5570        | 386         | 1.29    |
| **FN-BMD, sex-specific tertiles (Ref=tertile 1)** | | | |
| FN-BMD - tertile 2 - Women  | 6757        | 814         | 1.2     |
| FN-BMD - tertile 3 - Women  | 6757        | 814         | 1.45    |
| FN-BMD - tertile 2 - Men    | 5570        | 388         | 1.06    |
| FN-BMD - tertile 3 - Men    | 5570        | 388         | 1.76    |
| **Alcohol, yes**            |             |             |         |
| Alcohol - Women             | 5961        | 676         | 1.23    |
| Alcohol - Men               | 4590        | 299         | 1.08    |
| **Smoking status, ever (Ref=never)** | | | |
| Ever smoking - Women        | 7416        | 877         | 1.11    |
| Ever smoking - Men          | 6068        | 418         | 0.92    |
| **Total PA, sex-specific tertiles (Ref=tertile 1)** | | | |
| Total PA - tertile 2 - Women| 5778        | 586         | 1       |
| Total PA - tertile 3 - Women| 5778        | 586         | 1.17    |
| Total PA - tertile 2 - Men  | 4563        | 284         | 1.27    |
| Total PA - tertile 3 - Men  | 4563        | 284         | 1.85    |
| **Education level - SES-UNESCO (Ref=Higher)** | | | |
| Primary - Women             | 7418        | 879         | 0.85    |
| Lower - Women               | 7418        | 879         | 0.94    |
| Intermediate - Women        | 7418        | 879         | 0.9     |
| Primary - Men               | 6065        | 416         | 1.32    |
| Lower - Men                 | 6065        | 416         | 1.16    |
| Intermediate - Man          | 6065        | 416         | 1.23    |
Sex-stratified results for the association between incidence of RKOA and OA-related risk factors

| OA-related risk factors                        | N.obs.knees | N.inc.knees | adj. RR |
|-----------------------------------------------|-------------|-------------|---------|
| ~ Hip OA, yes                                 |             |             |         |
| Hip OA - Women                                | 7373        | 875         | 1.13    |
| Hip OA - Men                                  | 6027        | 413         | 0.83    |
| ~ Bilateral Thumb OA, yes                     |             |             |         |
| Bilateral Thumb OA - Women                    | 6213        | 755         | 1.63    |
| Bilateral Thumb OA - Men                      | 5202        | 389         | 1.21    |
| ~ Bilateral Finger OA, yes                    |             |             |         |
| Bilateral Finger OA - Women                   | 6217        | 754         | 1.44    |
| Bilateral Finger OA - Men                     | 5172        | 388         | 1.29    |
| ~ Disability index, yes                       |             |             |         |
| Disability index - Women                      | 6799        | 828         | 1.15    |
| Disability index - Men                        | 5591        | 397         | 0.97    |
| ~ Lower-limb disability, yes                  |             |             |         |
| Lower-limb disability - Women                 | 6799        | 828         | 1.15    |
| Lower-limb disability - Men                   | 5591        | 397         | 0.96    |
| ~ Upper-limb disability, yes                  |             |             |         |
| Upper-limb disability - Women                 | 6799        | 828         | 1.5     |
| Upper-limb disability - Men                   | 5591        | 397         | 0.73    |
| ~ KL score 1 at baseline, yes                 |             |             |         |
| KL1 - Women                                   | 7455        | 884         | 3.89    |
| KL1 - Men                                     | 6093        | 419         | 5.48    |