Relative impact of radiographic osteoarthritis and pain on quadriceps strength, proprioception, static postural sway and lower limb function

Michelle C Hall, University of Nottingham, UK
Simon P Mockett, University of Nottingham, UK
Michael Doherty, Nottingham City Hospital, UK

Correspondence to
Michelle Hall
Division of Physiotherapy Education
University of Nottingham
Clinical Sciences Building
Hucknall Rd
Nottingham NG5 1PB
UK

E-mail: michelle.hall@nottingham.ac.uk
ABSTRACT

Aims: To investigate the relative impact of radiographic OA (ROA) and current knee pain on lower limb physical function, quadriceps strength, knee joint proprioception and postural sway.

Methods: Using a 2x2 factorial design, 142 community-derived subjects aged over 45 were divided into four sub-groups based on the presence or absence of (1) ROA (Kellgren & Lawrence >Grade 2) and (2) knee pain (as assessed by NHANES questions and a 100mm VAS score). Maximal isometric contraction of the quadriceps, knee joint proprioceptive acuity, static postural sway and WOMAC index (both Whole and Function Subscale) were assessed in all subjects.

Results: Compared to normal subjects, reported disability was greater for all other sub-groups (p<0.01). Subjects with both ROA and knee pain reported the greatest disability, and those with knee pain only had greater disability than those with ROA only. Quadriceps weakness was observed in all groups compared to normal subjects (p<0.01) though they were not significantly different from each other. Subjects with knee pain had a greater sway area than those without (p<0.05) but the presence of ROA was not associated with increased postural sway. No differences in proprioception acuity were observed between groups.

Conclusions: The presence of knee pain has a negative association with quadriceps strength, postural sway and disability compared to ROA. However the presence of pain-free ROA has a significant negative influence on relative quadriceps strength and reported disability.

Keywords: knee pain; osteoarthritis; quadriceps strength; proprioception; postural sway.
INTRODUCTION
The risk of disability associated with knee osteoarthritis (OA) in those aged over 65 is reportedly greater than any other medical condition affecting the elderly.[1] Over 30% of people over 65 years of age have radiographic knee OA (ROA) and 25% of people experience knee pain.[2] However only a modest correlation exists between them.[2] Although the presence of ROA is associated with impaired physical function, the association with knee pain is significantly stronger.[3][4][5] The odds of disability are doubled in those with knee pain compared to those with ROA alone and the additional presence of ROA in those with knee pain does not increase this risk.[3]

Quadriceps strength is strongly associated with lower limb function in the elderly, and the established decline in strength of normal aged individuals is compounded by the presence of OA.[4][6][7] Quadriceps weakness has been demonstrated in subjects with ROA and or knee pain but is greater in those with both.[8] Pain, intracapsular swelling and structural remodelling have been cited as contributing factors.[8][9]

Knee joint proprioception is important in the activation of reflex responses which protect and stabilise the knee.[10] Proprioceptive acuity diminishes with increasing age,[9][11] and is further reduced in those with symptomatic knee OA.[12][13] Moderate but significant correlations have been reported between impaired knee proprioception and decreased function,[9][11] but other studies have failed to find a relationship.[14]

Control of balance requires integration of the visual, vestibular, somatosensory and neuro-muscular systems.[15] Postural sway, the periodic translation of the body’s centre of pressure (COP) used to maintain upright balance, has been shown to increase with age.[7][9][16] Further increases in postural sway have been observed in subjects with knee OA.[12][17][18] and a relationship with quadriceps weakness and increased disability shown.[12] Inconsistent associations with pain and radiographic severity have been reported.[12][18][19][20]

Whilst the association of ROA and knee pain with disability have been reported, the individual contributions of pain and ROA on quadriceps strength, proprioception, postural sway and function have yet to be examined rigorously in a single population. We therefore undertook the following study to determine the relative impact of ROA and knee pain on quadriceps strength, proprioception, postural sway and function by measuring these functions in individuals with ROA and knee pain using a factorial design.

METHODS

Subjects
A 2x2 factorial design was used with subjects derived from a postal survey concerned with knee pain. This survey which has been described elsewhere,[21] was conducted on 4057 men and women aged 47-70 registered at several large general practices in Nottingham. Postal invites were sent to 409 subjects who yielded a 44% response rate. These subjects were screened and allocated to one of four sub-groups based on the presence or absence of knee pain and...
radiographic knee OA. Subjects were excluded if they had rheumatoid arthritis, any lower limb joint replacements, lower limb amputations, severe cardiac conditions or any neurological, visual or vestibular condition that overtly impaired their balance. Gender, body mass index, medication use and co-morbidity were documented but did not form part of the eligibility criteria.

The study was approved by the local ethics committee (EC00/06) and signed consent was obtained from all participants.

**Radiographic status**

Standardised antero-posterior extended weight-bearing radiographs and skyline views (30° knee flexion) of both knees (obtained within the previous 5 years), were graded by a single reader using the Kellgren and Lawrence system and an atlas of standardised radiographs.[22] ROA was defined as the presence of definite osteophytes and definite joint space narrowing (greater than Kellgren and Lawrence grade 2). Knees were considered normal if osteophytes and joint space narrowing were absent or if only possible osteophytes were observed (i.e. less than Kellgren and Lawrence grade 2). Subjects with Kellgren and Lawrence grade 2 were excluded from the analysis.

**Pain status**

Knee pain was determined using two questions from the National Health and Nutrition Examinations Survey,[23] which ask “Have you ever had pain in or around your knees on most days for at least a month? If so “Have you experienced any knee pain during the last year?” Only subjects answering “yes” to both parts were considered pain positive. They then scored their current knee pain on a 100mm visual analogue (VAS) scale where 0 = no pain and 100 = worse pain ever. Scores less than 20 and greater than 80mm on the VAS were excluded from the analysis.

**Physical function**

Measures of physical function were assessed by one investigator, who was blinded to the x-ray and pain status of the subjects. All tests were carried out on a single limb. The most affected knee by radiographic assessment or most symptomatic (in the case of painful knees) was assigned by an independent observer. Where these differed the most symptomatic knee was assessed and for those with normal knees a random limb was chosen. The order in which the tests were performed was block randomised.

**Isometric Quadriceps strength**

Maximal voluntary contraction (MVC) was measured using a standard protocol.[12] Subjects sat in a modified Tornvall chair with hips and knees flexed to 90° and pelvis secured. A non-extendable strap attached around the test ankle was connected to a load cell (TKA-100A), horizontal and perpendicular to the ankle. This was connected to an amplifier and digital display unit that showed the force generated (in Newtons) during isometric knee extension. Subjects were asked to push as hard as possible against the ankle strap until a peak value was obtained on the digital display unit. A 30 second rest period was allowed between each attempt and the mean of three MVC’s was calculated for each subject.

**Proprioceptive acuity**
Proprioceptive acuity was measured using an active repositioning test in a modified Tornvall chair previously described.[12] From a resting knee joint position of 90° flexion, the subject’s knee was passively moved to a random angle (the criterion angle) between 20 - 50° knee flexion out of vision of the patient. The knee was held at the criterion angle for 5 seconds before returning to its resting position. The subject was asked to actively reposition their knee at the criterion angle. The accuracy to which this was achieved was recorded for three different criterion angles and the mean value calculated.

**Postural sway**

Postural sway was measured using the Balance Performance Monitor (BPM) previously described by our group.[12] Subjects were asked to stand as still as possible on two footplates, for a period of 30 seconds for 3 tests under two conditions, eyes open and eyes closed. A 30 second rest period was allowed between each attempt. Postural sway was recorded at a rate of 10 Hz and the BPM produced a range of variables related to the movement of the subject’s centre of pressure. These included (i) sway path (the distance travelled by the subjects COP in mm) (ii) sway area (the area of an ellipse encompassing the sway path in mm²), and (iii) lateral sway co-efficient (an arbitrary value which denotes the standard deviation of weight shift around the subject’s mean weight distribution). The means for each sway variable was calculated for each condition.

**Self-reported function**

Function was assessed using the self-administered Western Ontario and MacMaster Universities Osteoarthritis Index (WOMAC). [24] All sections of the index were completed.

**Statistical analysis**

Power calculations were based on a previous study of knee joint proprioception.[12] Power was set at 0.8 and the level of statistical significance at p< 0.05. Statistical analysis was carried out using SPSS v11. All tests were two-tailed. Differences between the four sub-groups were analysed using the ANOVA and post-hoc Scheffe tests for normally distributed data and the Kruskal-Wallis and Mann Whitney-U tests for non-normally distributed data. Ordinal data produced by the WOMAC index was subjected to both parametric and non-parametric analysis as recommended.[25]

**RESULTS**

A total of 181 subjects between the ages of 50 and 82 were recruited to the study. Thirty nine subjects were excluded, 12 because of co-existing conditions, 15 due to incomplete data, 4 were omitted from the analysis as their current knee pain scores fell below 20 mm on the VAS and a further 8 as their x-ray scores equalled Kellgren and Lawrence grade 2. A total of 142 subjects were included in the final analysis.

Table 1 shows the anthropometric data for each sub-group. There were more women than men in each sub-group but was significant only for the normal sub-group (p<0.01). No differences existed between sub-groups for age or height. Subjects with both pain and ROA were significantly heavier and had a
greater BMI than normal subjects (p<0.01). Subjects with pain without ROA also had a greater BMI compared to normal subjects (p=0.05).

Table 2 presents the results for the physical function tests and self-reported WOMAC scores.

**Quadriceps strength**

Quadriceps strength was measured in Newtons and expressed as a ratio relative to body weight (N/kg). Reduced strength was observed in all sub-groups compared to normal subjects (p < 0.01), but were not significantly different from each other (Figure 1).

**Proprioceptive acuity**

A wide range of proprioceptive acuity scores was observed (0.67-17.33) but no differences were found between groups. A trend was observed where subjects with knee pain (regardless of the presence of ROA) had poorer proprioceptive acuity (mean 6.14; SD 3.55) than subjects without knee pain (mean 5.09; SD 2.95) but did not reach statistical significance (t=1.92, p=.057).

**Postural sway**

Increased sway area was demonstrated in subjects with painful ROA (p=0.02) and subjects with pain without ROA (p<0.01) compared with normal subjects (figure 2). Subjects with ROA without pain did not differ from normal subjects.

When subjects were analysed in respect of pain only (regardless of ROA), subjects with pain were found to have increased postural sway for a number of variables; sway area with eyes open (z=-3.09, p<0.01) sway path with eyes open (z=-2.02, p<0.05) and lateral sway co-efficient with eyes open (z= -2.06, p<0.05). No differences were found between subjects with and without ROA (regardless of knee pain). Adjusting for quadriceps strength and age did not affect the results.

**WOMAC scores**

Normal subjects reported less disability (entire index score and function sub-scale) compared to other subgroups (p<0.01) and each sub-group was significantly different from each other (p<0.01) (figure 3). Significant differences in scores for reported knee joint stiffness were also observed between normal subjects and all other sub-groups (p<0.001) (figure 4).

**DISCUSSION**

**Summary of findings**

Subjects with knee pain had weaker quadriceps strength, greater postural sway and greater self-reported disability than subjects with ROA. Subjects with ROA had weaker quadriceps strength and greater disability than normal subjects but postural sway was not found to differ. Proprioceptive acuity was not found to differ between any groups.

**Evaluation of methodology and population studied**

The radiographic definition of knee OA used for this study was set to include the presence of definite osteophytes and definite joint space narrowing. Intra-observer reliability for scoring radiographs was high (Kappa>0.7). Radiographs for the study were obtained between 1997 and 2001. Consequently, 5 years may have elapsed between radiographs being obtained and participation in the study. Incidence of new knee ROA in the over 60’s has been estimated at less than
2%.[26] and therefore 2 subjects with previously pain-free normal knees may have developed new ROA.

Knee pain was determined by questions taken from the NHANES study.[23] It has been previously noted that the wording of the questions does not require the presence of current knee pain,[21] and therefore subjects were also required to score their current knee pain on a 100 mm VAS. Scores below 20mm and greater than 80mm were excluded to minimise the influence of pain severity. When analysed, the results were not affected by pain severity.

Reproducibility for measures of quadriceps strength, proprioceptive acuity and postural sway have been previously reported by our group as good.[12]

This was a community-derived sample. The age of the population was normally distributed with no difference between the four sub-groups. Subjects with knee pain and ROA, and knee pain without ROA had a significantly greater BMI than normal subjects. Increased weight and obesity are both recognised risk factors for the development of knee OA and knee pain,[27][28][29] though the mean BMI for each sub-group did not fall within the obese range.[30]

The findings of the study

This study confirms previous findings that those with both ROA and knee pain experience greater disability than those with either ROA or pain alone and that the presence of pain has a stronger association than radiological change.[3][4][31] However the disability experienced by subjects with ROA without pain was also significantly greater than those with normal knees (p=0.01).

Reduced quadriceps strength has been widely demonstrated in the presence of ROA and knee pain.[7][9][12] This study confirms that those with pain or ROA or both are significantly weaker compared to normal subjects (p<0.01). However they were not significantly different from each other. It is known that measurement of MVC does not account for variation in muscle activation due to pain, joint effusion, arthrogenic muscle inhibition or motivational factors which reportedly reduce activation and in turn force generated by as much as 60%.[32] It has also been suggested that deterioration in quadriceps strength may reach a critical threshold below which function is compromised.[4] Subjects participating in this study were living independently in the community and it is therefore unlikely that their quadriceps strength would have decreased beyond a level where functional daily activities became impossible.

Diminished proprioceptive acuity has been observed in those with painful ROA.[11][12][33] However, our results did not demonstrate any difference between the four sub-groups. This was somewhat surprising but could be attributed to a number of factors. Knee joint swelling is a possible confounding variable. The effects of acute joint swelling on joint proprioception have been inconclusive and no acute effusions were noted among the participant in the study. However it has been proposed that chronic effusion may influence proprioception by either the inflammatory constituents of the fluid or the effects on capsular compliance.[34] It is possible that some subjects may have had chronic intra-capsular swelling. Knee joint swelling has also been shown to have an inhibitory effect on the motor-neuron activity in the quadriceps which may have affected the active repositioning of the limb.[35] It has also been suggested
that diminished proprioception may precede structural changes,[13][36] which could potentially counter-act the group effects of subjects without ROA. As with quadriceps strength it is also possible that the decline in proprioceptive acuity reaches a threshold that preserves function and beyond which the decline does not progress. It was noted that the mean values for proprioceptive acuity for each group in this study are greater than those reported in other studies which have used the same method for testing joint position sense,[20][31] but are less than those used to determine the power of the study.[12]

Subjects with knee OA have shown greater postural sway denoting poorer balance compared with controls.[12][18][31] In this study, subjects with knee pain (both with and without ROA) had a significantly greater sway area (eyes open) compared to normal subjects. When all subjects with knee pain were compared to pain-free subjects they were found to have greater sway for a number of variables. No differences were found between subjects with and without ROA which may suggest that the presence of knee OA has little bearing on postural sway or that individuals are better able to compensate for aberrations in sway due to ROA than pain. A correlation between pain intensity and postural sway has been reported but was not observed in this study.[18][19] All groups demonstrated greater postural sway with their eyes shut but performance with eyes open was more discriminatory between groups but there was no particular variable(s) that consistently demonstrated differences between groups.

**Implications of findings**

Although each sub-group displayed differences from each other in terms of function, there was wide variability within the 4 groups, confirming the heterogeneity of knee OA and knee pain. Those with knee pain showed increased postural sway, reduced quadriceps strength, proprioceptive acuity, and physical function compared to those with ROA. However those with ROA were also weaker and reported poorer function than normal subjects. This however does not infer causality and there are other factors which may contribute to the results.

Statistically it has shown that people with ROA without knee pain are different from people with normal pain-free knees. They have a significantly greater BMI, weaker quadriceps strength and report greater stiffness and disability than normal subjects. Is it not yet clear whether this difference in reported disability is clinically important? A recent report estimated a WOMAC function subscale score of 31/100 as being a baseline value of function that patients consider acceptable.[36] If this were applied to our study population then the disability reported by this group would not be clinically significant. However this group are relatively unstudied as a population and this study has highlighted that they warrant further prospective investigation to determine the factors associated with the development of knee pain and increased disability.

**Future Work**

The association of structural change and knee pain with joint stiffness provided an interesting adjunct to this study. Differences in reported knee stiffness as determined by the WOMAC index were found between those with normal knees and all other groups. Those with knee pain reported greater joint stiffness than
those with ROA but both were statistically significant though it is uncertain whether this difference is clinically relevant. It is beyond the scope of this paper to speculate on the possible mechanisms but it would appear that anatomical remodelling is not the only factor involved. Knee stiffness as a clinical symptom, has been relatively ignored but it has been shown to double the odds for locomotor disability compared to structural changes,[3] and the preliminary findings in this study warrant further exploration.

**Acknowledgments:** The authors would like to thank Margaret Ball, Eleanor Berrill, Sally Doherty, Joanna Ramowski and Margaret Wheeler from the Division of Academic Rheumatology and the Division of Physiotherapy Education for their assistance with this project.

The Corresponding Author has the right to grant on behalf of all authors and does grant on behalf of all authors, an exclusive licence (or non exclusive for government employees) on a worldwide basis to the BMJ Publishing Group Ltd and its Licensees to permit this article (if accepted) to be published in the Annals of the Rheumatic Diseases editions and any other BMJPGL products to exploit all subsidiary rights, as set out in our licence (http://ard.bmjjournals.com/misc/ifora/licenceform.shtml).
REFERENCES


Table 1. Anthropometric data of each sub-group

<table>
<thead>
<tr>
<th></th>
<th>[ROA-, KP-]</th>
<th>[ROA+, KP-]</th>
<th>[ROA-, KP+]</th>
<th>[ROA+, KP+]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>17</td>
<td>7</td>
<td>9</td>
<td>14</td>
</tr>
<tr>
<td>Female</td>
<td>38</td>
<td>16</td>
<td>19</td>
<td>22</td>
</tr>
<tr>
<td>Total</td>
<td>55</td>
<td>23</td>
<td>28</td>
<td>36</td>
</tr>
<tr>
<td>Data</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>Age</td>
<td>67.49 (8.45)</td>
<td>69.22 (5.78)</td>
<td>67.36 (6.46)</td>
<td>68.78 (7.80)</td>
</tr>
<tr>
<td>Height</td>
<td>1.65 (0.09)</td>
<td>1.64 (0.11)</td>
<td>1.67 (0.09)</td>
<td>1.65 (0.09)</td>
</tr>
<tr>
<td>Weight</td>
<td>70.42 (12.79)</td>
<td>76.78 (15.66)</td>
<td>74.66 (13.82)</td>
<td>80.44 (12.16)</td>
</tr>
<tr>
<td>BMI</td>
<td>25.89 (3.97)</td>
<td>28.45 (4.69)</td>
<td>26.70 (3.93)</td>
<td>29.72 (4.40)</td>
</tr>
</tbody>
</table>

**Key:**
- KP+ : Knee Pain Positive
- KP- : Knee Pain Negative
- ROA+ : Radiographic OA Positive
- ROA- : Radiographic OA Negative
Table 2. Descriptive data for measures of physical function and self-reported function

<table>
<thead>
<tr>
<th>Data</th>
<th>Unit</th>
<th>[ROA-, KP-]</th>
<th>[ROA+, KP-]</th>
<th>[ROA-, KP+]</th>
<th>[ROA+, KP+]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>Quadriceps strength</td>
<td>N</td>
<td>26.58 (9.62)</td>
<td>22.19 (7.03)</td>
<td>20.67 (8.74)</td>
<td>19.47 (7.57)</td>
</tr>
<tr>
<td>Quadriceps strength: weight</td>
<td>N/Kg</td>
<td>0.38 (0.10)</td>
<td>0.29 (0.08)</td>
<td>0.28 (0.11)</td>
<td>0.24 (0.08)</td>
</tr>
<tr>
<td>Proprioceptive acuity</td>
<td>degrees</td>
<td>5.10 (3.02)</td>
<td>5.06 (2.84)</td>
<td>6.52 (4.00)</td>
<td>5.84 (3.20)</td>
</tr>
<tr>
<td>Sway area (eyes open)</td>
<td>mm²</td>
<td>305.21 (279.64)</td>
<td>332.12 (278.96)</td>
<td>553.73 (592.18)</td>
<td>632.44 (1043.18)</td>
</tr>
<tr>
<td>Sway path (eyes open)</td>
<td>mm</td>
<td>347.05 (113.46)</td>
<td>357.58 (135.55)</td>
<td>366.06 (103.89)</td>
<td>402.28 (149.21)</td>
</tr>
<tr>
<td>Lat sway co-eff (eyes open)</td>
<td></td>
<td>2.62 (1.42)</td>
<td>2.65 (1.88)</td>
<td>3.27 (2.05)</td>
<td>3.36 (2.05)</td>
</tr>
<tr>
<td>WOMAC Scores</td>
<td></td>
<td>Median (IQ range)</td>
<td>Median (IQ range)</td>
<td>Median (IQ range)</td>
<td>Median (IQ range)</td>
</tr>
<tr>
<td>Overall (0-96)</td>
<td></td>
<td>4 (4-7.3)</td>
<td>12 (4-18)</td>
<td>29.5 (21-41.75)</td>
<td>40 (34-54)</td>
</tr>
<tr>
<td>Subscales: Pain (0-20)</td>
<td></td>
<td>0 (0-1)</td>
<td>1 (0-2)</td>
<td>6 (4-8.75)</td>
<td>8 (5-10.75)</td>
</tr>
<tr>
<td></td>
<td>Stiffness (0-8)</td>
<td>0 (0)</td>
<td>1 (0-2)</td>
<td>4 (2-4)</td>
<td>4 (3-4)</td>
</tr>
<tr>
<td></td>
<td>Function (0-68)</td>
<td>4 (4-6)</td>
<td>8 (4-16)</td>
<td>18 (13-29.25)</td>
<td>30 (24-30)</td>
</tr>
</tbody>
</table>
FIGURE LEGENDS

Figure 1 Box plot of Quadriceps Strength relative to Weight (N/kg) for each sub-group.

Figure 2 Box plots showing Sway area (eyes open) for each sub-group.

Figure 3 Box plots showing Overall WOMAC Scores for each sub-group.

Figure 4 Box plots showing WOMAC Stiffness Scores for each sub-group.
Relative impact of radiographic osteoarthritis and pain on quadriceps strength, proprioception, static postural sway and lower limb function

Michelle C Hall, Simon P Mockett and M Doherty

Ann Rheum Dis published online November 24, 2005

Updated information and services can be found at:
http://ard.bmj.com/content/early/2005/11/24/ard.2005.043653.citation

These include:

Email alerting service
Receive free email alerts when new articles cite this article. Sign up in the box at the top right corner of the online article.

Topic Collections
Articles on similar topics can be found in the following collections
Pain (neurology) (883)
Degenerative joint disease (4641)
Musculoskeletal syndromes (4951)
Osteoarthritis (931)

Notes

To request permissions go to:
http://group.bmj.com/group/rights-licensing/permissions

To order reprints go to:
http://journals.bmj.com/cgi/reprintform

To subscribe to BMJ go to:
http://group.bmj.com/subscribe/