The trajectory of recovery and the inter-relationships of symptoms, activity and participation in the first year following total hip and knee replacement

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Running title: Recovery following joint replacement
Abstract (249 words)

Objective: Primary hip (THR) and knee (TKR) replacement outcomes typically include pain and function with a single time of follow-up post-surgery. This research evaluated the trajectory of recovery and inter-relationships within and across time of physical impairments (PI) (e.g. symptoms), activity limitations (AL), and social participation restrictions (PR) in the year following THR and TKR for osteoarthritis.

Design: Participants (hip: n=437; knee: 494) completed measures pre-surgery and at 2 weeks, 1, 3, 6 and 12 months post-surgery. These included PI (HOOS/KOOS symptoms and Chronic Pain Grade); AL (HOOS/KOOS activities of daily living and sports/leisure activities); and, PR (Late Life Disability and the Calderdale community mobility). RANOVA was used to evaluate the trajectory of recovery of outcomes and the inter-relationships of PI, AL and PR were evaluated using path analysis. All analyses were adjusted for age, sex, obesity, THR/TKR, low back pain and mood.

Results: THR: age 31-86 years with 55% female; TKR: age 35-88 years with 65% female. Significant improvements in outcomes were observed over time. However, improvements were lagged over time with earlier improvements in PI and AL and later improvements in PR. Within and across time, PI was associated with AL and AL was associated with PR. The magnitude of these inter-relationships varied over time.

Conclusion: Given the lagged inter-relationship of PI, AL and PR, the provision and timing of interventions targeting all constructs are critical to maximizing outcome. Current care pathways focusing on short-term follow-up with limited attention to social and community participation should be re-evaluated.

Key words: knee replacement, hip replacement, recovery, outcomes, path analysis
Introduction

Total hip (THR) and knee replacement (TKR) are well-established, effective interventions for people with moderate to severe osteoarthritis (OA) resulting in large and significant improvements in pain and functional limitations. Pain and function outcomes usually are reported with separate subscales of a measure or measures representing individual constructs and they are most often reported pre-surgery and at 6 or 12 months post-surgery. The few studies that have looked at recovery over multiple time points have only evaluated a limited range of outcomes or have used a measure that combines constructs such as physical function and social and leisure activities. Additionally, these outcomes have been evaluated separately and studies have not considered concurrently how, for example, current pain affects current physical function, future pain and or future physical function as people recover. Among people with arthritis and other chronic conditions, cross-sectional studies have suggested that current pain affects current function and, in longitudinal studies, prior pain has been shown to impact future function. Hence, we would anticipate that outcomes such as pain and function would be inter-related over the course of recovery following THR and TKR. However, as data regarding the trajectory of recovery are limited, we do not understand the inter-relationships of the pain and function trajectories. Understanding how and when in the trajectory of recovery various outcomes affect each other is critical to identifying targets for treatment and maximizing outcome for people with THR and TKR.

In addition, while the benefits from joint replacement (TJR) typically have been quantified using standardized patient-reported outcomes that evaluate symptoms (mainly pain)
and function in day-to-day activities, recent studies indicate that people with arthritis also are concerned about their return to higher demand activities and participation in social roles, leisure pursuits and their community interactions (collectively referred to as participation). There is a paucity of literature evaluating participation in people who have undergone TJR, particularly using standardized patient-reported outcome measures. To our knowledge, no research to date has evaluated the trajectory of recovery of participation following THR or TKR or the inter-relationships of the various outcomes over time.

The purpose of this study was to describe, for the first time, the trajectory of recovery of symptoms, daily activities and participation individually and to evaluate how these various outcomes, relevant to people with THR and TKR, influence each other within and over time during the first year following surgery.

**Methods**

**Study design and setting**

This prospective longitudinal study recruited participants between 2005 and 2008 who were between the ages of 18 and 85 years from four tertiary care centers in Toronto, Canada who were undergoing primary THR or TKR surgery for OA and subsequent rehabilitation based on a standardized care pathway (Bone and Joint Health Network at http://www.boneandjointhealthnetwork.ca/?sec_id=243&msid=3). The over arching model for care once the decision for surgery is made is based on same day admission for surgery, four day acute hospital stay with discharge home for 8 visits of home-based therapy over 6 weeks or a
three day acute hospital stay with discharge to inpatient rehabilitation for 7 days. Criteria for inpatient rehabilitation include meeting two of the following: inability to walk one city block or 15 minutes pre-surgery (gait aids are allowed); unstable cardiac disease; or, no social supports. The rehabilitation care maps are based on daily (acute care) or weekly plans that include components of assessment, interventions, outcome targets and ‘red flags or warnings that would require notification of concerns to the surgeon. The care maps are not prescriptive but rather guidelines within which the rehabilitation staff have the flexibility to meet individual patient needs.

Those undergoing revision arthroplasty or hemi arthroplasty were excluded. Exclusion criteria also included joint replacement for trauma or malignancy. Participants required sufficient fluency in English to complete the self-report questionnaires. Informed consent was obtained in accordance with the ethics review boards that approved the study at the participating institutions.

Consenting participants completed pre-surgery questionnaires within two weeks prior to surgery at their pre-admission clinic visit and then at 2 weeks, 1, 3, 6 and 12 months post-surgery by mail. The proportion completing questionnaires for THR and TKR respectively relative to these times was: within three weeks pre-surgery: 87.7, 87.4; post surgery 10 to 21 days: 88.0, 84.8; 4-6 weeks: 88.7, 86.0; 12 to 16 weeks: 91.7, 90.2; 24 to 28 weeks: 81.7, 75.4; and, 50 to 54 weeks: 79.1, 75.2. In addition to the standardized patient reported outcome measures described below, age, sex, obesity based on body mass index (BMI) >30, education, work status (full-time, part-time or not working), THR or TKR, comorbidity (based on a no/yes response to the listing on the American Academy of Orthopedic Surgeons questionnaire)\textsuperscript{15, 16} and presence or absence of low back pain were recorded pre-surgery on the self-report questionnaire.
Measures

Our choice of outcome measures was guided by the World Health Organization framework of International Classification of Functioning, Disability and Health (ICF) \(^\text{17}\). The ICF framework is a biopsychosocial model describing human functioning through the capture of body structure and function, activity and participation in the context of a person’s social and physical environment. These constructs of the ICF are defined as follows \(^\text{17}\). Impairment of body structure or function is a loss or abnormality in body structure or physiological function (including mental functions). Activity limitations are difficulties an individual may have in executing activities. An activity limitation may range from slight to severe deviation in terms of quality or quantity in executing the activity in a manner or to the extent that is expected of people without the health condition. Participation restrictions are problems an individual may experience in involvement in life situations and roles. Personal or environmental contextual factors may facilitate or hinder performance across ICF constructs.

The Physical impairments construct included the Hip Disability (HOOS) \(^\text{18}\) and Knee Injury (KOOS) \(^\text{19}\) and Osteoarthritis Outcome Score pain subscales and the Chronic Pain Grade \(^\text{20,21}\). The HOOS- and KOOS-pain subscales assess the extent of pain during activities such as ‘walking on a flat surface’ and ‘going up and down stairs’. The HOOS-pain and KOOS-pain are 10- and 9-item scales respectively with response options ranging from 0-‘none’ to 4-‘extreme’ and scores are summed. The Chronic Pain Grade measures pain intensity based on the responses
to three questions with scores ranging from 1-‘no pain’ to 10-‘pain as bad as it could be’. The scores are summed.

*Impairment of mood* included fatigue measured by the Profile of Mood States (POMS) subscale 22 and the anxiety and depression subscales of the Hospital Anxiety and Depression Scale (HADS) 23. The POMS is a frequently used measure of mainly mental (as opposed to physical) fatigue and has been used in studies across a range of chronic conditions 22. The HADS has been widely used in community-based and outpatient populations 24. Fatigue was evaluated through 5 items scored 0-‘not at all’ to 4-‘extremely’; scores are summed. The anxiety and depression subscales both consist of 7 items. There are four response options scored 0-3, some of which are reverse scored, ranging from none to maximum experience of the item. The total score is the sum of items scores and ranges from 0-21 where higher scores indicate more anxiety and depression.

*The Activity Limitation* construct was captured by measures commonly used in TJR samples; the HOOS/KOOS Function in daily living subscale (which includes the same items as The Western Ontario and McMaster University Osteoarthritis Index (WOMAC) 2 function subscale) and the HOOS/KOOS Function in sport and recreation subscale 18, 19. The HOOS/KOOS Function in daily living subscale evaluates an individual’s basic mobility and activities of daily living (e.g., walking on flat ground, rising from sitting, climbing stairs, etc.) in 17 questions with response options ranging from 0-‘not at all difficult’ to 4-‘extreme difficulty’. The HOOS/KOOS Function in sport and recreation subscale evaluates more demanding activities (e.g. twisting on a loaded leg, squatting, etc.) in 4 and 5 items respectively with the
same response options. For both subscales, scores are summed and converted to a 0-100 score.

*Participation Restrictions* as a construct were captured by the Late Life Disability Instrument (LLDI)\(^\text{25}\) and a measure evaluating community mobility. For the LLDI, respondents rate: a) the frequency; and, b) the extent to which they feel limited in their ability to personally perform 16 socially defined life tasks expected of an individual (e.g. social, leisure, exercise and household and personal management roles) within a typical social, cultural and physical environment on a 1-‘completely’ to 5-‘not at all’ scale. Additionally, respondents completed a community mobility measure, adapted from the Calderdale Rheumatic Disablement Survey\(^\text{26}\), that assessed the extent to which a respondent’s chronic condition limited their mobility or ability to travel within their community with 4 items scored 1-‘none’ to 5-‘can no longer do’. For both the LLDI and mobility measures item scores are summed.

In addition to reporting the individual measures, we also created summary measures for each of impairments (symptoms), activity limitations, and participation restriction constructs. For ease of comparison, all impairment, activity limitation and participation measures were transformed to a 0-10 scale with higher scores indicating worse health/more difficulty. Summary variables were constructed for each of physical impairments (score range 0-20), impairment of mood (score range 0-30), activity limitations (score range 0-20) and participation restrictions (score range 0-30) by summing the individual measure scores within each ICF construct.

*Analysis*
Descriptive analyses were conducted for all variables using the Statistical Analysis System (SAS) v. 9.2 software. Data were checked to identify outliers and examine the distributional properties using the skewness and kurtosis values. The distribution of all variables approximated normality. Nevertheless, the final model in our path analysis, evaluating the inter-relationships of impairments, activity limitations and participation restrictions within and over time that is described later, was estimated using Maximum Likelihood with a mean adjusted chi-square test statistic to take account of any small deviations from normality.

In addition to reporting the individual outcome measure and construct scores at each time point descriptively, the data for impairments, activity limitations and participation restrictions constructs were graphed over time. In this case, the summary scores were converted to a 0-10 scales and graphed relative to zero-centered pre-surgery construct scores. Multivariate repeated measures analysis of variance was conducted to confirm statistically significant improvements over time for each construct after testing for model assumptions. The model was adjusted for age, sex, THR/TKR, obesity and low back pain and the pre-surgery status for the given construct.

Finally, we used path analysis to evaluate how impairments, activity limitations and participation restrictions influenced each other within and across time, adjusting for age, sex, THR/TKR, obesity and low back pain. A diagram that summarizes the hypothesized relationships among the constructs is shown in Figure 1. Based on clinical knowledge we anticipated that the time of recovery would also vary by construct. We expected earlier
improvements in impairments, followed by activity limitations and participation restrictions improving later post-surgery. If present, this time effect would be reflected in the magnitude of the path coefficients.

It should be noted that we initially conceptualized impairments to include both physical impairments and mood. However, initial descriptive and correlational analyses (correlational data not shown) indicated that physical impairments and mood were likely separate constructs. As mood demonstrated little change over time and based on prior literature that found mood to be related to outcomes such as symptoms and function 29, pre-surgery mood was included as a covariate in our analyses.

Model analyses were conducted using Mplus 5.21 30. As suggested in the literature 31, several indices were examined to determine overall model fit, including Root Mean Square Error of Approximation (RMSEA), Comparative Fit Index (CFI), Tucker-Lewis Index (TLI) and Standardized Root Mean square Residual (SRMR). Good fit was supported by: RMSEA ≤0.05 with a 90% upper confidence limit <0.08 and non-significant p-value; SRMR≤0.08; and, CFI and TLI ≥0.9532-34. Once we established model fit, this model was the baseline model against which the testing of the cross-sectional and longitudinal stability of the relationships between the constructs of physical impairments, activity limitations and participation restrictions was initiated. Accordingly, as described in the supplementary data, we compared nested models using the chi-square difference test.
The direct maximum likelihood (DML) estimation method was used to handle missing data, assuming data were ‘missing at random’. Parameter estimates generated using DML are consistent and efficient. Overall, we had 85% complete data for the outcome measures.

Results

The mean age of the sample (n=931) was 64 years (range 31-88) and 60% were female. Forty-six percent of the sample had more than high school education and 34% were working either part-time or full-time prior to surgery. Fifty-three percent of participants were obese. The most frequent comorbidities were hypertension (44%), low back pain (22%), diabetes (12%) and respiratory disease (9%). Table 1 provides descriptive statistics for the entire sample and for those with THR (n=437) and TKR (n=494) separately.

As anticipated and is typical of people having THR or TKR, the sample had physical impairments, activity limitations and participation restrictions as well as impairment of mood prior to surgery (Table 2).

Multivariate repeated measures analysis of variance demonstrated that there was a statistically significant time effect (p<0.0001) for all outcome constructs. The largest improvements occurred through 3 months post-surgery for all ICF constructs although there were some incremental improvements through twelve months post-surgery as shown in Table 3. The trajectories of recovery for THR and TKR based on standardized scores are shown in Figures 2 and 3. People with THR had rapid improvement in physical impairment in the first 2 weeks post-
surgery; minimal change in mood; more gradual improvement in activity; and, early worsening of participation with subsequent rapid improvement through 3 months post-surgery. In contrast, people with TKR experienced gradual improvement in physical impairments over 3 months post-surgery with ongoing small improvements; little change in mood through the first post-surgical month and then a very small improvement; little change in activity limitations over the first month after which there is more rapid improvement; and, worsening of participation restrictions through the first month with rapid improvement through 3 months and subsequent smaller incremental gains.

The proportion of total change in physical impairments, activity limitations and participation restrictions from 3 to 12 months post-surgery was 6%, 20% and 18% respectively for THR patients. For TKR patients, the proportions were 18%, 28% and 27% respectively for physical impairments, activity limitations and participation restrictions over the same period. Mood demonstrated little change and stabilized quickly post-surgery for THR patients while 11% of the total change occurred between 3 and 12 months post-surgery for those with TKR. Of note, participations restrictions increased through the first month following surgery for both THR and TKR participants and then began to improve. Additionally, those who were younger, male, had a THR, were not obese and who did not have low back pain had statistically significantly better outcomes over time (p<0.02 for all covariates). The exception was for participations restrictions where age and joint replaced were not statistically significant (details not shown).

We next tested the inter-relationships of physical impairments, activity limitations and participation restrictions. The hypothesized model did not display overall good fit. However, after adjusting for covariates (age, sex, THR/TKR, obesity, low back pain and mood) and
subsequently, including longer-term effects of activity limitations at 3 months to 12 months post-surgery and from pre-surgery participation restrictions to each post-operative time, the model displayed good fit (see supplementary material including table S1).

Testing the time-dependency of the inter-relationships of physical impairments, activity limitations and participation restrictions, the analyses showed that the relationships between the constructs persisted over time, although their magnitudes varied. Adjusted for covariates and with equality constraints from previous activity limitations to current participation restrictions and from previous physical impairments to current activity limitations, Figure 4 displays the final model results with standardized coefficients. To summarize, the final model depicted in Figure 4 shows the following patterns:

1) physical impairments improve rapidly and then stabilize over time;
2) activity limitations improve rapidly but more slowly than physical impairments;
3) participation restrictions continue to improve over one year post-surgery although less so in the later months;
4) participation restrictions improve more slowly than physical impairments and activity limitations;
5) in the longer term, prior activity limitations influence future activity limitations;
6) pre-surgery participation restrictions influence future participations restrictions; and,
7) change in a construct influences future status of another construct. The negative coefficients on the diagonals in Figure 4 represent the effect of the change that occurs over time in one construct on the status of another construct such that the larger the improvement in, for example, physical impairments between times 1 and 2, the less activity limitations at time 2, etc.
Therefore, the ICF constructs were inter-related within time and there also were simultaneous direct and indirect effects demonstrated among (and between) different constructs over time. Also, the magnitude of the coefficients demonstrated a lagged time effect for the constructs as anticipated.

**Discussion**

To our knowledge, this is the first work that has evaluated participation restrictions as an outcome, in addition to physical impairment or symptoms and activity limitations, in people with THR and TKR in the first year following surgery. Additionally, the work for the first time simultaneously evaluated the inter-relationship of these constructs within and between post-operative time periods. As we hypothesized, the inter-relationships of the constructs, specifically physical impairment, activity limitations and participation restrictions, are not stable over time. The implications of these findings for outcome measurement are significant when examining change in outcome. That is, the time of measurement needs to be considered, as does the status and change of other relevant outcomes, when interpreting a given construct. Importantly, our work also suggests that the type and timing of rehabilitation interventions that address all relevant constructs are critical for optimizing outcome in people recovering from THR and THR. Wait time pressures over the past number of years have resulted in many institutions (including the recruitment sites in this study) adopting standardized care pathways through the continuum of care (acute care through rehabilitation) to facilitate efficiencies that allow management of increased surgical volumes. These care pathways tend to focus on the short-term, maximizing symptom relief, range of motion, strengthening and basic mobility with the majority of people
discharged from all rehabilitation services between 6 to 12 weeks post joint replacement. Given the later improvements observed in participation restrictions and the incremental ongoing improvements in physical impairments and activity limitations beyond 3 months post-surgery in this work, periodic guidance and or changes to home rehabilitation programs beyond these short-term care pathways should be evaluated in future work to determine if they hasten and further enhance outcome.

The trajectory of recovery we observed is consistent with what is observed clinically and confirmed our a priori hypothesis in that physical impairments improve sooner than activity limitations, although both improve early in the post operative period, whereas participation restrictions increase immediately post-surgery only starting to show improvement at 3 months post-surgery. In this sample, we also noted that mood was associated with very early post-surgery outcomes. We suspect that this reflects the anxiety related to having surgery and this is supported by others who have found that people undergoing general surgery and knee replacement experience anxiety related to their surgery.

While others have used different patient-reported outcomes and or times of follow-up in the first year following surgery compared to our study, the recovery patterns we observed for physical impairments and activity limitations are similar to those reported in the literature. Bachmeier et al. found that change in WOMAC pain, stiffness and function subscales scores was largest at 3 months post-surgery and that THR patients had greater pain relief overall than TKR patients. Their results, while reported at three-month intervals in the first year post-surgery, must be interpreted with caution as the sample attrition over the year of reporting was
approximately 50%. Zimmerman reported outcomes at 2, 6 and 12 months in people having cemented vs. uncemented THR and found little improvement in pain and function after 2 months post-surgery. Kennedy similarly found that most improvement in function occurred between 3 and 4 months post-surgery in people with TKR. Their work included the Lower Extremity Functional Scale, a self-report measure that combines activity limitation and participation restriction items into a single score, as well as the 6-minute walk test.

All of our analyses included adjustments for age, sex, TKR/THR, obesity, low back pain, and mood. Consistent with the literature, we found that outcomes were better for people with THR, and that females and those who were older, had more comorbidities including obesity and low back pain generally had poorer outcomes.

In choosing our outcomes, while we used measures that are commonly reported for THR and TKR patients, we deliberately chose measures that represented activity limitations and participation restrictions as separate entities. The ICF framework itself does not separate activity and participation. However, a number of authors have argued that activity and participation are distinct and should not be combined and still others have demonstrated that activity and participation are two distinct constructs. Although not the intent of this work, our results also confirm this distinction between activity and participation based on the differing patterns of recovery and their inter-relationships.

We recognize that there continues to be much debate about the definition of participation and how the construct should be measured. As such, some may criticize the LLDI as a
measure of participation restrictions and suggest that the personal and social roles as operationalized by the measure more closely represent activity limitations, albeit of higher demand than those of the HOOS and KOOS. However, when this study began, the LLDI was deemed the best available measure. Additional measures of participation restrictions have since been developed although they are yet to be used in people with joint replacement. Given the identified impact of arthritis on participation and the importance of it as an outcome for joint replacement, we would recommend that participation be included as a separate outcome in future studies of patients undergoing total joint replacement.

The main limitation of this study was that recruitment included patients who had their surgery in academic, tertiary care centers. This may limit the generalizability of the results for those who have their joint replacement in community hospitals. However, comparison of pre-surgery and outcome scores on the WOMAC between patients treated in academic (two of which were recruitment sites for this current work) and community-based hospitals have demonstrated no difference.

In conclusion, this work reported on the trajectory of recovery in the first year following THR and TKR and showed that although the greatest improvement in physical impairments, activity limitations and participation restrictions occurs by 3 months post-surgery, up to 28% of the total improvement occurs between 3 and 12 months post-surgery depending on the outcome construct. Additionally, while physical impairments, activity limitations and participation restrictions are inter-related within and across time, the inter-relationships among constructs are not stable over time. As such, recovery time and the impact of one outcome on another outcome,
need to be considered in interpreting outcome. The results have implications for rehabilitation following hip and knee replacement. Specifically, provision and appropriate timing of rehabilitation interventions that target all of outcomes are critical to maximizing outcomes.

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This work was written solely by the authors.

Contributions

Contributions of the authors are as follows:

Conception and design: Davis, Badley, Streiner, Gignac, Ibrahim, Hogg-Johnson, Perruccio, Beaton, Flannery, Schemitisch, Mahomed

Analysis and interpretation of the data: Ibrahim, Hogg-Johnson, Perruccio, Davis, Badley, Streiner, Gignac, Beaton, Côté, Flannery, Schemitisch, Mahomed

Drafting of the article: Davis, Ibrahim, Perruccio, Hogg-Johnson, Wong

Critical revision of the article for important intellectual content: Davis, Badley, Ibrahim, Hogg-Johnson, Perruccio, Streiner, Beaton, Gignac, Flannery, Schemitisch, Mahomed
Final approval of the article: Davis, Badley, Streiner, Gignac, Ibrahim, Hogg-Johnson, Perruccio, Streiner, Wong, Beaton, Gignac, Flannery, Schemitisch, Mahomed

Provision of study materials or patients: Schemitsch, Mahomed

Statistical expertise: Hogg-Johnson, Ibrahim, Perruccio

Obtaining of funding: Davis

Administrative, technical, or logistic support: Wong, Davis

Collection and assembly of data: Wong, Ibrahim

Dr. Aileen Davis, adavis@uhnresearch.ca, assumes responsibility for the integrity of the work as a whole, from inception to finished article.

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**Competing interests**

None of the authors have any competing interests in relation to this work.
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Figure Captions

Figure 1. Hypothesized model of the inter-relationships within and among physical impairments, activity limitations and participation restrictions within and across time in people with primary hip and knee replacement.

PI=Physical impairments; AL=Activity limitations; and, PR=Participation restrictions

Figure 2. Trajectory of recovery in the year following total hip replacement (n=437) for physical impairments, mood, activity limitations and participation restrictions.

Constructs have been graphed as change relative to a zero-centred pre-surgery score. All constructs are standardized 0-10 scores where 0 represents less of the construct such that negative change represents improvement. Time 0=pre-surgery; times 1, 2, 3, 4, 5 represent 2 weeks and 1, 3, 6 and 12 months post-surgery respectively.

PI=Physical impairments; MI=Mood impairments; AL=Activity limitations; and, PR=Participation restrictions

Figure 3. Trajectory of recovery in the year following total knee replacement (n=494) for physical impairments, mood, activity limitations and participation restrictions.

Constructs have been graphed as change relative to a zero-centred pre-surgery score. All constructs are standardized 0-10 scores where 0 represents less of the construct such that negative change represents improvement.

Time 0=pre-surgery; times 1, 2, 3, 4, 5 represent 2 weeks and 1, 3, 6 and 12 months post-surgery respectively.
**Figure 4. Final model of the inter-relationships of physical impairments, activity limitations and participation restrictions within and across time.**

The model is adjusted for covariates of age, sex, hip versus knee replacement, obesity, low back pain and mood. Values on pathways are completely standardized coefficients. Time 0=pre-surgery; times 1, 2, 3, 4, 5 represent 2 weeks and 1, 3, 6 and 12 months post-surgery respectively.

PI=Physical impairments; MI=Mood impairments; AL=Activity limitations; and, PR=Participation restrictions
Table 1: Description of Participants Pre-surgery with Total Hip (THR) and Total Knee (TKR) Replacement

<table>
<thead>
<tr>
<th></th>
<th>Hip (n=437)</th>
<th>Knee (n=494)</th>
<th>Total sample (n=931)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean age, sd (range)</td>
<td>63, 12 (31-86)</td>
<td>65, 10 (35-88)</td>
<td>64, 11 (31-88)</td>
</tr>
<tr>
<td>Sex: female</td>
<td>240 (55%)</td>
<td>321 (65%)</td>
<td>561 (60%)</td>
</tr>
<tr>
<td>BMI:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25-29.9</td>
<td>148 (34%)</td>
<td>188 (38%)</td>
<td>336 (47%)</td>
</tr>
<tr>
<td>≥30</td>
<td>153 (35%)</td>
<td>222 (45%)</td>
<td>375 (53%)</td>
</tr>
<tr>
<td>Missing</td>
<td>136 (31%)</td>
<td>84 (17%)</td>
<td>220 (24%)</td>
</tr>
<tr>
<td>Education: some university</td>
<td>228 (53%)</td>
<td>199 (40%)</td>
<td>427 (46%)</td>
</tr>
<tr>
<td>Lives alone</td>
<td>91 (20%)</td>
<td>121 (25%)</td>
<td>212 (23%)</td>
</tr>
<tr>
<td>Paid work (FT/PT)*</td>
<td>161 (37%)</td>
<td>155 (31%)</td>
<td>316 (34%)</td>
</tr>
<tr>
<td>Comorbidity:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cardiac</td>
<td>26 (6%)</td>
<td>35 (7%)</td>
<td>61 (6%)</td>
</tr>
<tr>
<td>Hypertension</td>
<td>240 (55%)</td>
<td>173 (35%)</td>
<td>413 (44%)</td>
</tr>
<tr>
<td>Lung disease**</td>
<td>61 (14%)</td>
<td>25 (5%)</td>
<td>86 (9%)</td>
</tr>
<tr>
<td>Diabetes</td>
<td>74 (17%)</td>
<td>35 (7%)</td>
<td>109 (12%)</td>
</tr>
<tr>
<td>Low back pain</td>
<td>114 (26%)</td>
<td>89 (18%)</td>
<td>203 (22%)</td>
</tr>
</tbody>
</table>

*Paid work (FT/PT) includes those working full-time or part-time
** includes chronic obstructive lung disease and asthma
Table 2: Total hip and knee replacement outcome measure descriptives over time

<table>
<thead>
<tr>
<th>Measure</th>
<th>Pre-surgery</th>
<th>2 weeks mean (sd)</th>
<th>1 month mean (sd)</th>
<th>3 months mean (sd)</th>
<th>6 months mean (sd)</th>
<th>12 months mean (sd)</th>
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<td>Total group (n=931)</td>
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<tr>
<td>Physical Impairments (PI) (0-20)</td>
<td>11.3 (3.8)</td>
<td>7.6 (4.1)</td>
<td>5.9 (3.8)</td>
<td>3.9 (3.4)</td>
<td>3.5 (3.5)</td>
<td>2.8 (3.2)</td>
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<tr>
<td>Impairment of Mood (MI) (0-30)</td>
<td>9.6 (5.3)</td>
<td>9.6 (5.4)</td>
<td>7.8 (5.2)</td>
<td>6.0 (4.9)</td>
<td>6.0 (5.1)</td>
<td>5.8 (4.9)</td>
</tr>
<tr>
<td>Activity Limitations (AL) (0-20)</td>
<td>14.2 (2.9)</td>
<td>13.5 (2.6)</td>
<td>11.8 (3.0)</td>
<td>9.1 (3.8)</td>
<td>8.2 (4.2)</td>
<td>7.6 (4.2)</td>
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<tr>
<td>Participation Restrictions (PR) (0-30)</td>
<td>12.9 (5.0)</td>
<td>17.6 (5.5)</td>
<td>13.7 (5.6)</td>
<td>7.8 (5.1)</td>
<td>6.8 (4.9)</td>
<td>6.4 (4.8)</td>
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<td>THR (n=437)</td>
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<td>Physical Impairments (PI)</td>
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<tr>
<td>HOOS pain (0-10)</td>
<td>5.1 (1.8)</td>
<td>2.7 (1.7)</td>
<td>2.0 (1.4)</td>
<td>1.3 (1.3)</td>
<td>1.2 (1.4)</td>
<td>1.1 (1.3)</td>
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<tr>
<td>Chronic Pain Grade (0-10)</td>
<td>6.1 (2.2)</td>
<td>3.0 (2.1)</td>
<td>1.9 (1.7)</td>
<td>1.3 (1.6)</td>
<td>1.2 (1.6)</td>
<td>1.0 (1.5)</td>
</tr>
<tr>
<td>Total PI (0-20)</td>
<td>11.2 (3.6)</td>
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<td>3.9 (2.8)</td>
<td>2.7 (2.7)</td>
<td>2.4 (2.8)</td>
<td>2.1 (2.7)</td>
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<td>Impairment of Mood (MI) (0-20)</td>
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<tr>
<td>POMS fatigue (0-10)</td>
<td>4.1 (2.6)</td>
<td>3.8 (2.3)</td>
<td>2.68 (2.1)</td>
<td>2.2 (2.1)</td>
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<td>2.1 (2.0)</td>
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<td>HADS anxiety (0-10)</td>
<td>3.0 (1.9)</td>
<td>2.2 (1.7)</td>
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<td>1.8 (1.7)</td>
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<tr>
<td>HADS depression (0-10)</td>
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<td>1.5 (1.4)</td>
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<td>Activity Limitations (AL) (0-20)</td>
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<td>WOMAC physical (0-10)</td>
<td>5.3 (1.8)</td>
<td>4.1 (1.8)</td>
<td>2.9 (1.5)</td>
<td>2.0 (1.4)</td>
<td>1.6 (1.5)</td>
<td>1.5 (1.5)</td>
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<tr>
<td>HOOS recreation and leisure (0-10)</td>
<td>8.6 (1.6)</td>
<td>8.6 (1.3)</td>
<td>7.6 (1.8)</td>
<td>5.5 (2.5)</td>
<td>4.7 (2.7)</td>
<td>4.3 (2.7)</td>
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<tr>
<td>Total AL (0-20)</td>
<td>13.9 (3.1)</td>
<td>12.7 (2.7)</td>
<td>10.5 (2.9)</td>
<td>7.5 (3.7)</td>
<td>6.4 (3.9)</td>
<td>5.8 (3.9)</td>
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<tr>
<td>Participation Restrictions (PR)</td>
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<td></td>
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</tr>
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<td>LLDI frequency (0-10)</td>
<td>4.0 (1.5)</td>
<td>5.6 (2.0)</td>
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<td>3.4 (1.6)</td>
<td>3.1 (1.6)</td>
<td>3.0 (1.5)</td>
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<td>LLDI limitation (0-10)</td>
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<td>5.6 (2.3)</td>
<td>4.2 (2.3)</td>
<td>2.01 (2.1)</td>
<td>1.6 (1.9)</td>
<td>1.6 (1.9)</td>
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<td>Calderdale community mobility (0-10)</td>
<td>5.2 (2.4)</td>
<td>6.3 (2.7)</td>
<td>4.2 (2.7)</td>
<td>2.0 (2.1)</td>
<td>1.6 (1.9)</td>
<td>1.5 (1.8)</td>
</tr>
<tr>
<td>Total PR (0-30)</td>
<td>13.1 (5.1)</td>
<td>17.6 (5.3)</td>
<td>13.1 (5.8)</td>
<td>7.2 (5.1)</td>
<td>6.2 (4.8)</td>
<td>5.9 (4.5)</td>
</tr>
</tbody>
</table>
TKR (n=494)

**Physical Impairments (PI)**

| KOOS pain (0-10) | 5.2 (1.2) | 4.2 (1.8) | 3.6 (1.7) | 2.4 (1.7) | 2.1 (1.80) | 1.7 (1.6) |
| Chronic Pain Grade (0-10) | 6.1 (2.4) | 5.1 (2.2) | 4.1 (2.2) | 2.5 (2.1) | 2.3 (2.2) | 1.8 (2.0) |

**Total PI (0-20)**

| 11.3 (3.9) | 9.4 (3.7) | 7.8 (3.6) | 5.0 (3.5) | 4.4 (3.7) | 3.5 (3.4) |

**Impairment of Mood (MI)**

| POMS fatigue (0-10) | 3.9 (2.8) | 4.7 (2.6) | 3.8 (2.5) | 2.77 (2.3) | 2.8 (2.5) | 2.7 (2.4) |
| HADS anxiety (0-10) | 3.1 (1.9) | 2.8 (2.1) | 2.6 (1.9) | 2.1 (1.8) | 2.1 (2.0) | 2.1 (1.9) |
| HADS depression (0-10) | 2.5 (1.7) | 3.1 (2.0) | 2.7 (1.9) | 1.9 (1.7) | 1.8 (1.7) | 1.6 (1.6) |

**Total MI (0-30)**

| 9.5 (5.4) | 10.5 (5.6) | 9.1 (5.4) | 6.7 (5.2) | 6.6 (5.5) | 6.4 (5.2) |

**Activity Limitations (AL)**

| KOOS physical (0-10) | 4.9 (1.8) | 4.6 (1.9) | 3.6 (1.7) | 2.5 (1.6) | 2.3 (1.7) | 2.1 (1.6) |
| KOOS recreation and leisure (0-10) | 9.3 (1.2) | 9.5 (0.9) | 9.1 (1.4) | 7.9 (2.1) | 7.5 (2.4) | 7.0 (2.6) |

**Total AL (0-20)**

| 14.2 (2.7) | 14.1 (2.4) | 12.8 (2.6) | 10.5 (3.3) | 9.9 (3.7) | 9.1 (3.8) |

**Participation Restrictions (PR)**

| LLDI frequency (0-10) | 3.9 (1.5) | 5.3 (2.1) | 4.8 (1.8) | 3.5 (1.6) | 3.2 (1.6) | 3.1 (1.6) |
| LLDI limitation (0-10) | 3.8 (2.1) | 5.3 (2.5) | 4.3 (2.3) | 2.4 (2.2) | 2.0 (2.0) | 1.8 (1.9) |
| Calderdale community mobility (0-10) | 5.0 (2.3) | 6.8 (2.4) | 5.1 (2.6) | 2.7 (2.2) | 2.3 (2.2) | 2.0 (2.2) |

**Total PR (0-30)**

| 12.7 (4.9) | 17.6 (5.6) | 14.2 (5.4) | 8.4 (5.1) | 7.4 (4.9) | 6.8 (4.9) |

POMS=Profile of Mood States  
HADS=Hospital Anxiety and Depression Scale  
HOOS=Hip disability and Osteoarthritis Outcome Scale  
KOOS=Knee injury and Osteoarthritis Outcome Score  
LLDI=Late Life Disability Instrument
Table 3: Change of ICF Constructs over Time

<table>
<thead>
<tr>
<th>ICF Construct</th>
<th>Pre-surgery to 12 months post-surgery</th>
<th>Pre-surgery to 3 months post-surgery</th>
<th>3 months to 12 months post-surgery</th>
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<tr>
<td></td>
<td>Mean change</td>
<td>Mean change</td>
<td>Percentage of total change</td>
</tr>
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<td>THR (n=437)</td>
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<tr>
<td>Physical Impairments (0-20)</td>
<td>9.1</td>
<td>8.5</td>
<td>93</td>
</tr>
<tr>
<td>Impairment of Mood (0-30)</td>
<td>4.5</td>
<td>4.5</td>
<td>100</td>
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<tr>
<td>Activity Limitations (0-20)</td>
<td>8.0</td>
<td>6.4</td>
<td>80</td>
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<td>Participation Restrictions (0-30)</td>
<td>7.2</td>
<td>5.9</td>
<td>82</td>
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<td>TKR (n=494)</td>
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<tr>
<td>Physical Impairments (0-20)</td>
<td>7.8</td>
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<td>Impairment of Mood (0-30)</td>
<td>3.1</td>
<td>2.8</td>
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<td>Activity Limitations (0-20)</td>
<td>5.1</td>
<td>3.7</td>
<td>72</td>
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<tr>
<td>Participation Restrictions (0-30)</td>
<td>5.9</td>
<td>4.4</td>
<td>74</td>
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</tbody>
</table>
Supplementary data: Approach to Path Analysis to Obtain the Final Model

Table S1 shows the model fit for our hypothesized model, the model including covariate adjustment and our final baseline model as described in the text of the manuscript.

Nested models were tested against the baseline model. Five sets of constraints (i.e. equality constraints over time) were sequentially introduced into the model and tested against the baseline model (M3) using chi-square difference testing. Where no statistically significant difference between one model and the next was found, this was interpreted as stability in the respective relationships over time. In these cases, the equality constraints were retained in the model. On the other hand, where a significant difference was detected, this was interpreted as a non-stable, or time-dependent relationship over time. Equality constraints were not retained in this case.

The set of five equality constraints tested were as follows:

Mc1: a model where paths from previous physical impairment to current activity limitation were constrained to be equal across time;

Mc2: a model where paths from previous activity limitation to current participation restriction were constrained to be equal across time;

Mc3: a model where paths from current physical impairment to current activity limitation were constrained to be equal across time.

Mc4: a model where paths from current activity limitation to current participation restrictions were constrained to be equal across time;

Mc5: a model where paths from current physical impairment to current participation restriction were constrained to be equal across time; and,
As shown in table S1, the model comparisons indicated that there was no degradation in model fit with the introduction of across time equality constraints (Mc1 versus baseline: $\Delta \chi^2 = 3.6$, df =4, p-value =.4628; and, Mc2 versus baseline: $\Delta \chi^2 = 5.0$, df =4, p-value =.2873). However, the within time equality constraints were not equal i.e. the inter-relationships of the constructs were not stable over time as shown in table S1 (i.e. Mc3, Mc4 and Mc5 each versus baseline).

With the final model established, the model was re-assessed using Maximum Likelihood with a mean adjusted chi-square test statistic to ensure robustness against any non-normality.
### Table S1. Goodness-of fit for different models based on path analysis

<table>
<thead>
<tr>
<th>Model comparison</th>
<th>Model</th>
<th>$\chi^2$ (df)</th>
<th>CFI</th>
<th>TLI</th>
<th>RMSEA</th>
<th>SRMR</th>
<th>$\Delta \chi^2$ (df)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M1: Hypothesized model</td>
<td>1457 (200)</td>
<td>.895</td>
<td>.863</td>
<td>.086</td>
<td>.129</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>M2: Initial modified model</td>
<td>1160 (196)</td>
<td>.920</td>
<td>.893</td>
<td>.076</td>
<td>.102</td>
<td>M1 vs. M2</td>
<td>297.0 (4) &lt;.0001</td>
</tr>
<tr>
<td></td>
<td>M3: Initial final model (Baseline model)</td>
<td>781.3 (186)</td>
<td>.950</td>
<td>.930</td>
<td>.061</td>
<td>.084</td>
<td>M2 vs. M3</td>
<td>378.7 (10) &lt;.0001</td>
</tr>
<tr>
<td>Adding constraints to Baseline Model</td>
<td>Mc1: Path from previous physical impairment to current activity limitation constrained</td>
<td>784.9 (190)</td>
<td>.950</td>
<td>.932</td>
<td>.060</td>
<td>.084</td>
<td>Mc2 vs. M3</td>
<td>3.6 (4) .4628</td>
</tr>
<tr>
<td></td>
<td>Mc2: Path from previous activity limitation to current participation restriction constrained</td>
<td>786.3 (190)</td>
<td>.950</td>
<td>.932</td>
<td>.061</td>
<td>.084</td>
<td>Mc1 vs. M3</td>
<td>5.0 (4) .2873</td>
</tr>
<tr>
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<td>Mc3: Path from current physical impairment to current activity limitation constrained</td>
<td>796.8 (190)</td>
<td>.949</td>
<td>.931</td>
<td>.061</td>
<td>.084</td>
<td>Mc5 vs. M3</td>
<td>15.6 (5) .0081</td>
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<tr>
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<td>Mc4: Path from current activity limitation to current participation restriction constrained</td>
<td>904.6 (191)</td>
<td>.941</td>
<td>.919</td>
<td>.066</td>
<td>.089</td>
<td>Mc3 vs. M3</td>
<td>123.3 (5) &lt;.0001</td>
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<td></td>
<td>Mc5: Path from current physical impairment to current participation restriction constrained</td>
<td>806.1 (191)</td>
<td>.949</td>
<td>.930</td>
<td>.061</td>
<td>.084</td>
<td>Mc4 vs. M3</td>
<td>24.8 (5) .0002</td>
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<tr>
<td>Description</td>
<td>$\chi^2$</td>
<td>df</td>
<td>CFI</td>
<td>TLI</td>
<td>RMSEA</td>
<td>Final vs. M3</td>
<td>Note</td>
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<tr>
<td>Final Model</td>
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<td>.950</td>
<td>.933</td>
<td>.060</td>
<td>.084</td>
<td>Final vs. M3 8.6 (8) .3772</td>
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<tr>
<td>(MLR)</td>
<td>731.7</td>
<td>194</td>
<td>.949</td>
<td>.932</td>
<td>.057</td>
<td>.084</td>
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</tbody>
</table>

$\chi^2 = \text{chi-square, df = degrees of freedom; CFI = Comparative Fit Index; TLI = Tucker-Lewis Index; RMSEA = Root Mean Square Error of Approximation; SRMR = Standardized Root Mean Square Residual.}$

Note: All models were adjusted for age, sex, knee/hip replacement, obesity, low back pain and mood.
Figure 2