Objective monitoring of functional recovery after total knee and hip arthroplasty using sensor-derived gait measures

Ramon Boekesteijn [Corresp., 1, 2], **José Smolders** [3], **Vincent Busch** [3], **Noël Keijsers** [1], **Alexander Geurts** [2], **Katrijn Smulders** [1]

[1] Department of Research, Sint Maartenskliniek, Nijmegen, The Netherlands

[2] Department of Rehabilitation, Donders Institute for Brain Cognition and Behaviour, Radboud University Medical Center, Nijmegen, The Netherlands

[3] Department of Orthopedic Surgery, Sint Maartenskliniek, Nijmegen, The Netherlands

Corresponding Author: Ramon Boekesteijn
Email address: r.boekesteijn@maartenskliniek.nl

Background: Inertial sensors hold the promise to objectively measure functional recovery after total knee (TKA) and hip arthroplasty (THA), but their value in addition to patient-reported outcome measures (PROMs) has yet to be demonstrated. This study investigated recovery of gait after TKA and THA using inertial sensors, and compared results to recovery of self-reported scores of pain and function. Methods: PROMs and gait parameters were assessed before and at two and fifteen months after TKA (n=24) and THA (n=24). Gait parameters were compared with healthy individuals (n=27) of similar age. Gait data were collected using inertial sensors on the feet, lower back, and trunk. Participants walked for two minutes back and forth over a 6m walkway with 180° turns. PROMs were obtained using the Knee Injury and Osteoarthritis Outcome Scores and Hip Disability and Osteoarthritis Outcome Score. Results: Gait parameters recovered to the level of healthy controls after both TKA and THA. Early improvements were found in gait-related trunk kinematics, while spatiotemporal gait parameters mainly improved between two and fifteen months after TKA and THA. Compared to the large and early improvements found in of PROMs, these gait parameters showed a different trajectory, with a marked discordance between the outcome of both methods at two months post-operatively. Conclusion: Sensor-derived gait parameters were responsive to TKA and THA, showing different recovery trajectories for spatiotemporal gait parameters and gait-related trunk kinematics. Fifteen months after TKA and THA, there were no remaining gait differences with respect to healthy controls. Given the discordance in recovery trajectories between gait parameters and PROMs, sensor-derived gait parameters seem to carry relevant information for evaluation of physical function that is not captured by self-reported scores.

1 **Objective monitoring of functional recovery after total**

2 **knee and hip arthroplasty using sensor-derived gait**

3 **measures**

5 Ramon J. Boekesteijn [1,2], José M.H. Smolders [3], Vincent J.J.F. Busch [3], Noël L.W. Keijsers [1],

6 Alexander C.H. Geurts [2], Katrijn Smulders [1]

8 [1] Department of Research, Sint Maartenskliniek, Nijmegen, The Netherlands.

9 [2] Department of Rehabilitation, Donders Institute for Brain, Cognition and Behaviour, Radboud

10 University Medical Center, Nijmegen, The Netherlands.

11 [3] Department of Orthopedic Surgery, Sint Maartenskliniek, Nijmegen, The Netherlands.

13 Corresponding Author:

14 Ramon J. Boekesteijn [1,2]

15 Hengstdal 3, Nijmegen, 6500 GM, The Netherlands

16 Email address: r.boekesteijn@maartenskliniek.nl

19 **Abstract**

21 Background: Inertial sensors hold the promise to objectively measure functional recovery after
22 total knee (TKA) and hip arthroplasty (THA), but their value in addition to patient-reported
23 outcome measures (PROMs) has yet to be demonstrated. This study investigated recovery of gait
24 after TKA and THA using inertial sensors, and compared results to recovery of self-reported
25 scores of pain and function.

26

27 Methods: PROMs and gait parameters were assessed before and at two and fifteen months
28 after TKA (n=24) and THA (n=24). Gait parameters were compared with healthy individuals
29 (n=27) of similar age. Gait data were collected using inertial sensors on the feet, lower back, and
30 trunk. Participants walked for two minutes back and forth over a 6m walkway with 180° turns.
31 PROMs were obtained using the Knee Injury and Osteoarthritis Outcome Scores and Hip
32 Disability and Osteoarthritis Outcome Score.

33

34 Results: Gait parameters recovered to the level of healthy controls after both TKA and
35 THA. Early improvements were found in gait-related trunk kinematics, while spatiotemporal gait
36 parameters mainly improved between two and fifteen months after TKA and THA. Compared to
37 the large and early improvements found in of PROMs, these gait parameters showed a different
38 trajectory, with a marked discordance between the outcome of both methods at two months post-
39 operatively.

40

41 Conclusion: Sensor-derived gait parameters were responsive to TKA and THA, showing
42 different recovery trajectories for spatiotemporal gait parameters and gait-related trunk
43 kinematics. Fifteen months after TKA and THA, there were no remaining gait differences with
44 respect to healthy controls. Given the discordance in recovery trajectories between gait
45 parameters and PROMs, sensor-derived gait parameters seem to carry relevant information for
46 evaluation of physical function that is not captured by self-reported scores.

Introduction

Walking is essential for many activities of daily living, and a good walking capacity is key for participation in society. Previous reports have identified walking speed as 'sixth vital sign', given its correlation with essential health parameters, including quality of life (1), risk of future hospitalization (2), and mortality (3). In individuals with end-stage osteoarthritis (OA) of the knee and hip, walking capacity is reduced (4), thereby leading to decreased physical functioning and a lower quality of life (5). As final step in the treatment of severe knee and hip OA, total joint arthroplasty can be performed in order to resolve OA-related symptoms (e.g. pain, stiffness, instability) and improve physical functioning.

Although total knee arthroplasty (TKA) and total hip arthroplasty (THA) are very successful and cost-effective procedures (6), a subset of patients is dissatisfied with treatment outcome (7-9). In addition to patients with identified complications, this includes patients who had an uneventful procedure, but did not achieve their expected level of functional recovery (7). Early identification of individuals at-risk of limited functional recovery is crucial in order to enable clinicians to intervene timely, and may help to readjust patient expectations (10). However, it has been challenging to identify these patients. In part, this is due to a lack of outcomes of physical functioning with good psychometric properties (11). Current diagnostics (e.g. radiographs, physical exam, self-reported outcomes) are limited to static or non-weightbearing situations, or are not necessarily reflective of someone's actual performance during daily life activities (12, 13). Moreover, patient-reported outcomes (PROMs) are inherently subjective, largely influenced by pain, and suffer from early ceiling effects (14). Although PROMs often contain subscales related to limitations in activities of daily life, such as KOOS/HOOS-ADL or WOMAC function score, these outcomes seem to be more reliant on a patients' own reflections on their capacity rather than their actual performance (13). Hence, there is a need for objective data that can bridge this gap in clinical assessment.

As an alternative to these subjective scores, performance-based tests have been proposed to objectively capture physical function. For example, evaluation of sit-to-stand transfers, walking short distances, and stair negotiation has been endorsed by the OARSI as core-activities for individuals with knee and hip OA (15). While these tests are well-suited to quickly obtain a global picture of a patient's physical function, they are limited to a single outcome measure, being the time to perform the task or activity, completed distance, or number of repetitions. These tests provide no information about compensations or underlying biomechanics relevant to the performance, and thus may lack important details. Wearable, inertial sensors, are promising tools to instrument performance-based tests in order to obtain more detailed insights into physical functioning. These inertial sensors are easy to use, have been proven to be valid and reliable (16), do not require lengthy procedures or specialized laboratories, and can be used in clinal settings or even remotely in the home environment (17). Not surprisingly, inertial sensors have gained interest

87 over the past few years to objectively monitor changes in physical function after total knee and hip
88 arthroplasty (18, 19). In particular, the focus has been on studying gait recovery (18, 19),
89 potentially due to the fact that gait parameters are predictive of limitations in other activities of
90 daily living (20) and gait improvements are an important goal for patients after TKA and THA
91 (21). In the same settings, turning could also be evaluated (22), which has been suggested to be
92 even more sensitive to sensorimotor impairments than straight ahead gait (23). However, before
93 such technologies can be clinically adopted, it is important that the derived outcome measures
94 fulfill the following requirements: they must 1) be sensitive to pre-operative impairment, 2) be
95 responsive to interventions aimed at improving mobility, and 3) provide clinically relevant
96 information about physical functioning.
97
98 Multiple gait and turning parameters derived from inertial sensors have shown to be sensitive to
99 mobility impairment in end-stage knee and hip OA (22). The next step herein is to evaluate
100 responsiveness of these parameters to unilateral TKA and THA, and to assess whether post-
101 operative function recovers to the level of healthy individuals. While recovery of gait has
102 previously been investigated using inertial sensors at different timepoints after TKA (13, 17, 24-
103 28) and THA (12, 29-31), a comprehensive study is lacking that maps the recovery trajectory –
104 including turning capacity – at multiple timepoints matching routine follow-up after TKA and
105 THA. In addition, there is a lack of clarity whether gait can be assumed to be 'normal' one year
106 after joint replacement (32-34). Finally, little is known about how gait recovery compares to self-
107 reported recovery of physical function (e.g. PROMs). Therefore, the aims of this study were
108 threefold: 1) to investigate gait recovery at two and fifteen months after TKA and THA using
109 inertial sensors, 2) to compare gait 15 months after TKA and THA with data from healthy
110 participants, and 3) to compare recovery trajectories between objective gait parameters and self-
111 reported scores physical functioning.
112

Materials & Methods

114
115 *Participants*
116 Individuals with end-stage OA scheduled for TKA (n=24) or THA (n=24) at the Sint
117 Maartenskliniek participated in this study. A group of healthy controls (HC; n=27) within the same
118 age range of 50 to 75 years old was recruited from the community for reference purposes. Healthy
119 participants had no pain in the lower extremities, nor were they familiar with a clinical diagnosis
120 of knee or hip OA. All participants had to be able to walk for more than two minutes without the
121 use of any assistive device. Exclusion criteria were: 1) joint replacement within a year following
122 surgery (including revisions), or symptomatic OA in another weight-bearing joint than the joint
123 scheduled for surgery, 2) BMI > 40 kg/m^2, and 3) any other musculoskeletal or neurological
124 impairment interfering with gait or balance. Participants who received any other joint replacement
125 to the lower extremities, or had a revision surgery within the period of fifteen months follow-up,
126 were labeled as lost to follow-up. In these cases, data that had been collected until the time of the

127 second surgery was still used for analysis. Written informed consent was obtained from all
128 participants prior to testing. This study was exempt from ethical review by the CMO
129 Arnhem/Nijmegen (2018-4452) as it was not subject to the Medical Research Involving Human
130 Subjects Act (WMO). All study procedures were conducted in accordance with the Declaration of
131 Helsinki.
132
133 *Power calculation*
134 Sample sizes were based on the smallest difference that we aimed to detect in this study, which
135 was the difference in gait parameters between individuals 15 months after arthroplasty and HC.
136 Effect sizes for this comparison were informed by studies from Senden *et al.* (25) and Kluge *et al.*
137 (27). When using a standardized mean difference for stride length of 1.1, a power of 80%, and a
138 significance level of 0.05, 22 participants were required per group. To account for potential drop-
139 outs, 24 individuals were recruited for each study group.
140
141 *Surgical procedure*
142 TKA was performed using the medial parapatellar approach. All individuals scheduled for TKA
143 received the Genesis II posterior stabilized knee prosthesis (Smith & Nephew, Memphis, TN). The
144 patella was resurfaced in 58% of the patients. THA was performed using the posterolateral
145 approach. Specific types of hip implants differed among individuals scheduled for THA and are
146 listed in Supplementary file 1. In total, TKA was performed by seven different surgeons in this
147 study, whereas THA was performed by ten different surgeons. All patients followed an enhanced
148 recovery protocol with mobilization on the day of surgery and hospital discharge within two days.
149 All patients were referred to out-of-hospital physical therapy, which was focused on optimizing
150 functionality, mobility, muscle power, coordination, stability, and walking improvement.
151 Although physical therapy protocols were not standardized, patients usually continued physical
152 therapy for 6-12 months, until their functional goals had been reached.
153
154 *Demographic and clinical assessment*
155 Severity of radiological OA was determined using Kellgren and Lawrence (KL) grades (35) as
156 scored by JS and VB. Baseline anthropometric characteristics (e.g. body mass, height, and BMI)
157 were obtained during the pre-operative screening visit. In addition, PROMs were assessed using
158 the Knee Injury and Osteoarthritis Outcomes Score (KOOS) for TKA (36) and Hip Disability
159 Osteoarthritis Outcome Score (HOOS) (37) for THA patients. More specifically, HOOS and
160 KOOS subscales "Pain" and "Activities of Daily Living (ADL)" were used to represent pain and
161 physical function. PROMs and gait were assessed pre-operatively – on the same day as the pre-
162 operative screening visit – and at two and fifteen months follow-up. Follow-up measurements were
163 initially set to take place at one year, but measurements were delayed with three months due to the
164 COVID-19 pandemic. Timepoints of follow-up were chosen to match routine follow-up after TKA
165 and THA in the Netherlands, and roughly reflect the moments when patients can walk

166 independently without an assistive device (e.g. 2 months) and when full recovery has been
167 achieved (e.g. 1 year). For HC, gait was investigated at only one occasion.

168

169 *Gait protocol*
170 Experimental procedures of the gait assessments were similar to the methods described in
171 Boekesteijn *et al.* (22). Four inertial sensors (*Opal V2, APDM Inc., Portland, OR)* were attached
172 to the dorsum of both feet, the waist (sacrolumbar level), and the sternum. Participants walked
173 back and forth along a six meter trajectory making 180° turns for a total duration of two minutes
174 (Figure 1). Gait tests were performed at comfortable, self-selected speed.

175

176 *Data analysis*
177 Raw inertial data was processed using validated Mobility Lab v2 software (38). Turning steps were
178 separated from straight walking based on the gyroscope data of the lumbar sensor (39). Gait
179 parameters were calculated for each stride during steady-state walking phases, excluding the two
180 steps preceding and following a turn. Parameters were summarized as mean value of all valid
181 strides or turns. Based on non-redundancy and size of the difference between individuals with end-
182 stage knee and hip OA and HC as found previously (22), the following outcomes were extracted
183 (Figure 1): 1) gait speed, 2) stride length, 3) cadence 4), step time asymmetry, 5) stride time
184 variability, 6) peak turning velocity, 7) lumbar sagittal range of motion, 8) lumbar coronal range
185 of motion, and 9) trunk coronal range of motion. Parameters were only evaluated for the TKA or
186 THA group in case they were previously found to be sensitive to mobility impairment in knee or
187 hip OA (22). For this reason, step time asymmetry, lumbar sagittal range of motion, and lumbar
188 coronal range of motion were not evaluated in the TKA group.

189

190 *Statistical analysis*
191 Recovery trajectories of gait parameters and KOOS/ HOOS scores were visualized on group level
192 by the mean and 95% confidence intervals (CI). Linear mixed models with gait parameters and
193 KOOS or HOOS scores as dependent variable, time as two independent dummy variables (e.g. T2
194 and T15), and subject ID as random effect factor were constructed to investigate the effect of time
195 on gait and KOOS/HOOS scores for TKA and THA separately. Addition of random slopes was
196 evaluated, but these were not included in the final model for reasons of parsimony, as this did not
197 contribute to a better model fit. Gait parameters of TKA and THA groups were compared with HC
198 at 15 month follow-up using an independent samples t-test or non-parametric Mann-Whitney U
199 test in case data was not normally distributed. Inferences of statistical significance were based on
200 p<0.05. Since multiple outcome parameters were used for the same construct (e.g. gait) we
201 controlled the family-wise error rate using the Hommel procedure (40), by adjusting the p-values
202 for the number of gait parameters involved in each comparison. To assess discrepancies between
203 gait and self-reported scores of physical function, we compared trajectories between gait speed,
204 which was found to be most sensitive to gait impairment in knee and hip OA (22), and
205 KOOS/HOOS-ADL scores. Meaningful improvements were defined as a change in gait speed

206   >0.10 m/s (41) and a change in KOOS/HOOS ADL score >20 points (42). Data were processed in
207   Python 3.8.3 and statistical analyses were conducted in RStudio 3.6.1 using the lme4 package
208   (version 1.1-26) (43).

209

210

211   **Results**

212

213   *Participant characteristics*
214   The study groups did not differ significantly in age, sex, height, or BMI (Table 1). Compared to
215   HC, body mass was significantly higher in individuals scheduled for TKA and THA. All
216   individuals scheduled for TKA or THA had moderate to severe OA (KL grades 3 or 4). In total we
217   had missing data for eleven participants. Three participants had a complication within the study
218   window. For details regarding missing data and complications, see Supplementary file 2.

219

220   *Recovery of gait after arthroplasty*
221   Two months after surgery, gait speed, stride length, and cadence were not significantly different
222   from baseline, both after TKA and THA (Table 2; Figure 2A-C). Peak turning velocity improved
223   with 19.1 deg/s (95% CI: 6.9, 31.5) in the first two months after THA, but not after TKA (Table
224   2). There were no changes in step time asymmetry within the first two months after THA (Table
225   2), nor were there changes in stride time variability after TKA and THA at this timepoint (Table
226   2). As for kinematics of the trunk, trunk coronal RoM was slightly lower two months after TKA
227   (mean diff: -1.0 deg, 95% CI: -1.6, -0.3) compared to pre-operatively, whereas lumbar sagittal
228   RoM was lower two months after THA (mean diff: -1.9 deg, 95% CI: -3.0, -0.8) (Table 2).

229

230   Between two and fifteen months, large improvements in gait speed, cadence, and stride length
231   were observed after both TKA and THA (Table 2; Figure 2A-C). For gait speed, the gain between
232   two and fifteen months was 0.22 m/s (95% CI: 0.15, 0.29) after TKA and 0.14 m/s (95% CI: 0.06,
233   0.20) after THA. Peak turning velocity did not change significantly (mean diff: 17.4 deg/s, 95%
234   CI: 1.7, 33.0, p_{ajd} = 0.105) between two and fifteen months after TKA. There were no significant
235   improvements in turning velocity between two and fifteen months after THA (Table 2). Step time
236   asymmetry did not change between two and fifteen months after THA. There were no changes in
237   stride time variability, or trunk coronal RoM between two and fifteen months after TKA and THA
238   (Table 2). Individuals after THA showed an increase of 1.4 degrees (95% CI: 0.6, 2.1) in lumbar
239   coronal RoM between two and fifteen months. Finally, none of the gait parameters were
240   significantly different from HC at fifteen months after TKA and THA (Table 3; Figure 2A-I).

241

242   *Changes on PROMs after arthroplasty*
243   Two months after TKA, individuals improved on all KOOS subscales, except for 'Symptoms'
244   (Table 4). For all other subscales, self-reported scores showed large improvements (> 20 points)
245   with some individuals already reaching (sub)maximal scores (≥90 points) within the first two

246   months (Figure 2J & 2K). Further improvements were found for all KOOS subscales from two to
247   fifteen months follow-up (Table 4). As for the HOOS, all subscales improved from baseline to two
248   months after THA, as well as from two to fifteen months follow-up, with the largest magnitude of
249   effects taking place in the first two months (Table 4).
250
251   *Relation between recovery trajectories of gait parameters and PROMs*
252   When comparing recovery trajectories of self-reported scores with gait parameters, substantial
253   differences were observed (Figure 2). Where KOOS and HOOS scores showed large
254   improvements over almost all subscales in the first two months after surgery (Table 4), gait
255   parameters generally improved between 2 and 15 months, with the exception of trunk-related gait
256   parameters. More specifically, discrepancies between HOOS/KOOS-ADL scores and
257   spatiotemporal parameters were present at two months after surgery. For gait speed specifically,
258   there were no significant changes between baseline and two months after TKA and THA, while
259   HOOS/KOOS-ADL improved with 42 points and 21 points, respectively. To illustrate, two months
260   after surgery, 10/23 individuals after TKA reported meaningful improvements in ADL scores,
261   while merely 4/23 showed a meaningful improvement in gait speed. Similarly, after THA, 20/23
262   individuals reported meaningful improvements in ADL scores at 2 months, with 10/23 individuals
263   showing meaningful improvements in gait speed.
264
265   **Discussion**
266
267   This study evaluated the use of inertial sensors to monitor functional recovery after TKA and THA.
268   In concordance with our previous work, that sensor-derived gait parameters show sensitive to knee
269   and hip OA (22), this study showed that these parameters were also responsive to TKA and THA
270   at two and fifteen months after surgery, and recovered to the same level as HC fifteen months after
271   surgery. In addition, discrepancies between recovery trajectories of spatiotemporal gait parameters
272   and HOOS/KOOS scores were observed, particularly at two months post-operatively.
273
274   *Recovery trajectory of gait after TKA and THA*
275   There were limited improvements in spatiotemporal gait parameters two months after TKA and
276   THA, which is in agreement with previous studies (25, 33). However, the observed faster turning
277   in absence of higher gait speed two months after THA is interesting, and may suggest that turning
278   is more sensitive to short-term improvements in physical function after THA than gait speed. In
279   contrast to these basic spatiotemporal parameters, normalization of trunk movement was found
280   already two months after TKA and THA. Pre-operatively, individuals with knee OA may increase
281   lateral trunk lean as a strategy to reduce knee joint loading and/or pain (44-46), which is no longer
282   required two months after TKA. Increased lumbar RoM in the sagittal plane, in its turn, may serve
283   as pre-operative compensation for individuals with hip OA to overcome pain and hip joint stiffness
284   (47, 48). Taken together, these results suggest that while two months is too early for meaningful

285 recovery of spatiotemporal gait parameters, pre-operative compensations of the trunk and pelvis
286 already disappear within the first two months after TKA and THA.

287

288 Large and clinically relevant improvements were observed on spatiotemporal parameters between
289 two and fifteen months after TKA and THA. This is in agreement with literature investigating gait
290 with inertial sensors one year after TKA (13, 24, 27) and THA (12, 31). Recovery of muscle
291 strength (e.g. quadriceps and hip abductors) – which coincides with this period (49, 50) – may
292 underly these improvements in walking capacity. As for trunk kinematics, both individuals after
293 TKA and THA showed an increase in lumbar coronal RoM from two to fifteen months after
294 surgery, which may relate to the restored ability of the hip abductors to control frontal plane pelvic
295 movement (12, 51). Compensations like lateral trunk lean, which limit pelvic RoM, are then longer
296 required (52). When combining these results with those of gait recovery at two months, it can thus
297 be concluded that a wide range of sensor-derived gait metrics is responsive to TKA and THA, with
298 spatiotemporal parameters and trunk kinematics each showing a distinctive recovery trajectory.

299

300 None of the gait parameters were different from HC mean values at fifteen months after TKA and
301 THA. This in contrast with some earlier studies reporting remaining gait differences between HC
302 and individuals one year after TKA (27, 32, 53) or THA (33). Although one year after arthroplasty
303 is generally considered as endpoint of recovery, these differences between studies might be
304 attributed to the longer follow-up time in our study. This seems like a reasonable explanation given
305 that improvements in gait were larger in our study compared to these earlier studies (27, 32, 33).
306 Our findings underscore the success of TKA and THA in improving physical functioning, and
307 indicate that normal spatiotemporal gait parameters and normal trunk kinematics may be achieved
308 15 months after TKA and THA. Whether other aspects of gait, including lower-extremity
309 kinematics and kinetics, also recover to the level of healthy controls remains to be elucidated.
310 Despite our findings of full recovery after TKA and THA, current literature suggest that more
311 advanced parameters, including lower extremity kinematics and kinetics, may still reveal deficits
312 in gait one year after surgery (32, 33, 53).

313

314 *Relationship between PROMs and objective gait measures*
315 Objective gait parameters showed a different recovery trajectory than subjective reports of
316 physical function and pain. Scores on the KOOS and HOOS greatly improved within the first two
317 months, while spatiotemporal gait parameters mainly improved between two and fifteen months
318 after surgery. Similar discrepancies between PROMs, gait, and performance-based tests have
319 previously been recognized in the literature (12, 14, 32, 54-56). For example, inverse recovery
320 trajectories (i.e. early improvements in PROMs compared to worsening of performance-based
321 outcomes) have been observed between KOOS/HOOS ADL scores and performance-based
322 outcomes, including the 6 minute walk test, stair climbing test, and timed up and go test, during
323 the first month of recovery after TKA and THA (14, 54-56). For sensor-derived gait parameters
324 specifically, poor agreement with PROM scores has been found after TKA and THA (12, 24). On

325 a similar note, Fransen *et al.* found that, although perceived walking ability and self-reported
326 physical function improved, there were no improvements in quality or quantity of daily life gait
327 three months after surgery (17). The current study adds that the discordance between gait
328 parameters and self-reported function scores is most prominent at two months after surgery, with
329 the exception of parameters related to trunk motion. The general consensus is that physical
330 function subscales of PROMs assess a different domain than performance-based tests and gait
331 analysis (13). This discrepancy may first be related to a strong relation of physical function
332 subscales with pain (14), as was also apparent from the similarity between the recovery trajectories
333 of HOOS/KOOS Pain and ADL subscales in our study. One potential explanation for this is that
334 improvements in pain directly translate to a more positive reflection on daily life performance, and
335 that patients considered pain as the main limiting factor in their daily life activities. Second, these
336 self-reported scores ask about experienced difficulty during a wide range of activities, rather than
337 how they execute a specific activity, which is inherently different from what these gait parameters
338 measure. Finally, there is evidence that objective parameters of physical function are more
339 sensitive to remaining functional deficits after TKA than PROMs (32), which may attributed to
340 early ceiling effects of PROMs. Since improving mobility – specifically walking – is an important
341 goal of joint replacement (57), these sensor-derived parameters may thus add a relevant dimension
342 to evaluation of physical functioning, although their clinical value still has to be demonstrated.
343
344 *Limitations and future directions*
345 This study has a number of limitations which merit attention. First, we measured gait recovery in
346 a well-defined cohort of patients with unilateral osteoarthritis without pain complaints in any other
347 joint or previous joint replacement. While this was relevant for the aims of the current study, this
348 limits the generalizability of our findings. Second, in the present study, evaluation of physical
349 function was limited to gait and turning in the present study while other daily life activities,
350 including sit-to-stand transfers and stair climbing, are also relevant for physical functioning after
351 TKA and THA (15). Third, gait parameters in this study were limited to spatiotemporal parameters
352 and gait-related trunk kinematics. Other parameters, such as knee and hip kinematics that can be
353 derived from a different set-up of inertial sensors may provide additional information about gait
354 recovery after TKA and THA, especially in light of remaining gait deficits (33). While the current
355 study touches upon the potential value of objective measurement of physical function, the actual
356 value of clinical implementation of gait tests cannot be derived from our study results. Future
357 studies with larger samples and a more diverse population are required to investigate the
358 applicability of objective gait assessment systems to identify poor-responders. Another valuable
359 direction would be to explore whether such data can be used to adjust patient expectations during
360 clinical visits and to further tailor post-operative care. Finally, there is a need for studies employing
361 inertial sensors for remote monitoring during daily life, which may not only enable more efficient
362 (digital) healthcare pathways in the future, but may also contribute to data with greater ecological
363 validity (58, 59).
364

Conclusions

This study showed that objective gait measures derived from inertial sensors are responsive to TKA and THA. Not only speed-related parameters, but also turning and trunk motion provide important information about functional status before and at two and fifteen months after joint replacement. There were no remaining gait differences between individuals after TKA or THA and healthy participants at fifteen months. Recovery trajectories of objective gait data were different from those of KOOS and HOOS ADL subscales, with a marked discordance at two months after surgery. Altogether, these results strengthen the premise that sensor-derived gait metrics may provide meaningful information about recovery of physical functioning after TKA and THA that is not captured by self-reported ADL or pain scores.

References

1. Schmid A, Duncan Pamela W, Studenski S, Lai Sue M, Richards L, Perera S, et al. Improvements in Speed-Based Gait Classifications Are Meaningful. Stroke. 2007;38(7):2096-100.
2. Montero-Odasso M, Schapira M, Soriano ER, Varela M, Kaplan R, Camera LA, et al. Gait Velocity as a Single Predictor of Adverse Events in Healthy Seniors Aged 75 Years and Older. The Journals of Gerontology: Series A. 2005;60(10):1304-9.
3. Hardy SE, Perera S, Roumani YF, Chandler JM, Studenski SA. Improvement in Usual Gait Speed Predicts Better Survival in Older Adults. Journal of the American Geriatrics Society. 2007;55(11):1727-34.
4. Thomas SG, Pagura SMC, Kennedy D. Physical Activity and its Relationship to Physical Performance in Patients With End Stage Knee Osteoarthritis. Journal of Orthopaedic & Sports Physical Therapy. 2003;33(12):745-54.
5. Neogi T. The epidemiology and impact of pain in osteoarthritis. Osteoarthritis and Cartilage. 2013;21(9):1145-53.
6. Ethgen O, Bruyère O, Richy F, Dardennes C, Reginster J-Y. Health-Related Quality of Life in Total Hip and Total Knee Arthroplasty: A Qualitative and Systematic Review of the Literature. JBJS. 2004;86(5).
7. Gunaratne R, Pratt DN, Banda J, Fick DP, Khan RJK, Robertson BW. Patient Dissatisfaction Following Total Knee Arthroplasty: A Systematic Review of the Literature. The Journal of Arthroplasty. 2017;32(12):3854-60.
8. Anakwe RE, Jenkins PJ, Moran M. Predicting Dissatisfaction After Total Hip Arthroplasty: A Study of 850 Patients. The Journal of Arthroplasty. 2011;26(2):209-13.
9. Nilsdotter AK, Toksvig-Larsen S, Roos EM. Knee arthroplasty: are patients' expectations fulfilled? Acta Orthopaedica. 2009;80(1):55-61.
10. Tolk JJ, Janssen RPA, Haanstra TM, van der Steen MC, Bierma-Zeinstra SMA, Reijman M. The influence of expectation modification in knee arthroplasty on satisfaction of patients: a randomized controlled trial. The Bone & Joint Journal. 2021;103-B(4):619-26.
11. Hossain FS, Konan S, Patel S, Rodriguez-Merchan EC, Haddad FS. The assessment of outcome after total knee arthroplasty. The Bone & Joint Journal. 2015;97-B(1):3-9.

409   12.   Bolink SAAN, Lenguerrand E, Brunton LR, Wylde V, Gooberman-Hill R, Heyligers IC, et
410   al. Assessment of physical function following total hip arthroplasty: Inertial sensor based gait
411   analysis is supplementary to patient-reported outcome measures. Clinical Biomechanics.
412   2016;32:171-9.
413   13.   Fransen BL, Mathijssen NMC, Slot K, de Esch NHH, Verburg H, Temmerman OPP, et
414   al. Gait quality assessed by trunk accelerometry after total knee arthroplasty and its association
415   with patient related outcome measures. Clinical Biomechanics. 2019;70:192-6.
416   14.   Stevens-Lapsley JE, Schenkman ML, Dayton MR. Comparison of Self-Reported Knee
417   Injury and Osteoarthritis Outcome Score to Performance Measures in Patients After Total Knee
418   Arthroplasty. PM&R. 2011;3(6):541-9.
419   15.   Dobson F, Hinman RS, Roos EM, Abbott JH, Stratford P, Davis AM, et al. OARSI
420   recommended performance-based tests to assess physical function in people diagnosed with
421   hip or knee osteoarthritis. Osteoarthritis and Cartilage. 2013;21(8):1042-52.
422   16.   Kobsar D, Charlton JM, Tse CTF, Esculier J-F, Graffos A, Krowchuk NM, et al. Validity
423   and reliability of wearable inertial sensors in healthy adult walking: a systematic review and
424   meta-analysis. Journal of NeuroEngineering and Rehabilitation. 2020;17(1):62.
425   17.   Fransen BL, Pijnappels M, Butter IK, Burger BJ, van Dieën JH, Hoozemans MJM.
426   Patients' perceived walking abilities, daily-life gait behavior and gait quality before and 3 months
427   after total knee arthroplasty. Archives of Orthopaedic and Trauma Surgery. 2021.
428   18.   Small SR, Bullock GS, Khalid S, Barker K, Trivella M, Price AJ. Current clinical utilisation
429   of wearable motion sensors for the assessment of outcome following knee arthroplasty: a
430   scoping review. BMJ Open. 2019;9(12):e033832.
431   19.   Kobsar D, Masood Z, Khan H, Khalil N, Kiwan MY, Ridd S, et al. Wearable Inertial
432   Sensors for Gait Analysis in Adults with Osteoarthritis—A Scoping Review. Sensors.
433   2020;20(24).
434   20.   Potter JM, Evans AL, Duncan G. Gait speed and activities of daily living function in
435   geriatric patients. Archives of Physical Medicine and Rehabilitation. 1995;76(11):997-9.
436   21.   Scott CEH, Bugler KE, Clement ND, MacDonald D, Howie CR, Biant LC. Patient
437   expectations of arthroplasty of the hip and knee. The Journal of Bone and Joint Surgery British
438   volume. 2012;94-B(7):974-81.
439   22.   Boekesteijn RJ, Smolders JMH, Busch VJJF, Geurts ACH, Smulders K. Independent
440   and sensitive gait parameters for objective evaluation in knee and hip osteoarthritis using
441   wearable sensors. BMC Musculoskeletal Disorders. 2021;22(1):242.
442   23.   Mancini M, Schlueter H, El-Gohary M, Mattek N, Duncan C, Kaye J, et al. Continuous
443   Monitoring of Turning Mobility and Its Association to Falls and Cognitive Function: A Pilot Study.
444   The Journals of Gerontology: Series A. 2016;71(8):1102-8.
445   24.   Bolink SAAN, Grimm B, Heyligers IC. Patient-reported outcome measures versus inertial
446   performance-based outcome measures: A prospective study in patients undergoing primary
447   total knee arthroplasty. The Knee. 2015;22(6):618-23.
448   25.   Senden R, Grimm B, Meijer K, Savelberg H, Heyligers IC. The importance to including
449   objective functional outcomes in the clinical follow up of total knee arthroplasty patients. The
450   Knee. 2011;18(5):306-11.
451   26.   Jolles BM, Grzesiak A, Eudier A, Dejnabadi H, Voracek C, Pichonnaz C, et al. A
452   randomised controlled clinical trial and gait analysis of fixed- and mobile-bearing total knee
453   replacements with a five-year follow-up. The Journal of Bone and Joint Surgery British volume.
454   2012;94-B(5):648-55.
455   27.   Kluge F, Hannink J, Pasluosta C, Klucken J, Gaßner H, Gelse K, et al. Pre-operative
456   sensor-based gait parameters predict functional outcome after total knee arthroplasty. Gait &
457   Posture. 2018;66:194-200.

458   28.   Youn I-H, Leutzinger T, Youn J-H, Zeni JA, Knarr BA. Self-Reported and Performance-
459   Based Outcome Measures Estimation Using Wearables After Unilateral Total Knee
460   Arthroplasty. Frontiers in Sports and Active Living. 2020;2(128).
461   29.   Reininga IHF, Stevens M, Wagenmakers R, Boerboom AL, Groothoff JW, Bulstra SK, et
462   al. Comparison of gait in patients following a computer-navigated minimally invasive anterior
463   approach and a conventional posterolateral approach for total hip arthroplasty: A randomized
464   controlled trial. Journal of Orthopaedic Research. 2013;31(2):288-94.
465   30.   Nelms NJ, Birch CE, Halsey DH, Blankstein M, McGinnis RS, Beynnon BD. Assessment
466   of Early Gait Recovery After Anterior Approach Compared to Posterior Approach Total Hip
467   Arthroplasty: A Smartphone Accelerometer–Based Study. The Journal of Arthroplasty.
468   2020;35(2):465-70.
469   31.   Wada O, Asai T, Hiyama Y, Nitta S, Mizuno K. Gait Variability in Women With Hip
470   Osteoarthritis Before and After Total Hip Replacement: A Prospective Cohort Study. American
471   Journal of Physical Medicine & Rehabilitation. 2019;98(10).
472   32.   Naili JE, Iversen MD, Esbjörnsson A-C, Hedström M, Schwartz MH, Häger CK, et al.
473   Deficits in functional performance and gait one year after total knee arthroplasty despite
474   improved self-reported function. Knee Surgery, Sports Traumatology, Arthroscopy.
475   2017;25(11):3378-86.
476   33.   Bahl JS, Nelson MJ, Taylor M, Solomon LB, Arnold JB, Thewlis D. Biomechanical
477   changes and recovery of gait function after total hip arthroplasty for osteoarthritis: a systematic
478   review and meta-analysis. Osteoarthritis and Cartilage. 2018;26(7):847-63.
479   34.   Milner CE. Is gait normal after total knee arthroplasty? Systematic review of the
480   literature. Journal of Orthopaedic Science. 2009;14(1):114-20.
481   35.   Kellgren JH, Lawrence JS. Radiological Assessment of Osteo-Arthrosis. Annals of the
482   Rheumatic Diseases. 1957;16(4):494.
483   36.   de Groot IB, Favejee MM, Reijman M, Verhaar JAN, Terwee CB. The Dutch version of
484   the knee injury and osteoarthritis outcome score: A validation study. Health and Quality of Life
485   Outcomes. 2008;6(1):16.
486   37.   de Groot IB, Reijman M, Terwee CB, Bierma-Zeinstra SMA, Favejee M, Roos EM, et al.
487   Validation of the Dutch version of the Hip disability and Osteoarthritis Outcome Score.
488   Osteoarthritis and Cartilage. 2007;15(1):104-9.
489   38.   Morris R, Stuart S, McBarron G, Fino PC, Mancini M, Curtze C. Validity of Mobility Lab
490   (version 2) for gait assessment in young adults, older adults and Parkinson's disease.
491   Physiological Measurement. 2019;40(9):095003.
492   39.   El-Gohary M, Pearson S, McNames J, Mancini M, Horak F, Mellone S, et al. Continuous
493   Monitoring of Turning in Patients with Movement Disability. Sensors. 2014;14(1).
494   40.   Hommel G. A stagewise rejective multiple test procedure based on a modified
495   Bonferroni test. Biometrika. 1988;75(2):383-6.
496   41.   Bohannon RW, Glenney SS. Minimal clinically important difference for change in
497   comfortable gait speed of adults with pathology: a systematic review. Journal of Evaluation in
498   Clinical Practice. 2014;20(4):295-300.
499   42.   Lyman S, Lee Y-Y, McLawhorn AS, Islam W, MacLean CH. What Are the Minimal and
500   Substantial Improvements in the HOOS and KOOS and JR Versions After Total Joint
501   Replacement? Clinical Orthopaedics and Related Research®. 2018;476(12).
502   43.   Bates D, Mächler M, Bolker B, Walker S. Fitting Linear Mixed-Effects Models Using
503   lme4. Journal of Statistical Software; Vol 1, Issue 1 (2015). 2015.
504   44.   Mündermann A, Dyrby CO, Andriacchi TP. Secondary gait changes in patients with
505   medial compartment knee osteoarthritis: Increased load at the ankle, knee, and hip during
506   walking. Arthritis & Rheumatism. 2005;52(9):2835-44.

507   45.   Hunt MA, Birmingham TB, Bryant D, Jones I, Giffin JR, Jenkyn TR, et al. Lateral trunk
508   lean explains variation in dynamic knee joint load in patients with medial compartment knee
509   osteoarthritis. Osteoarthritis and Cartilage. 2008;16(5):591-9.
510   46.   Linley HS, Sled EA, Culham EG, Deluzio KJ. A biomechanical analysis of trunk and
511   pelvis motion during gait in subjects with knee osteoarthritis compared to control subjects.
512   Clinical Biomechanics. 2010;25(10):1003-10.
513   47.   Hurwitz DE, Hulet CH, Andriacchi TP, Rosenberg AG, Galante JO. Gait compensations
514   in patients with osteoarthritis of the hip and their relationship to pain and passive hip motion.
515   Journal of Orthopaedic Research. 1997;15(4):629-35.
516   48.   Lenaerts G, Mulier M, Spaepen A, Van der Perre G, Jonkers I. Aberrant pelvis and hip
517   kinematics impair hip loading before and after total hip replacement. Gait & Posture.
518   2009;30(3):296-302.
519   49.   Mizner RL, Petterson SC, Snyder-Mackler L. Quadriceps Strength and the Time Course
520   of Functional Recovery After Total Knee Arthroplasty. Journal of Orthopaedic & Sports Physical
521   Therapy. 2005;35(7):424-36.
522   50.   Ismailidis P, Kvarda P, Vach W, Cadosch D, Appenzeller-Herzog C, Mündermann A.
523   Abductor Muscle Strength Deficit in Patients After Total Hip Arthroplasty: A Systematic Review
524   and Meta-Analysis. The Journal of Arthroplasty. 2021.
525   51.   Reininga IHF, Stevens M, Wagenmakers R, Bulstra SK, Groothoff JW, Zijlstra W.
526   Subjects with hip osteoarthritis show distinctive patterns of trunk movements during gait-a body-
527   fixed-sensor based analysis. Journal of NeuroEngineering and Rehabilitation. 2012;9(1):3.
528   52.   Bolink SAAN, Brunton LR, van Laarhoven S, Lipperts M, Heyligers IC, Blom AW, et al.
529   Frontal Plane Pelvic Motion during Gait Captures Hip Osteoarthritis Related Disability. HIP
530   International. 2015;25(5):413-9.
531   53.   Outerleys JB, Dunbar MJ, Richardson G, Hubley-Kozey CL, Astephen Wilson JL.
532   Quantifying Achievable Levels of Improvement in Knee Joint Biomechanics During Gait After
533   Total Knee Arthroplasty Relative to Osteoarthritis Severity. Journal of Applied Biomechanics.
534   2021;37(2):130-8.
535   54.   Dayton MR, Judd DL, Hogan CA, Stevens-Lapsley JE. Performance-Based Versus Self-
536   Reported Outcomes Using the Hip Disability and Osteoarthritis Outcome Score After Total Hip
537   Arthroplasty. American journal of physical medicine & rehabilitation. 2016;95(2):132-8.
538   55.   Luna IE, Kehlet H, Peterson B, Wede HR, Hoevsgaard SJ, Aasvang EK. Early patient-
539   reported outcomes versus objective function after total hip and knee arthroplasty. The Bone &
540   Joint Journal. 2017;99-B(9):1167-75.
541   56.   Mizner RL, Petterson SC, Clements KE, Zeni JA, Irrgang JJ, Snyder-Mackler L.
542   Measuring Functional Improvement After Total Knee Arthroplasty Requires Both Performance-
543   Based and Patient-Report Assessments: A Longitudinal Analysis of Outcomes. The Journal of
544   Arthroplasty. 2011;26(5):728-37.
545   57.   Lange T, Schmitt J, Kopkow C, Rataj E, Günther K-P, Lützner J. What Do Patients
546   Expect From Total Knee Arthroplasty? A Delphi Consensus Study on Patient Treatment Goals.
547   The Journal of Arthroplasty. 2017;32(7):2093-9.e1.
548   58.   Van Ancum JM, van Schooten KS, Jonkman NH, Huijben B, van Lummel RC, Meskers
549   CGM, et al. Gait speed assessed by a 4-m walk test is not representative of daily-life gait speed
550   in community-dwelling adults. Maturitas. 2019;121:28-34.
551   59.   Takayanagi N, Sudo M, Yamashiro Y, Lee S, Kobayashi Y, Niki Y, et al. Relationship
552   between Daily and In-laboratory Gait Speed among Healthy Community-dwelling Older Adults.
553   Scientific Reports. 2019;9(1):3496.
554

Baseline characteristics

Note: TKA = total knee arthroplasty, THA = total hip arthroplasty, HC = healthy controls, BMI = body mass index, KL = Kellgren Lawrence. Data are presented as mean [95% CI].

2 **Table 1 :** baseline characteristics

	TKA (n=24)	THA (n=24)	HC (n=27)	Main effect	Post-hoc analysis
Age (y)	63 [61, 66]	64 [62, 67]	66 [63, 68]	$F_{(2,72)} = 0.81$, $p = 0.448$	
Sex (M:F)	12:12	16:8	13:14	χ^2 (2, N=75) = 2.07, $p = 0.355$	
Height (m)	1.73 [1.69, 1.77]	1.75 [1.72, 1.79]	1.72 [1.68, 1.75]	$F_{(2,72)} = 0.98$, $p = 0.381$	
Body mass (kg)	84.6 [78.6, 90.6]	86.0 [78.1, 94.0]	75.7 [71.5, 80.0]	$F_{(2,72)} = 3.66$, $p = 0.031$	TKA vs. HC: $t_{(49)} = 2.527$ $p = 0.015$
					THA vs. HC: $t_{(49)} = 2.428$; $p = 0.019$
BMI (kg/m²)	28.2 [26.6, 29.9]	27.9 [25.6, 30.2]	25.7 [24.5, 26.8]	$F_{(2,72)} = 2.91$, $p = 0.060$	
KL score (I:II:III:IV)	0:0:8:16	0:0:6:18	-		

3 *Note:* TKA = total knee arthroplasty, THA = total hip arthroplasty, HC = healthy controls, BMI = body mass index, KL = Kellgren Lawrence. Data are presented as mean [95%
4 CI].

Effects of time on gait parameters in the TKA and THA group

Note: TKA = total knee arthroplasty, THA = total hip arthroplasty, RoM = range of motion,

P_{corr} = Hommel adjusted p-value. Data are presented as mean (95% CI).

1   **Table 2:** Effects of time on gait parameters in the TKA and THA group.

Gait parameters	TKA (n=24)							THA (n=24)						
		baseline – 2 months			2 months – 15 months				baseline – 2 months			2 months – 15 months		
	Baseline (intercept)	Mean difference (95% CI)	P_{value}	P_{corr}	Mean difference (95% CI)	P_{value}	P_{corr}	Baseline (intercept)	Mean difference (95% CI)	P_{value}	P_{corr}	Mean difference (95% CI)	P_{value}	P_{corr}
Gait speed (m/s)	0.99	-0.04 (-0.10, 0.03)	0.272	0.569	0.22 (0.15, 0.29)	<0.001	<0.001	0.96	0.04 (-0.02, 0.10)	0.245	0.514	0.14 (0.06, 0.20)	<0.001	0.003
Stride Length (m)	1.16	-0.002 (-0.05, 0.05)	0.924	0.924	0.14 (0.09, 0.19)	<0.001	<0.001	1.11	0.05 (0.002, 0.10)	0.049	0.306	0.07 (0.02, 0.13)	0.013	0.076
Cadence (steps/min)	102.8	-3.8 (-6.8, -0.8)	0.016	0.081	10.1 (7.0, 13.2)	<0.001	<0.001	103.0	-1.1 (-3.9, 1.7)	0.453	0.514	6.9 (3.8, 10.1)	<0.001	<0.001
Peak turning velocity (deg/s)	164.0	8.5 (-6.5, 23.7)	0.275	0.759	17.4 (1.7, 33.0)	0.035	0.105	171.2	19.1 (6.9, 31.5)	0.004	0.033	11.1 (-2.5, 24.9)	0.121	0.484
Step time asymmetry (%)	-	-	-	-	-	-	-	4.3	-0.7 (-2.0, 0.6)	0.292	0.514	-1.0 (-2.4, 0.3)	0.155	0.553
Stride time variability (%)	2.3	0.2 (-0.2, 0.6)	0.380	0.569	-0.3 (-0.8, 0.1)	0.117	0.234	2.5	-0.1 (-0.5, 0.3)	0.514	0.514	-0.2 (-0.7, 0.2)	0.277	0.831
Lumbar sagittal RoM (deg)	-	-	-	-	-	-	-	8.1	-1.9 (-3.0, -0.8)	0.001	0.013	0.1 (-1.1, 1.3)	0.870	0.870
Lumbar coronal RoM (deg)	-	-	-	-	-	-	-	5.2	0.4 (-0.3, 1.3)	0.255	0.514	1.4 (0.6, 2.1)	0.001	0.010
Trunk coronal RoM (deg)	7.8	-1.0 (-1.6, -0.3)	0.009	0.049	0.1 (-0.6, 0.9)	0.710	0.710	8.1	-0.6 (-1.3, 0.1)	0.087	0.439	0.1 (-0.6, 0.8)	0.797	0.870

2   *Note:* TKA = total knee arthroplasty, THA = total hip arthroplasty, RoM = range of motion, P_{corr} = Hommel adjusted p-value.

3   Data are presented as mean (95% CI).

Post-operative situation compared to HC

Note: HC = healthy control, TKA = total knee arthroplasty, THA = total hip arthroplasty, RoM = range of motion, P_{corr} = Hommel adjusted p-value. Non-normal distributed data are presented in *italic* and are summarized as median (IQR) with median difference (95% CI). Test statistics represent either the t-value (normal data) or U (non-normal data).

1   **Table 3:** Post-operative situation compared to HC

Gait parameters	HC (n=27)	TKA – 15 mo (n = 21)	TKA vs HC				THA – 15 mo (n=18)	THA vs HC			
			Mean diff (95%CI)	Test statistic (df = 46)	P_{TKA-HC}	P_{corr}		Mean diff (95%CI)	Test statistic (df =43)	P_{THA-HC}	P_{corr}
Gait speed (m/s)	1.24 (1.18, 1.31)	1.19 (1.13, 1.24)	-0.06 (-0.15, 0.03)	1.31	0.197	0.569	1.16 (1.10, 1.22)	-0.08 (-0.18, 0.02)	1.70	0.096	0.441
Stride Length (m)	1.32 (1.26, 1.37)	1.30 (1.25, 1.36)	-0.02 (-0.10, 0.07)	0.40	0.691	0.691	1.26 (1.20, 1.31)	-0.06 (-0.15, 0.03)	-1.32	0.194	0.581
Cadence (steps/min)	113 (110, 117)	109 (105, 112)	-4 (-9, 1)	1.66	0.104	0.402	110 (107, 113)	-3 (-8, 2)	-1.13	0.265	0.794
Peak turning velocity (deg/s)	205 (190, 220)	190 (174, 206)	-15 (-38, 8)	1.30	0.201	0.569	207 (190, 223)	1 (-23, 26)	1.40	0.909	0.909
Step time asymmetry (%)	2.7 (1.9, 3.4)	-	-	-	-	-	2.6 (1.9, 3.2)	-0.2 (-1.3, 1.0)	-0.28	0.778	0.909
Stride time variability (%)	1.8 (1.6, 2.0)	2.1 (1.8, 2.4)	0.3 (-0.1, 0.7)	1.68	0.099	0.398	2.1 (1.8, 2.4)	0.3 (-0.03, 0.7)	1.86	0.069	0.397
Lumbar sagittal RoM (deg)	5.3 (4.7, 5.9)	-	-	-	-		6.3 (5.7, 6.8)	0.9 (-0.2, 2.1)	1.63	0.111	0.444
Lumbar coronal RoM (deg)	*8.1 (6.3, 9.0)*	-	-	-	-		*6.5 (5.3, 7.3)*	*-1.6 (-2.7, 0.1)*	U = 165.5	0.074	0.397
Trunk coronal RoM (deg)	6.6 (5.9, 7.3)	7.1 (6.2, 8.1)	0.5 (-0.7, 1.7)	0.89	0.379	0.691	7.5 (6.6, 8.5)	0.8 (-0.6, 2.1)	1.16	0.254	0.761

2   *Note:* HC = healthy control, TKA = total knee arthroplasty, THA = total hip arthroplasty, RoM = range of motion, P_{corr} = Hommel adjusted p-value.

3   Non-normal distributed data are presented in *italic* and are summarized as median (IQR) with median difference (95% CI). Test statistics represent either the t-value (normal data)

4   or U (non-normal data).

Patient-reported outcome scores for both groups at each timepoint

Note: OA = osteoarthritis, TKA = total knee arthroplasty, THA = total hip arthroplasty, HC = healthy controls, ADL = activities of daily living.

1 **Table 4:** Patient-reported outcome scores for both groups at each timepoint

PROM scores	TKA (n=24)					THA (n=24)				
	Baseline (estimate)	Pre-operative – 2 months		2 months – 15 months		Baseline (estimate)	Pre-operative – 2 months		2 months – 15 months	
		Mean difference (95% CI)	P-value	Mean difference (95%CI)	P-value		Mean difference (95% CI)	P-value	Mean difference (95%CI)	P-value
HOOS/KOOS										
1) Symptoms	50	5 (-3, 14)	0.210	27 (18, 36)	<0.001	41	37 (30, 44)	<0.001	12 (4, 20)	0.007
2) Pain	42	28 (20, 36)	<0.001	19 (10, 28)	<0.001	39	45 (39, 52)	<0.001	9 (2, 16)	0.017
3) ADL	52	21 (13, 29)	<0.001	18 (10, 26)	<0.001	39	42 (35, 45)	<0.001	12 (4, 20)	0.004
4) Sports/Recreation	16	22 (9, 34)	0.001	30 (17, 43)	<0.001	15	48 (39, 57)	<0.001	13 (3, 22)	0.014
5) Quality of life	26	25 (17, 33)	<0.001	29 (20, 37)	<0.001	24	42 (32, 51)	<0.001	19 (9, 29)	<0.001

2 *Note:* OA = osteoarthritis, TKA = total knee arthroplasty, THA = total hip arthroplasty, HC = healthy controls, ADL = activities of daily living.

Figure 1

Overview of the experimental set-up and outcome parameters

Wearable inertial sensors were used to capture gait parameters during a two minute walk test over a six meter walkway with 180 degree turns. The figure is adapted from Boekesteijn *et al.* (19) .
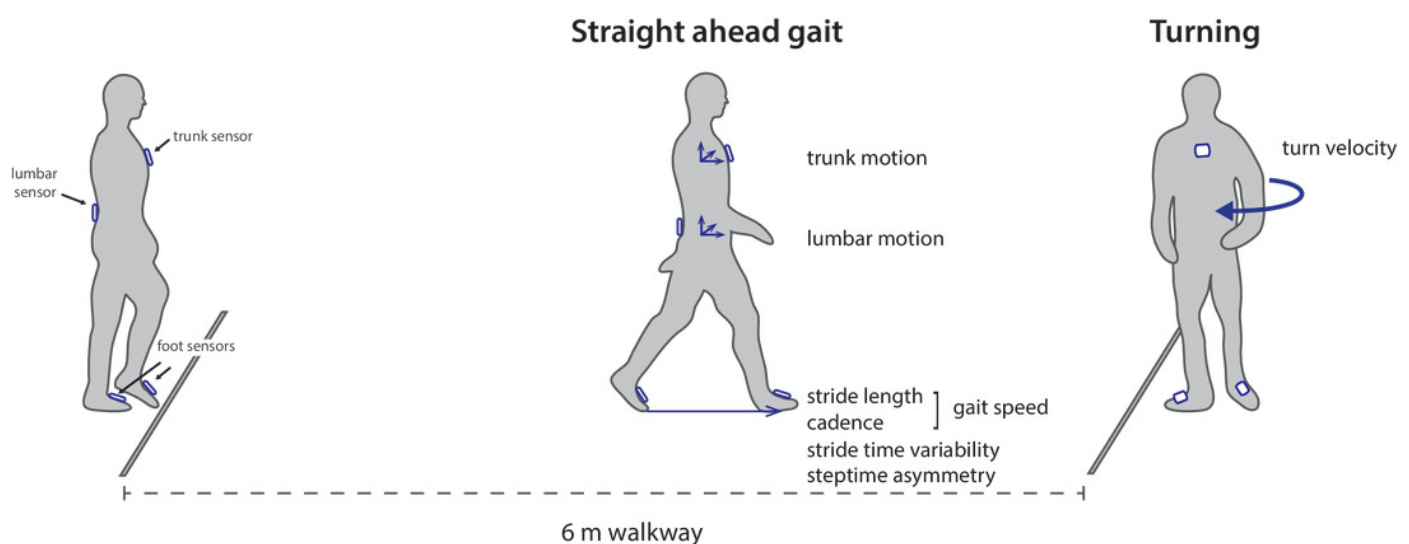
Figure 2

Recovery trajectories of gait parameters and PROMs.

Dots with error bars represent group means with 95% CI, whereas grey areas display HC group means with 95% CI. Individual datapoints are represented as small dots. Please note that dashed lines indicate linear recovery trajectories, which may deviate from the actual situation. *Note:* TKA = total knee arthroplasty, THA = total hip arthroplasty, HC = healthy controls.