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Altered sagittal plane kinematics and kinetics during sit-to-stand in individuals with knee osteoarthritis: A systematic review and meta-analysis

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ABSTRACT

Knee osteoarthritis (OA) progression is associated with an increase in peak external knee flexion torque (EKFT) during gait. However, the difference in the peak EKFT between individuals with knee OA and age-matched subjects was unclear. Therefore, to understand the kinematics, kinetics, and electromyogram characteristics in individuals with knee OA, we conducted a systematic review and meta-analysis of sagittal plane-dominant sit-to-stand (STS) motion. PubMed, PEDro, CINAHL, and Cochrane CENTRAL were used. Fourteen articles (knee-OA group: $n = 323$, mean age = 65.0 years, mean weight = 79.2 kg; control group: $n = 224$, mean age = 64.4 years, mean weight = 70.4 kg) were included, and the pooled standardized mean differences (SMDs) were calculated using a random-effects model. Meta-analysis showed that individuals with knee OA present significantly lower peak EKFT (pooled SMD: -1.62 ; 95% confidence interval [CI]: -2.36 to -0.88), significantly large trunk flexion angle (pooled SMD: 1.04; 95% CI: 0.69 to 1.39), and no significantly lower peak external knee adduction torque despite the significantly larger lateral-lean angle to the less affected side (pooled SMD: 1.04; 95% CI: 0.69 to 1.39). The quality of evidence for all outcomes was very low. The descriptive synthesis indicates that STS motion in individuals with knee OA might be an unsuitable motion strategy for knee muscle activity, force utilization from multiple joints to the knee joint, and their influence on knee joint cartilage, despite their lower peak EKFT. This information can help to better understand movement strategies and to optimize treatment approaches for individuals with knee OA.

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1. Introduction

Knee osteoarthritis (knee-OA) is a progressive and degenerative disease caused by biological, mechanical, and structural factors (Andriacchi et al., 2009). Knee-OA progression is associated with an increase in peak external knee adduction torque (EKAT) (Miyazaki et al., 2002), peak external knee flexion torque (EKFT) (Chehab et al., 2014; Erhart-Hledik et al., 2015), and knee muscle co-contraction (Hodges et al., 2016) during gait.

Among the mechanical factors, sagittal motion has received greater attention because the peak EKFT was correlated with initial knee-OA progression in a cohort study (Erhart-Hledik et al., 2015). However, a case-control study (Favre et al., 2014) and meta-analysis (Astefan et al., 2008; Mills et al., 2013) showed that the peak EKFT during gait was inconsistent between individuals with knee-OA and healthy age-matched controls. Therefore, evaluating movement characteristics in individuals with knee-OA in the sagittal plane that is superior to gait is needed. The reason for inconsistent differences in peak EKFT may be associated with gait properties. Knee excursion is as low as 20° during the stance phase where the peak EKFT occurs (Favre et al., 2014), and it is lower than that during activities of daily living such as stair climbing and sit-to-stand (STS) movements. Hence, there is a possibility that the biomechanical differences in the sagittal plane is detected by

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selecting a task that has higher mechanical demand and a wider range of motion in the sagittal plane.

STS motion is a sagittal plane-dominant movement because it is important to move the center of mass (CoM) forward with trunk and hip flexion and upward during trunk and lower limb extension (Roebroek et al., 1994). It is supported by the results of kinematics changes, which involve larger movements of the trunk and lower limb in the sagittal plane than in the frontal and horizontal planes during STS motion (Gilleard et al., 2008; Roebroek et al., 1994; Tully et al., 2005). STS motion requires higher lower limb torques than gait (Su et al., 1998); thus, STS motion is more likely to reflect characteristics of sagittal movement in individuals with knee-OA unlike gait, which involves changes in peak EKAT (Asthen et al., 2008; Mills et al., 2013).

The objective of this systematic review was to provide comprehensive understanding of the kinetics, kinematics, and electromyography (EMG) characteristics during STS motion especially in the sagittal plane.

2. Methods

2.1. Literature search strategy

A literature search was conducted up to December 21, 2017. The search strategy (Supplementary Method 1) was applied to electronic journal databases, including PubMed, Physiotherapy Evidence Database (PEDro), Cumulative Index to Nursing and Allied Health Literature (CINAHL), and Cochrane Central Register of Controlled Trials (CENTRAL). All fields within PubMed, PEDro, and CINAHL were utilized. Search manager was used to search the Cochrane database, and combinations of medical subject headings and related words were used to search PubMed. Google Scholar functioned as a complementary search engine. Furthermore, a manual search of reference lists of past systematic reviews was performed. The search strategy was discussed and approved by MS and HI in advance.

2.2. Criteria for study inclusion and exclusion

After excluding duplicate studies, MS and HI independently screened titles and abstracts under pre-determined eligibility criteria. MS and HI were the content expert and methodologist, respectively. The inclusion criteria were studies that were published in a peer-reviewed journal, were written in English, included individuals diagnosed with radiographic OA in the tibiofemoral or patellofemoral joints, recruited age-matched subjects as a control group and that measured any kinematic/kinetic parameter and EMG activity during STS motion. Studies found via the established search strategy were screened in their entirety, and studies that satisfied the eligibility criteria were included.

2.3. Data extraction

This review focused on STS time, kinematics, kinetics, muscle strength, and EMG. Means and standard deviations (SDs) of quantitative primary outcome data were extracted. Unless otherwise indicated, the data of the more severe limb were extracted. If data were only plotted and the mean and SD values were not provided, the data were obtained from the author (s) of the study. In case a reply was not received, or the author could not be contacted, WebPlotDigitizer (<https://automeris.io/WebPlotDigitizer/>), software designed to extract data from digital plot images, was used. A single reviewer (MS) collected the data on authors, years, subject population, knee-OA severity, outcome measures, and funding sources using standardized data forms.

2.4. Risk of bias assessment in included studies

The quality of risk of bias assessment was independently assessed by the same two reviewers using the Downs and Black scale (Downs and Black, 1998). This scale was modified to include only six domains (bias: four items [items 15, 16, 18, and 20] and confounding factors: two items [items 22 and 25]) to assess internal validity (0–6 points) as used in the systematic review of observational studies (Iijima et al., 2018). In case of disagreement between reviewers, consensus was reached by discussion. Interrater reliability of the modified scale was evaluated with kappa (κ) statistics for four bias-related items ($\kappa = 0.659$) and two confounding-related items ($\kappa = 0.667$).

2.5. Data analysis

The pooled estimate and 95% confidence intervals (CI) for standardized mean differences (SMD) were calculated using Review Manager version 5.3 (Nordic Cochrane Centre, Cochrane Collaboration, Copenhagen, Denmark). Meta-analysis was performed using the random effect model (Deeks and Higgins, 2010). The size of the SMD was interpreted using Cohen's d (<0.5: small effect size; 0.5–0.8: moderate effect size; ≥ 0.8 : large effect size) (Cohen, 1992).

The inter-study heterogeneity of the synthesized data was assessed using I^2 , which can be used even if the number of included studies is small (Higgins et al., 2003). If $I^2 \geq 50\%$, a meta-regression analysis was performed using the following parameters: age (year), percentage of female subjects, height (cm), body mass (kg), and study sample size. A p -value < 0.05 was considered statistically significant. To assess publication bias, a funnel plot was generated. However, Egger's test (Egger et al., 1997), a test for funnel plot asymmetry, was not performed because the number of studies in each outcome measure was less than 10.

2.6. Quality assessment of body of evidence: GRADE approach

The quality of evidence within each study was assessed using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach (Balslem et al., 2011). The quality of the body of evidence for each primary outcome measure was downgraded by the following criteria based on five domains (risk of bias, inconsistency, indirectness, imprecision, and publication bias) (Iijima et al., 2018). The criteria were Downs and Black scale < 3 points (<50% of maximum points), heterogeneity among trials was more than substantial ($I^2 \geq 50\%$), the large 95% CI or SMD, existence of publication bias or publication bias could not be assessed because of lack of included publications (<10), and no downgrade was applied to the indirectness domain, since all studies included individuals with knee-OA with relevant outcomes and direct comparisons (Guyatt et al., 2011).

3. Results

3.1. Study selection

In total, 527 articles were collected. Fig. 1 shows the flowchart of the study selection process. After excluding duplicate articles, the titles and abstracts of 392 articles were screened to exclude articles that did not clearly satisfy the eligibility criteria. For the remaining articles, full-text articles ($n = 60$) were collected and screened according to the eligibility criteria. Forty-four articles were excluded for the following reasons (Supplementary Table 1): no peer-review ($n = 10$), no control group ($n = 23$), subjects had undergone total knee arthroplasty ($n = 10$), and/or the outcome

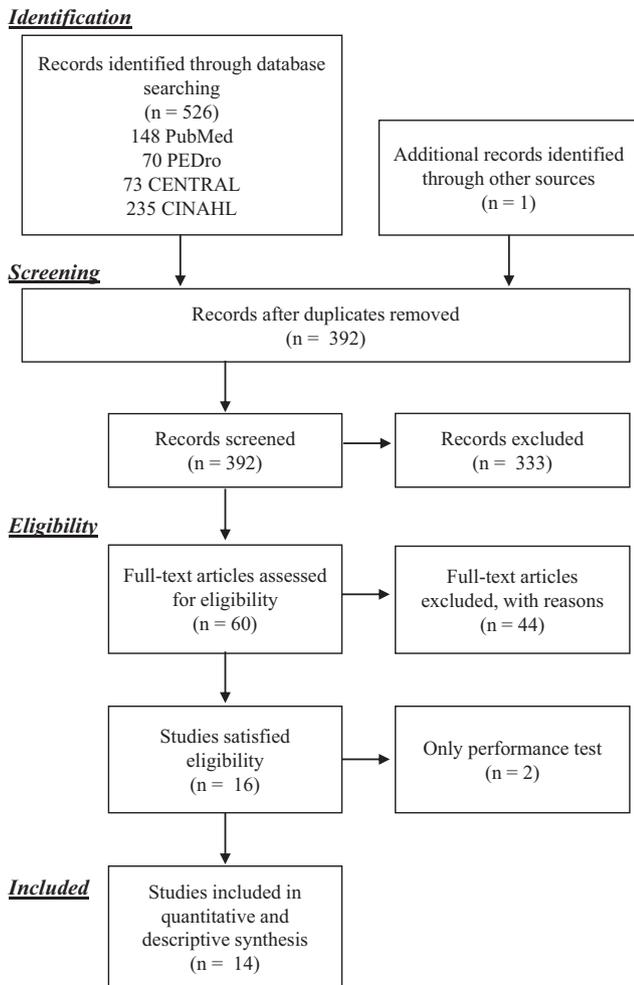


Fig. 1. Flowchart of study selection process.

measures targeted movements other than STS ($n = 1$). Overall, 16 studies satisfied the eligibility criteria, and 14 were included, with the exception of two studies implementing an STS performance test such as the five-times STS test (Christiansen and Stevens-Lapsley, 2010; Davidson et al., 2013).

3.2. Study characteristics

Table 1 provides the characteristics of the included studies. Totally, 547 subjects (224 control subjects, 323 individuals with knee-OA) were included in 14 studies. Twelve studies reported radiographic severity of knee-OA using the Kellgren and Lawrence grade (Kellgren and Lawrence, 1957) or to be mild, moderate, and severe. With the exception of some studies, subject attributions were reported: control subjects (mean age: 64.4 years; mean height: 165.1 cm; mean mass: 70.4 kg; percentage of female subjects: 66.2%), individuals with knee-OA (mean age: 65.0 years; mean height: 164.9 cm; mean mass: 79.2 kg; percentage of female subjects: 63.7%). Nine studies reported funding sources. STS motion are affected by chair height, use of armrests, and foot position (Janssen et al., 2002); this information is presented in Supplementary Table 2.

3.3. Risk of bias

The mean value of the Downs and Black scale score was 2.9 ± 1.0 points (range, 2–4), and the studies included were poor

to moderate overall quality (Table 2). All studies had points deducted due to inadequate blinding and a lack of information about the subject's recruitment time.

3.4. Outcome measures

The following outcome measures were available for synthesis: STS time, joint angle and excursion, peak joint torque, ground reaction force (GRF), knee joint compression force, and muscle strength. Non-pooled data were synthesized descriptively and are provided in Supplementary Table 3. The two studies (Boonstra et al., 2010; Duffell et al., 2013) were not included in the meta-analysis because the outcome measures mentioned above were not listed.

3.4.1. STS time

As for outcome measures related to STS time, the overall STS motion time (Anan et al., 2015; Bouchouras et al., 2015; Epifanio et al., 2008; Hoglund et al., 2014; Pai et al., 1994; Sagawa et al., 2017; Turcot et al., 2012), first phase time (Anan et al., 2015; Turcot et al., 2012), and second phase time (Anan et al., 2015; Sagawa et al., 2017) were synthesized.

STS time was divided into two phases: the first phase was from sitting to buttocks-off and the second phase was from buttocks-off to standing. Although two other studies reported phase time (Bouchouras et al., 2015; Turcot et al., 2012), both were excluded from the meta-analysis of phase time because the reported phase definition was different from other definition (Farquhar et al., 2008; Schenkman et al., 1990) (Supplementary Table 4).

STS time and second phase time were extended in individuals with knee-OA compared to controls with a large effect size (95% CI: 0.27 to 1.50, $p = 0.005$, and 95% CI: 0.11 to 2.10, $p = 0.05$, respectively; Fig. 2). Meta-regression analysis for the second phase time ($I^2 = 91\%$) was not associated with any variables, while longer STS time ($I^2 = 85\%$) was associated with higher percentage of female subjects (Supplementary Table 5).

3.4.2. Kinematics

Peak trunk flexion angle (Sagawa et al., 2017; Turcot et al., 2012), peak trunk lateral lean angle to the less-affected side (Sagawa et al., 2017; Turcot et al., 2012), joint excursion in sagittal plane of hip (Bouchouras et al., 2015; Pai et al., 1994), knee (Bouchouras et al., 2015; Epifanio et al., 2008; Larsen et al., 2013; Pai et al., 1994), ankle joint (Bouchouras et al., 2015; Pai et al., 1994) were synthesized as kinematics outcome measures. Individuals with knee-OA had significantly increased peak trunk flexion angle (95% CI: 0.69 to 1.39, $p < 0.001$), peak trunk lateral-lean angle to the less-affected side (95% CI: 0.69 to 1.39, $p < 0.001$), and decreased knee joint excursion (95% CI: -1.95 to -0.34 , $p = 0.005$) with large effect sizes compared to control subjects (Fig. 3). There were no significant differences in the hip and ankle joints excursion. Meta-regression analysis for the peak trunk lateral-lean angle to less-affected side ($I^2 = 72$) and hip joint excursion ($I^2 = 52$) showed no association with any variables; however, larger knee joint excursion ($I^2 = 74$) was associated with taller height (Supplementary Table 6).

3.4.3. Kinetics

The peak external hip flexion torque (Anan et al., 2015; Pai et al., 1994; Turcot et al., 2012; Wretenberg et al., 1993), peak EKFT (Anan et al., 2015; Epifanio et al., 2008; Pai et al., 1994; Turcot et al., 2012; Worsley et al., 2013; Wretenberg et al., 1993), peak EKAT (Larsen et al., 2013; Turcot et al., 2012; Worsley et al., 2013), peak external ankle plantar-flexion torque (Anan et al., 2015; Pai et al., 1994) were synthesized. Individuals with knee-OA showed significantly lower peak EKFT, which was less than that of the control group with a large effect size (95% CI: -2.36 to

Table 1
Summary of included studies.

| Author (Year) | Subject Population | Grade | Outcomes | Founding Source |
|--------------------------|---|---|---|---|
| Anan et al. (2015) | C: Control group (N = 17; age: 69.8 ± 4.3 y; height: 152.1 ± 4.6 cm; body mass: 49.1 ± 6.1 kg; 100%F) E: Knee-OA group (N = 20; age: 69.7 ± 4.4 y; height: 150.2 ± 4.7 cm; body mass: 55.0 ± 5.8 kg; 100%F) | C: – E: I(N = 4), II(N = 7) III(N = 9) | Temporal: sit-to-stand time, phase time Kinematics: segment angle and angular velocity (thorax, pelvis, shank) Kinetics: peak/mean joint torque and joint torque impulse (hip flexion, knee flexion, ankle dorsal-flexion), mechanical works and mean power (pelvis, thigh, shank), the anteroposterior horizontal distance of CoM | Grant-in-Aid 21700532 from the Japan Society for the Promotion of Science (JSPS) |
| Anan et al. (2016) | C: Control group (N = 11; age: 68.9 ± 4.2 y; height: 152 ± 4 cm; body mass: 49.0 ± 7.1 kg; 100%F) E: Knee-OA group (N = 13; age: 71.1 ± 4.7 y; height: 150 ± 4 cm; body mass: 54.3 ± 6.3 kg; 100%F) | C: – E: II(N = 8) III(N = 5) | Muscle Strength: knee extensors, hip extensors Electromyogram: %MVC (Gluteus maximus, Medial hamstrings, Vastus medialis, Rectus femoris), mean power frequency change (Gluteus maximus, Medial hamstrings, Vastus medialis, Rectus femoris), rate of the frequency (Rectus femoris) | – |
| Bouchouras et al. (2015) | C: Control group (N = 11; age: 61.90 ± 3.12 y; height: 163 ± 3 cm; body mass: 78.30 ± 4.91 kg; – % F) E: Knee-OA group (N = 11; age: 66.90 ± 4.51 y; height: 163 ± 2 cm; body mass: 77.63 ± 5.4 kg; 100% F) | C: – E: II or III | Temporal: sit-to-stand time, phase time Kinematics: joint excursion (hip, knee, ankle), Kinetics: vertical GRF Electromyogram: amplitude (Vastus lateralis, Biceps femoris, Erector spinae), co-activation time (knee), co-contraction index (knee) | The Aristotle University Research Committee |
| Boonstra et al. (2010) | C: Control group (N = 27; age: 66.1 ± 8.4 y; height: – cm; body mass: – kg; 70%F) E: Knee-OA group (N = 16; age: 65.4 ± 9.2y; height: – cm; body mass: – kg; 69%F) | C: – E: End Stage | Kinematics: peak angular velocity (knee) Kinetics: loading symmetry ratio | Johnson & Johnson, Leeds, United Kingdom, |
| Duffell et al. (2013) | C: Control group (N = 19; age: 57.3 ± 12.1 y; height: 169 ± 13 cm; body mass: 76.2 ± 0.10 kg; – %F) E: Knee-OA group (N = 19; age: 56.5 ± 12.6 y; height: 169 ± 8 cm; body mass: 68.6 ± 13.5 kg; – %F) | C: – E: Mild | Kinetics: integrated torque (knee), mean reaction force (Ground, Seat, Right arm rest, Left arm rest), GRF integral | Medical Engineering Solutions in Osteoarthritis Centre of Excellence, funded by the Wellcome Trust and the EPSRC |
| Epifanio et al. (2008) | C: Control group (N = 10; age: – y; height: – cm; body mass: – kg; 50%F) E: Knee-OA group (N = 21; age: 60–85 y; age: – y; height: – cm; body mass: – kg; 57%F) | C: – E: – | Temporal: sit-to-stand time, time instant of minimum/maximum knee torque Kinematics: angle at sitting/standing (knee), joint excursion (knee) Kinetics: Peak knee flexion/extension torque | Spanish Government Grant DPI2006-14722-C02-01, CICYTMTM2005-08689- C02-02, TIN2006-10134 and Fundació Caixa Castelló P11B2004-15 |
| Hoglund et al. (2014) | C: Control group (N = 7; age: 55.3 ± 8.7 y; height: 164 ± 4 cm; body mass: 73.1 ± 10.0 kg; 86%F) E: Knee-OA group (N = 8; age: 52.0 ± 7.5 y; height: 166 ± 8 cm; body mass: 91.6 ± 21.5 kg; 88%F) | C: – E: – | Temporal: sit-to-stand time Kinematics: joint angle (hip, knee, ankle), segment angle (tibia) angle at sitting/standing (hip, tibia) Muscle Strength: Quadriceps, Hip abductors, Hip extensors, Hip external rotators | Orthopedic Section of the American Physical Therapy Association and Temple University (College of Health Professions Dean's Research Incentive Award) |
| Larsen et al. (2013) | C: Control group (N = 23; age: 66.50 ± 4.80 y; height: 1.70 ± 0.08 m; body mass: 80.30 ± 11.80 kg; 48%F) E: Knee-OA group (N = 23; age: 63.70 ± 10.60 y; height: 1.70 ± 0.08 m; body mass: 80.30 ± 11.60 kg; 35%F) | C: – E: I or II(N = 11) III or IV (N = 12) | Temporal: sit-to-stand time Kinematics: joint angle (knee), joint excursion (trunk, knee) Kinetics: maximum/minimum knee adduction torque, medial GRF, medial knee compression force | – |

Table 1 (continued)

| Author (Year) | Subject Population | Grade | Outcomes | Founding Source |
|--------------------------|---|--|---|--|
| Pai et al. (1994) | C: Control group (N = 12; age: 70.7 ± 5.4 y; height: 163 ± 9 cm; body mass: 66.7 ± 13.8 kg; - %F) E: Knee-OA group (N = 12; age: 69.6 ± 4.6 y; height: 166 ± 9 cm; body mass: 89.9 ± 16.6 kg; - %F) | C: – E: IV (N = 8) Unknown (N = 4) | Temporal: sit-to-stand time, relative event time Kinematics: joint excursion (hip, knee, ankle), joint angle at sitting/standing (hip, knee, ankle) Kinetics: Peak external joint torque (hip flexion/extension, knee flexion, ankle dorsal-flexion) | – |
| Patsika et al. (2011) | C: Control group (N = 11; age: 56.54 ± 5.46 y; height: 1.64 ± 0.05 m; body mass: 77.36 ± 13.34 kg; 100%F) E: Knee-OA group (N = 12; age: 60.33 ± 6.66 y; height: 1.61 ± 0.05 m; body mass: 77.08 ± 9.2 kg; 100%F) | C: – E: II or III | Kinematics: mean angular velocity (knee), center of pressure Electromyogram: amplitude %MVC (Biceps femoris, Vastus lateralis, Vastus medialis), Moment-to-RMS rate, antagonist RMS EMG | – |
| Sagawa et al. (2017)* | C: Control group (N = 27; age: – y; height: 1.68 ± 0.10 m; body mass: 67.31 ± 10.40 kg; 52%F) E1 C-STs: Knee-OA group (N = 24; age: – y; height: 1.68 ± 0.10 m; body mass: 83.56 ± 18.10 kg; – %F) E2 IC-STs: Knee-OA group (N = 59; age: – y; height: 1.65 ± 0.10 m; body mass: 85.56 ± 16.79 kg; – %F) E3 SI-STs: Knee-OA group (N = 18; age: – y; height: 1.62 ± 0.11 m; body mass: 82.78 ± 11.72 kg; – %F) | C: – E: III or IV | Temporal: sit-to-stand time, phase time Kinematics: peak angle of trunk flexion/lateral lean to less-affected side, | Orthopedic Surgery Service of the University Hospitals of Geneva, the Fonds de Recherche du Québec – Santé, the Clinical Research Center of the University Hospital, Faculty of Medicine, Geneva, and the Louis-Jeantet Foundation |
| Turcot et al. (2012) | C: Control group (N = 20; age: 67 ± 7 y; height: 1.70 ± 0.10 m; body mass: 67.4 ± 10.6 kg; 50%F) E: Knee-OA group (N = 25; age: 69 ± 5 y; height: 1.69 ± 0.08 m; body mass: 83.3 ± 15.4 kg; 44%F) | C: – E: IV | Temporal: sit-to-stand time, phase time Kinematics: peak angle of trunk flexion/lateral lean to less-affected side Kinetics: peak joint torque (hip flexion/extension, knee adduction/abduction/flexion/extension) | Orthopedic Surgery Service of the Geneva University Hospitals, the Clinical Research Center of the University Hospital, Faculty of Medicine of Geneva University, the Louis-Jeantet Foundation, and the “Fonds de la Recherche en Santé du Québec” |
| Worsley et al. (2013) | C: Control group (N = 20; age: 62 ± 6 y; height: 166 ± 11 cm; body mass: 78 ± 13 kg; 55%F) E: Knee-OA group (N = 34; age: 64 ± 10 y; height: 167 ± 10 cm; body mass: 85 ± 18 kg; 59%F) | C: – E: – | Kinetics: peak knee flexion/adduction torque, Knee adduction impulse, peak GRF, peak vertical knee reaction force | Engineering and Physical Sciences Research Council and Depuy, a Johnson & Johnson Company; Arthritis Research UK (Grant Ref. 18512) |
| Wretenberg et al. (1993) | C: Control group (N = 9; age: 20–32 y; height: 1.80 (1.73–1.94) m; body mass: 73 (64–87) kg; 0%F) E: Knee-OA group (N = 8; age: 70 (65–79) y; height: 1.71 (1.58–1.80) m; body mass: 73 (50–98) kg; 50%F) | C: – E: – | Kinetics: peak joint torque (hip, knee) | – |

y: years; F: female; KL grade: Kellgren–Lawrence grade; OA: osteoarthritis; –: no listed.

* Subgroups (compensated sit-to-stand [C-STs], inadequately compensated sit-to-stand [IC-STs], severely impaired sit-to-stand [SI-STs]) in Sagawa 2017 were from the first factor plane of the multiple correspondence analysis.

–0.88, $p < 0.001$); however, there were no significant differences in peak external hip joint flexion torque, peak EKAT, or peak external ankle dorsi-flexion torque between the two groups (Fig. 4). Meta-regression analysis results for the peak external hip flexion torque ($I^2 = 82$) and peak EKFT ($I^2 = 79$) were not associated with any variables (Supplementary Table 7).

3.4.4. Ground reaction force

In terms of GRF, only peak vertical GRF was synthesized (Bouchouras et al., 2015; Worsley et al., 2013). Peak vertical GRF of the less affected side showed no significant difference between individuals with knee-OA and controls (Fig. 5). Three studies (Boonstra et al., 2010; Duffell et al., 2013; Turcot et al., 2012) that

Table 2
Downs and Black scale score for each study.

| Author (year) | 15 | 16 | 18 | 20 | 22 | 25 | total |
|--------------------------|----|----|----|----|----|----|-------|
| Anan et al. (2015) | 0 | 1 | 1 | 1 | 0 | 0 | 3 |
| Anan et al. (2016) | 0 | 1 | 1 | 1 | 0 | 0 | 3 |
| Boonstra et al. (2010) | 0 | 1 | 1 | 1 | 0 | 1 | 4 |
| Bouchouras et al. (2015) | 0 | 1 | 1 | 0 | 0 | 0 | 2 |
| Duffell et al. (2013) | 0 | 1 | 0 | 1 | 0 | 0 | 2 |
| Epifanio et al. (2008) | 0 | 1 | 1 | 1 | 0 | 0 | 3 |
| Hoglund et al., (2014) | 0 | 1 | 1 | 1 | 0 | 1 | 4 |
| Larsen et al. (2013) | 0 | 1 | 1 | 0 | 0 | 1 | 3 |
| Pai et al. (1994) | 0 | 1 | 0 | 1 | 0 | 0 | 2 |
| Patsika et al. (2011) | 0 | 1 | 1 | 1 | 0 | 1 | 4 |
| Sagawa et al. (2017) | 0 | 1 | 1 | 1 | 0 | 0 | 3 |
| Turcot et al. (2012) | 0 | 1 | 0 | 1 | 0 | 0 | 2 |
| Worsley et al. (2013) | 0 | 1 | 0 | 1 | 0 | 1 | 3 |
| Wretenberg et al. (1993) | 0 | 1 | 0 | 1 | 0 | 0 | 2 |

| 1. Movement time | Sample size | | SMD [95% CI] | weight | |
|---|---------------|------------|--------------|---------------------------|------------|
| | Author (year) | knee-OA | | | control |
| 1.1 Sit-to-stand time | | | | | |
| Anan (2015) | | 20 | 17 | 0.68 [0.02, 1.35] | 11.6 |
| Bouchouras (2015) | | 11 | 11 | 0.98 [0.08, 1.87] | 10.4 |
| Epifanio (2008) | | 21 | 10 | 0.43 [-0.33, 1.19] | 11.1 |
| Hoglund (2014) | | 8 | 7 | 0.74 [-0.32, 1.80] | 9.6 |
| Pai (1994) | | 12 | 12 | 0.89 [0.04, 1.73] | 10.7 |
| Sagawa (2017) :C | | 24 | 27 | -0.56 [-1.12, 0.00] | 12.1 |
| Sagawa (2017) :IC | | 59 | 27 | 1.26 [0.76, 1.75] | 12.3 |
| Sagawa (2017) :SI | | 18 | 27 | 3.19 [2.28, 4.10] | 10.3 |
| Turcot (2012) | | 25 | 20 | 0.63 [0.03, 1.23] | 11.9 |
| Overall (Random Effects) | | 198 | 158 | 0.89 [0.27, 1.50] | 100 |
| Test for overall effect: $Z = 2.83$ ($P = 0.005$) | | | | | |
| Test for heterogeneity: $\text{Chi}^2 = 53.57$ ($P < 0.0001$); $I^2 = 85\%$ | | | | | |
| 1.2 First phase time | | | | | |
| Anan (2015) | | 20 | 17 | 0.65 [-0.02, 1.31] | 47.0 |
| Turcot (2012) | | 25 | 20 | 0.00 [-0.59, 0.59] | 53.0 |
| Overall (Random Effects) | | 45 | 37 | 0.30 [-0.33, 0.94] | 100 |
| Test for overall effect: $Z = 0.94$ ($P = 0.35$) | | | | | |
| Test for heterogeneity: $\text{Chi}^2 = 2.04$ ($P = 0.15$); $I^2 = 51\%$ | | | | | |
| 1.3 Second phase time | | | | | |
| Anan (2015) | | 20 | 17 | 0.70 [0.03, 1.37] | 24.8 |
| Sagawa (2017) :C | | 24 | 27 | -0.24 [-0.79, 0.31] | 25.6 |
| Sagawa (2017) :IC | | 59 | 27 | 1.40 [0.90, 1.91] | 25.9 |
| Sagawa (2017) :SI | | 18 | 27 | 2.43 [1.63, 3.22] | 23.8 |
| Overall (Random Effects) | | 121 | 98 | 1.05 [0.11, 2.10] | 100 |
| Test for overall effect: $Z = 1.97$ ($P = 0.05$) | | | | | |
| Test for heterogeneity: $\text{Chi}^2 = 34.76$ ($P < 0.0001$), $I^2 = 91\%$ | | | | | |

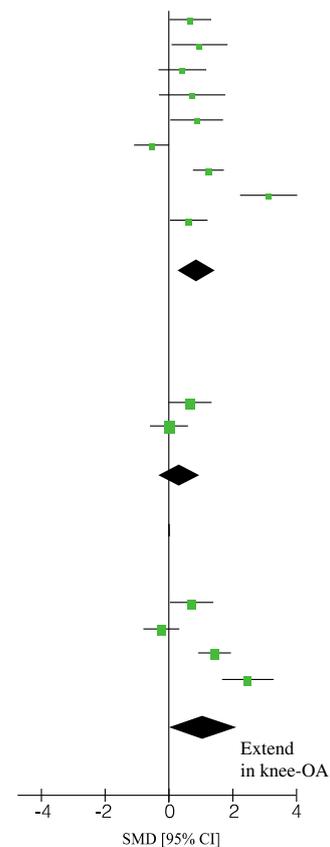


Fig. 2. Standardized mean difference (SMD) and 95% confidence interval (CI) for motion time during STS motion. The black diamond represents the pooled effect size. The vertical solid line at 0 represents no difference.

reported loading rate between affected and non-affected side were synthesized descriptively in [Supplementary Table 3](#). Meta-regression analysis for peak vertical GRF ($I^2 = 89$) was associated with a higher percentage of female subjects and shorter height ([Supplementary Table 8](#)).

3.4.5. Knee joint compression force

Knee joint compression force, the vertical force act on knee joint, was synthesized from two studies ([Larsen et al., 2013](#); [Worsley et al., 2013](#)). Knee joint compression force was not significantly different between individuals with knee-OA and control

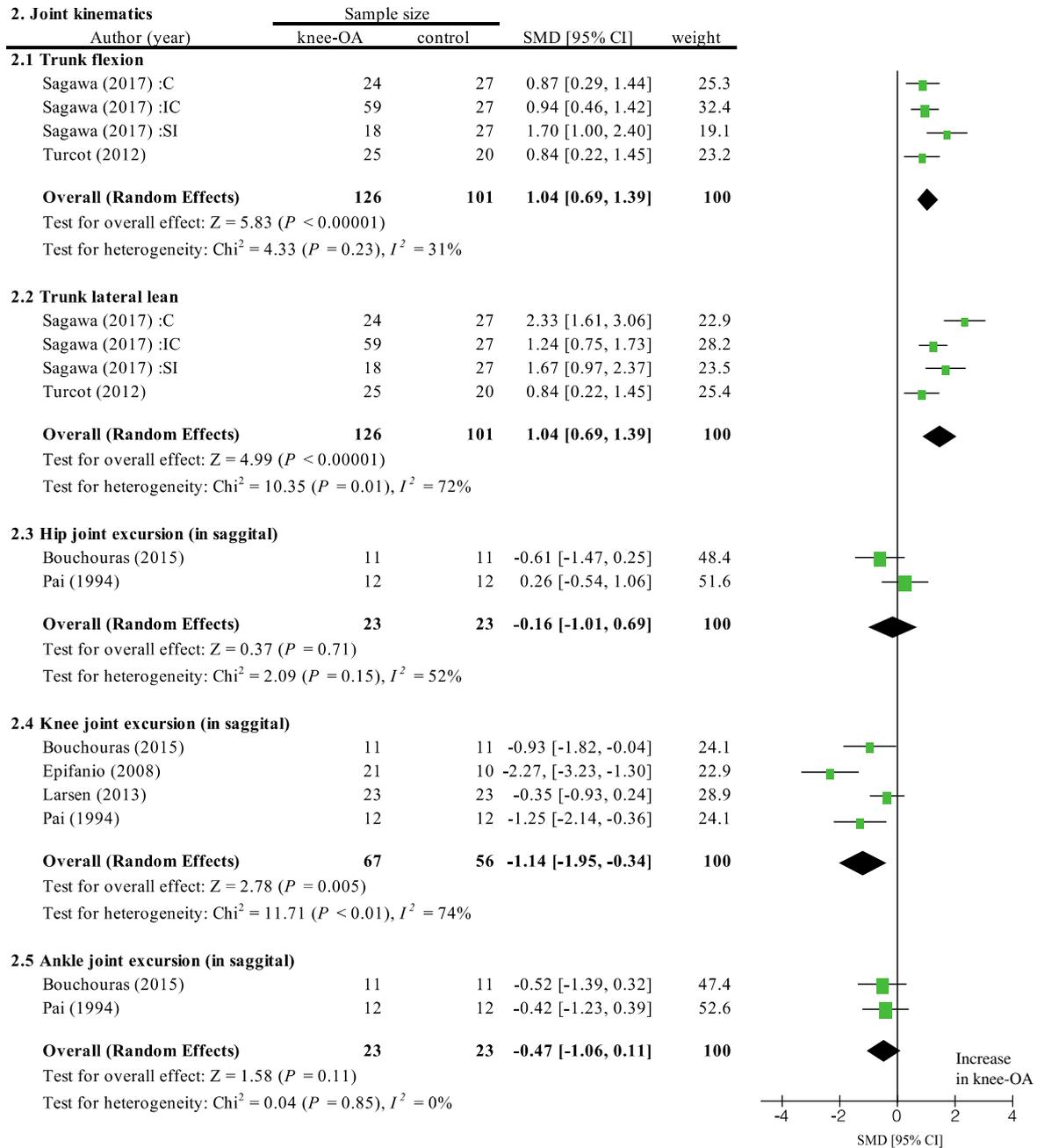


Fig. 3. Standardized mean difference (SMD) and 95% confidence interval (CI) for the kinematics during STS motion. The black diamond represents the pooled effect size. The vertical solid line at 0 represents no difference.

subjects (Fig. 5). Meta-regression analysis for peak knee joint compression force ($I^2 = 65$) was associated with taller height (Supplementary Table 9).

3.4.6. Electromyography

EMG was not synthesized in this meta-analysis due to the lack of studies reporting EMG outcome measures while reporting about EMG-related variables, such as percentage of maximum voluntary contraction (%MVC) and integrated EMG (Anan et al., 2016; Bouchouras et al., 2015; Patsika et al., 2011). Therefore, EMG data were synthesized descriptively in Supplementary Table 3.

3.4.7. Muscle strength

Individuals with knee-OA had lower knee extensor muscle strength, with a large effect size, compared with controls, but there

was no significant difference in hip extensor muscle strength between two groups (Fig. 6).

3.5. Publication bias

Funnel plots used to assess publication bias are shown in Supplementary Figs. 1 to 5. No publication bias could be determined visually.

3.6. Summary of quality of evidence

The results of the GRADE approach are shown in Table 3. The quality of evidence in each outcome measure was downgraded to “very low” by the following limitations: most studies were of poor quality as assessed by the Downs and Black scale (<3 points); more

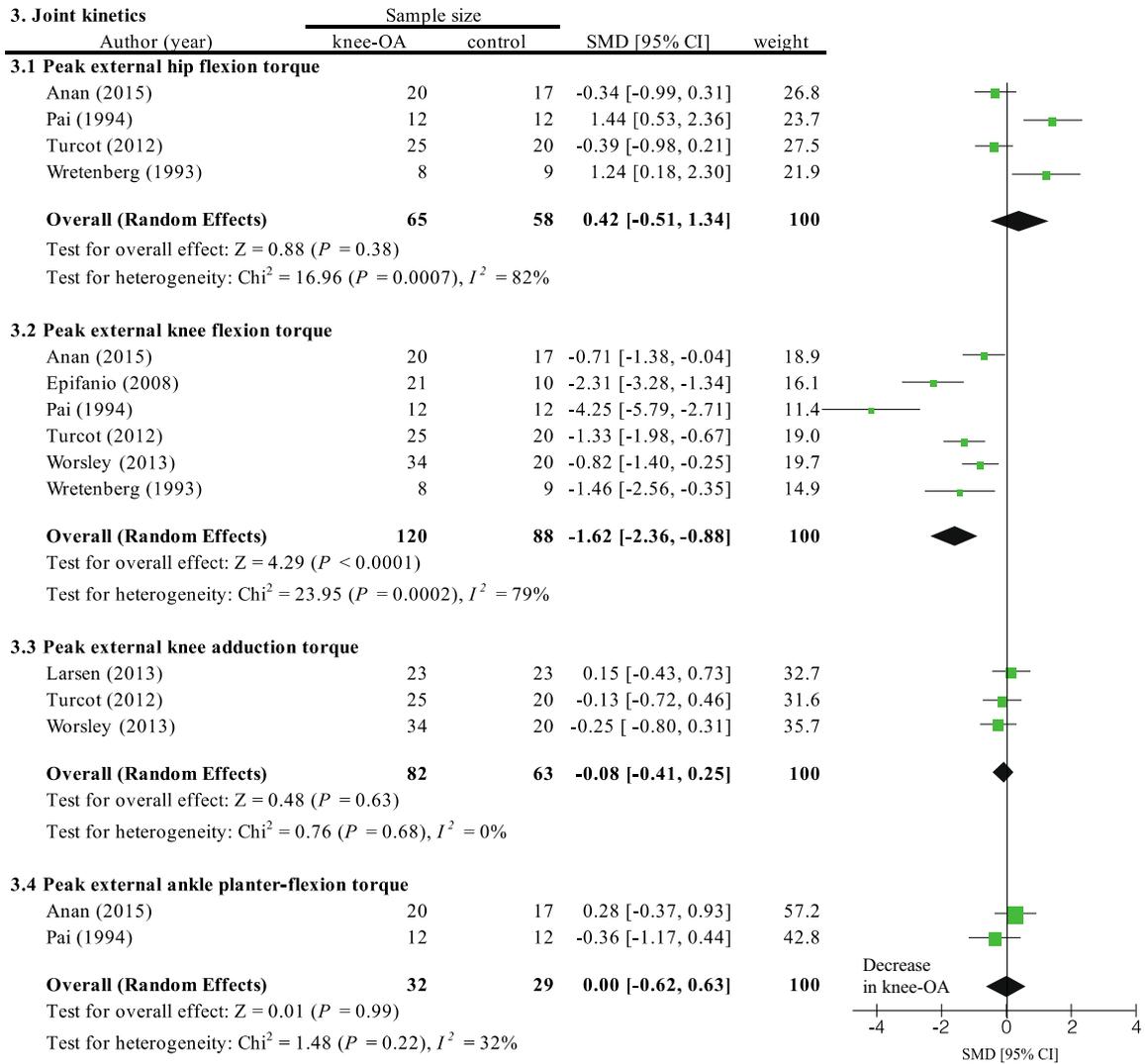


Fig. 4. Standardized mean difference (SMD) and 95% confidence interval (CI) for the kinetics during STS motion. The black diamond represents the pooled effect size. The vertical solid line at 0 represents no difference.

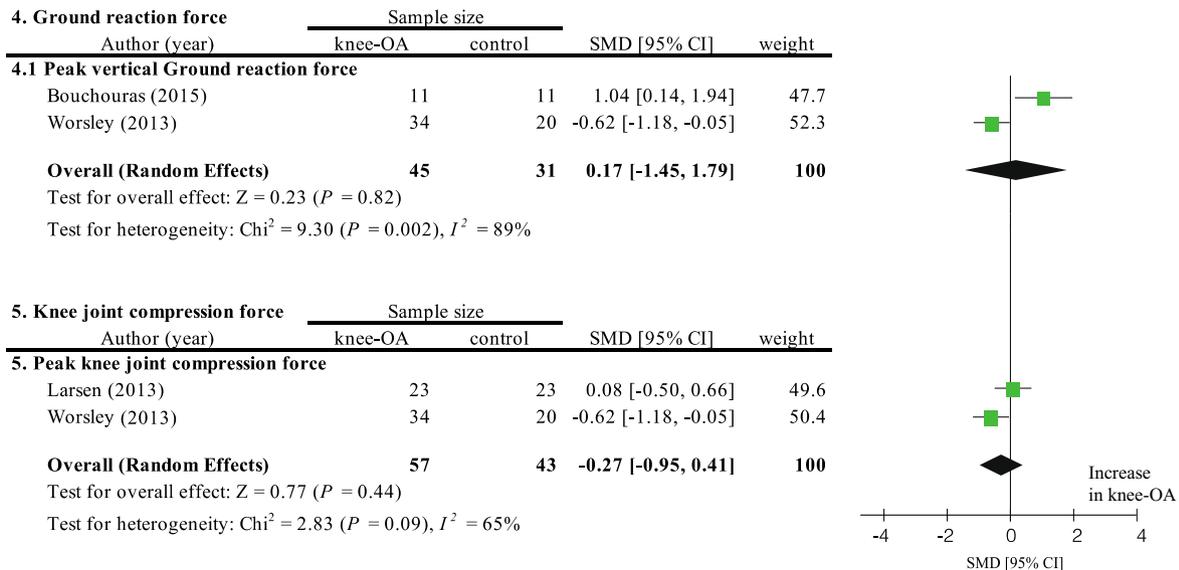


Fig. 5. Standardized mean difference (SMD) and 95% confidence interval (CI) for the ground reaction force and knee compression force during STS motion. The black diamond represents the pooled effect size. The vertical solid line at 0 represents no difference.

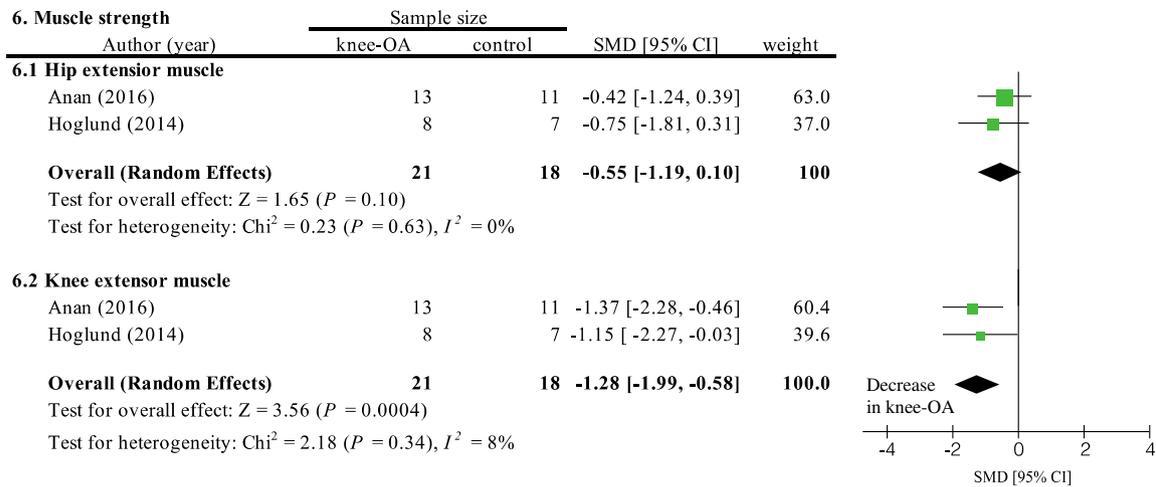


Fig. 6. Standardized mean difference (SMD) and 95% confidence interval (CI) for the muscle strength during STS motion. The black diamond represents the pooled effect size. The vertical solid line at 0 represents no difference.

than half of the studies had high heterogeneity ($I^2 > 50\%$); the studies may have had publication bias (which could not be determined because of the small data set).

4. Discussion

To our best knowledge, this is the first systematic review and meta-analysis to report STS motion in individuals with knee-OA. The results of this systematic review and meta-analysis revealed that kinematics and kinetics changes in individuals with knee-OA dominate in the sagittal plane, which include significantly larger peak trunk flexion angle and peak lateral-lean angle to the less-affected side in kinematics and lower peak EKFT in kinetics (Fig. 7). Individuals with knee-OA had longer STS time. However, as the quality of evidence was very low across all outcome measures, further high quality reviews of evidence will enhance the confidence of the effect estimate.

4.1. Change in STS time in individuals with knee-OA

This meta-analysis showed that individuals with knee-OA had significantly longer STS time when STS motion was performed at self-selected speeds. Extension of STS time in individuals with knee-OA appeared to be associated with various factors such as kinematics change, knee muscle weakness, and knee pain. Muscle strength is moderately and negatively correlated with performance test time such as the five-times STS test and the 30-second chair stand test (Jones et al., 1999; Lord et al., 2002). Therefore, the knee extensor muscle weakness in individuals with knee-OA shown in this meta-analysis may be related with extended STS time. The group with a large trunk flexion angle had a more prolonged STS time (Sagawa et al., 2017), which is supported by previous studies describing a relationship between increasing trunk movement and extended STS time (Su et al., 1998; Turcot et al., 2012). The WOMAC pain score is positively correlated with STS time in individuals with end-stage knee-OA (Turcot et al., 2012). Relationships between movement time and knee extensor muscle strength (Barker et al., 2004) or knee pain (Barker et al., 2004; Marcum et al., 2014) during gait have shown the same tendency as STS motion. However, there was no significant difference in the WOMAC pain score among the three groups classified by STS time in individuals with knee-OA with Kellgren and Lawrence grades II–IV (Sagawa et al., 2017; Segal et al., 2013), suggesting that STS time is modified by various factors and that the factors are related to

each other (e.g., a negative correlation between knee muscle strength and pain; Muraki et al., 2015), which renders the phenomenon during STS motion difficult to understand.

4.2. Kinematics and kinetics changes during STS motion

This systematic review indicated that individuals with knee-OA have decreased peak EKFT and have significantly increased trunk lateral-lean angle to the less affected side and trunk flexion. However, there was no significant difference in the peak EKAT between the two groups. Since lower peak EKFT was observed in individuals with knee-OA and no significant difference in peak EKAT was observed across all studies reporting those outcome measures, a change in knee joint kinetics in individuals with knee-OA that occurs predominantly in the sagittal plane during STS motion indicates a more consistent and robust tendency than during gait (Astefhen et al., 2008; Mills et al., 2013), implying that STS motion can be used to evaluate characteristic sagittal plane movements with less influence of the frontal plane.

As for kinetics variables, the decrease in peak EKFT in individuals with knee-OA might be caused by an increased trunk flexion angle since the CoM of individuals with knee-OA was further forward at the buttocks-off stage than that in control subjects (Anan et al., 2015). However, because the studies did not specify whether the peak EKFT occurred at the buttocks-off, further studies are needed to determine the relationship between CoM position and peak EKFT. The other possible cause of decreased peak EKFT is knee extensor muscle weakness. However, the correlation between internal knee extension torque and knee extensor strength is the weakest ($r = 0.32$) compared with the correlations between internal knee extension torque and knee flexor ($r = -0.42$), hip extensor ($r = 0.42$), hip flexor ($r = -0.46$), hip adductor ($r = -0.36$), and hip abductor ($r = -0.42$) strength (Samuel et al., 2012), which means that there are a number of strategies that can be used to perform STS motion even if they have knee extensor muscle weakness. Thus, we cannot conclude for now that lower peak EKFT is caused by knee extensor muscle weakness.

In this systematic review, in terms of kinematics change, the knee joint excursion was smaller in individuals with knee-OA than that in control subjects. Although heterogeneity indicated a relationship between body height and knee joint excursion, knee joint excursion is affected by posture differences in the final position, which probably reflects the range of motion in the knee joint (Pai et al., 1994).

Table 3
Summary of the body evidence according to the GRADE approach.

| Outcome | SMD [95% CI] | Study Design | Sample Size | Downs and BlackScale Score | Heterogeneity | Level of Evidence (GRADE) |
|---|----------------------|------------------------|---------------------------------------|--------------------------------------|---------------|---------------------------|
| 1. Movement time | | | | | | |
| 1.1 Sit-to-stand time | 0.89 [0.27, 1.50] | 7 × Case-control study | Knee-OA: n = 198 Control: n = 158 | 2.7 ± 0.7 (3.0 [2.0, 3.0]) points | $I^2 = 85\%$ | ⊕ ⊕ ⊕ ⊕* † ‡ |
| 1.2 First phase time | 0.30 [−0.33, 0.94] | 2 × Case-control study | Knee-OA: n = 45 Control: n = 37 | 2.5 ± 0.5 (2.5 [2.3, 2.8]) points | $I^2 = 51\%$ | ⊕ ⊕ ⊕ ⊕* † ‡ |
| 1.3 Second phase time | 1.05 [0.11, 2.10] | 4 × Case-control study | Knee-OA: n = 121 Control: n = 98 | 3.0 ± 0.0 (3.0 [3.0, 3.0]) points | $I^2 = 91\%$ | ⊕ ⊕ ⊕ ⊕† ‡ |
| 2. Joint Kinematics | | | | | | |
| 2.1 Trunk flexion | 1.04 [0.69, 1.39] | 2 × Case-control study | Knee-OA : n = 126 Control: n = 101 | 2.5 ± 0.5 (2.5 [2.3, 2.8]) points | $I^2 = 31\%$ | ⊕ ⊕ ⊕ ⊕* † ‡ |
| 2.2 Trunk lateral lean to less affected side | 1.04 [0.69, 1.39] | 2 × Case-control study | Knee-OA: n = 126 Control: n = 101 | 2.5 ± 0.5 (2.5 [2.3, 2.8]) points | $I^2 = 72\%$ | ⊕ ⊕ ⊕ ⊕* † ‡ |
| 2.3 Hip joint excursion (in sagittal) | −0.16 [−1.01, 0.69] | 2 × Case-control study | Knee-OA: n = 23 Control: n = 23 | 2.0 ± 0.0 (2.0 [2.0, 2.0]) points | $I^2 = 52\%$ | ⊕ ⊕ ⊕ ⊕* † ‡ |
| 2.4 Knee joint excursion (in sagittal) | −1.14 [−1.95, −0.34] | 4 × Case-control study | Knee-OA: n = 67 Control: n = 56 | 2.5 ± 0.5 (2.5 [2.0, 3.0]) points | $I^2 = 74\%$ | ⊕ ⊕ ⊕ ⊕* † ‡ |
| 2.5 Ankle joint excursion (in sagittal) | −0.47 [−1.06, 0.11] | 2 × Case-control study | Knee-OA: n = 23 Control: n = 23 | 2.0 ± 0.0 (2.0 [2.0, 2.0]) points | $I^2 = 0\%$ | ⊕ ⊕ ⊕ ⊕* † ‡ |
| 3. Joint Kinetics | | | | | | |
| 3.1 Peak external hip flexion torque | 0.42 [−0.51, 1.34] | 4 × Case-control study | Knee-OA: n = 65 Control: n = 58 | 2.3 ± 0.4 (2.0 [2.0, 2.3]) points | $I^2 = 82\%$ | ⊕ ⊕ ⊕ ⊕* † ‡ |
| 3.2 Peak external knee flexion torque | −1.62 [−2.36, −0.88] | 6 × Case-control study | Knee-OA: n = 120 Control: n = 88 | 2.5 ± 0.5 (2.5 [2.0, 3.0]) points | $I^2 = 79\%$ | ⊕ ⊕ ⊕ ⊕* † ‡ |
| 3.3 Peak external knee adduction torque | −0.08 [−0.41, 0.25] | 3 × Case-control study | Knee-OA: n = 82 Control: n = 63 | 2.7 ± 0.5 (3.0 [2.5, 3.0]) points | $I^2 = 0\%$ | ⊕ ⊕ ⊕ ⊕* † ‡ |
| 3.4 Peak external ankle planar-flexion torque | 0.00 [−0.62, 0.63] | 2 × Case-control study | Knee-OA : n = 32 Control: n = 29 | 2.5 ± 0.5 (2.5 [2.3, 2.8]) points | $I^2 = 32\%$ | ⊕ ⊕ ⊕ ⊕* † ‡ |
| 4. Ground Reaction Force | | | | | | |
| 4.1 Peak vertical Ground Reaction Force | 0.17 [−1.45, 1.79] | 2 × Case-control study | Knee-OA: n = 45 Control: n = 31 | 2.5 ± 0.5 (2.5 [2.3, 2.8]) points | $I^2 = 89\%$ | ⊕ ⊕ ⊕ ⊕* † ‡ |
| 5. Knee joint compression force | | | | | | |
| 5.1 Peak knee joint compression force | −0.27 [−0.95, 0.41] | 2 × Case-control study | Knee-OA: n = 57 Control: n = 43 | 3.0 ± 0.0 (3.0 [3.0, 3.0]) points | $I^2 = 65\%$ | ⊕ ⊕ ⊕ ⊕† ‡ |
| 6. Muscle force | | | | | | |
| 6.1 Hip extensors | −0.55 [−1.19, 0.10] | 2 × Case-control study | Knee-OA: n = 21 Control: n = 18 | 3.5 ± 0.7 (3.5 [3.3, 4.0]) points | $I^2 = 0\%$ | ⊕ ⊕ ⊕ ⊕* † ‡ |
| 6.2 Knee Extensors | −0.95 [−1.52, −0.39] | 2 × Case-control study | Knee-OA: n = 21 Control: n = 18 | 3.5 ± 0.7 (3.5 [3.3, 4.0]) points | $I^2 = 8\%$ | ⊕ ⊕ ⊕ ⊕* † ‡ |

CI: Confidence Interval; GRADE: Grades of Recommendation, Assessment, Development, and Evaluation; SMD: standardized mean difference.

* Downgraded for risk of bias (<3 points in the Downs and Black Scale score).

† Downgraded for inconsistency (results were heterogeneous across more than half of the included studies [$I^2 > 50\%$]).

‡ Downgraded for publication bias (unable to determine because of a few included studies [<10 data set]).

4.3. Interpretation of STS motion in individuals with knee-OA

Although the STS motion pattern mentioned above has been considered a suitable strategy to decrease knee burden (Pai et al., 1994; Turcot et al., 2012), whether this strategy is appropriate for individuals with knee-OA must be interpreted with caution because of the reasons outlined below.

4.3.1. Muscle activity around knee joint

The %MVC of VM and VL was non-significant difference (Patsika et al., 2011), and %MVCs and integrated amplitude in the biceps femoris were higher than those in control subjects (Bouchouras et al., 2015; Patsika et al., 2011). Although it is thought that reduced peak EKFT in individuals with knee-OA decreases knee joint force (Pai et al., 1994) and the muscle activity around the knee joint (Turcot et al., 2012), these results suggest that individuals with knee-OA require at least as the same levels of muscle activity around the knee joint as that of control subjects even though the peak EKFT is lower in individuals with knee-OA during STS motion. Thus, it is possible that the peak external knee torque currently used as indicator of knee burden (Andriacchi et al., 1980) is inappropriate during STS motion, which is partially supported by

the lack of significant difference in peak knee joint compression force in this meta-analysis. However, we compared the peak EKFT with muscle activity around the knee joint at different intervals because the peak EKFT represents only one point in time, whereas muscle activity was analyzed over the entire movement time or the period when the knee joint was in 90° to 10° during STS motion, except for one study. Hence, to clearly establish the relationship between torque and muscle activity, the peak EKFT and muscle activity around the knee joint or the knee joint compression force should be compared at the same time point in a future study. Furthermore, appropriately defining the phases of STS motion is needed, as STS requires different mechanical and control functions for the whole body and knee joint depending on the phase. Thus, the important characteristics of STS motion in individuals with knee-OA may be masked if phase division is not determined.

4.3.2. Force utilization efficiency from multi-joints to knee joint

The descriptive synthesized data indicated that individuals with knee-OA could not utilize the force generated from joints other than the knee joint based on following results and interpretation. Power analysis during STS motion showed that individuals with

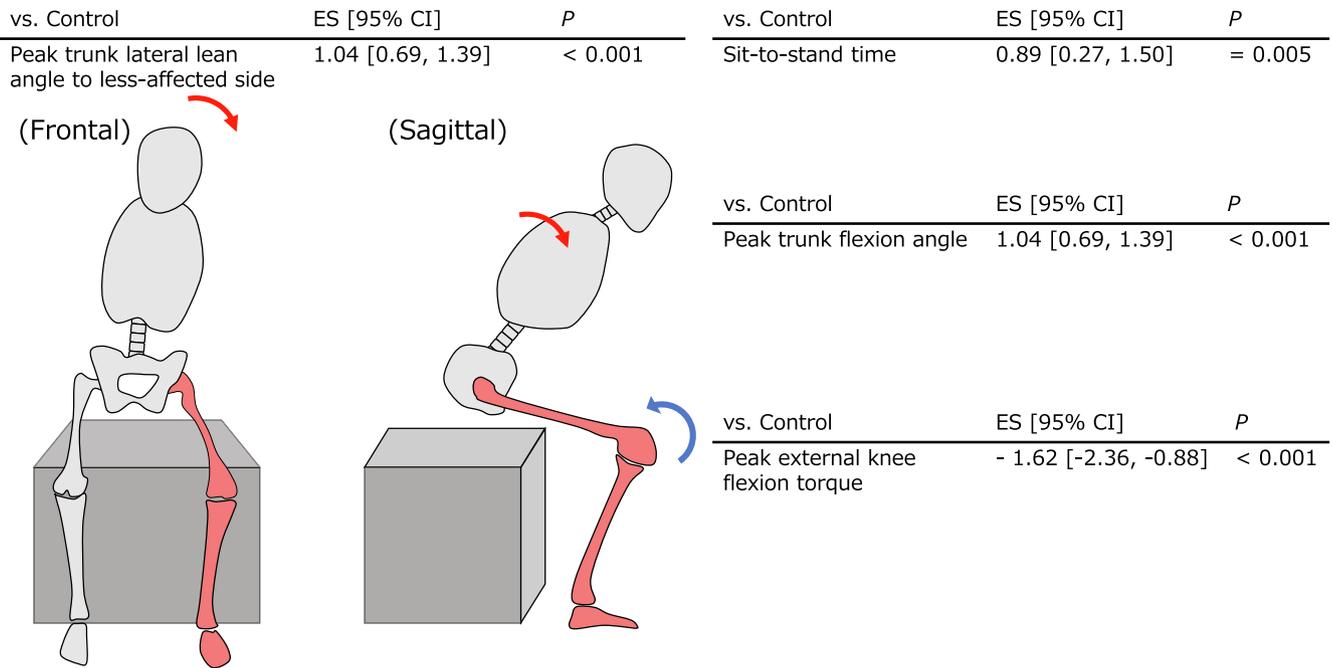


Fig. 7. Graphic abstract. Individuals with knee-OA have smaller peak external knee flexion torque (A) and larger peak trunk flexion angles (B) than age-matched subjects in the sagittal plane, and larger peak trunk lateral lean to less-affected side in the frontal plane than age-matched subjects with extended sit-to stand time. The more-affected side is indicated in pink. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

knee-OA could not increase the absorption of mechanical energy in the hip extensor with trunk flexion movement, whereas they decreased the absorption of mechanical energy in the knee extensor with the shank forward-lean movement following the buttocks-off movement (Anan et al., 2015). Furthermore, the extended time for STS motion interfered with the occurrence of inter-segment passive force (Bouchouras et al., 2015). These results and interpretation suggested that physiological energy such as muscle activity in the knee joint may have been increased due to the lack of force utilization from multiple joints to the knee joint.

4.3.3. Influence of knee joint cartilage

There was no significant difference in the peak knee joint compression force between groups, although the peak EKFT decreased in individuals with knee-OA. This may be attributed to the lack of significant differences in GRF between individuals with knee-OA and control subjects, with the same level of muscle activity around the knee joint found in this systematic review, since compression force is generated by muscle activity, gravity and external force (e.g., GRF) (Steele et al., 2012). However, descriptive synthesized data from three studies showed individuals with knee-OA loaded more on less affected side. As two of those three studies recruited individuals with end-stage knee-OA (Boonstra et al., 2010; Turcot et al., 2012) and one study permitted using armrest (Duffell et al., 2013), whether loading distribution is changed due to the stage of knee-OA or armrest use must be confirmed in a further study.

Our meta-analysis revealed significantly long STS time in individuals with knee-OA, which may lead to progression of knee-OA because the knee cartilage may be exposed to a certain degree of compression force for a prolonged period. However, it is unclear whether individuals with knee-OA have increased peak knee joint compression force when they perform STS motion in less STS time. As there is no definitive conclusion regarding whether long-term knee compression and increased peak knee joint compression force are more likely to affect cartilage, further studies are needed.

4.4. Study limitations

There are several limitations. First, the quality of evidence for each study was very low because of the study designs and high heterogeneity. High heterogeneity was attributed to differences in subject populations in terms of height, mass, and sex. Second, publication bias could not be denied because the number of studies reporting the outcome measures was insufficient. Furthermore, we could not stratify the analysis according to severity because of the variation in knee-OA grades of the included studies. Therefore, a systematic review should be performed once the number of available studies increases.

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Declaration of Competing Interest

The authors did not receive financial support or other benefits from commercial sources for the work reported in this manuscript or any other financial support that could create a potential conflict of interest or the appearance of a conflict of interest concerning the work.

Appendix A. Supplementary material

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jbiomech.2019.109331>.

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