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Review Article

Isokinetic testing of muscle strength in older adults with knee osteoarthritis: An integrative review

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Abstract.
BACKGROUND: Knee osteoarthritis (OA) is common among older adults and associated with impaired knee strength.
OBJECTIVE: Describe isokinetic testing procedures and clinimetric findings associated with the testing of knee strength in the presence of knee OA.
METHODS: Relevant articles were identified by an electronic search of PubMed using the search string "isokinet* AND knee osteoarthritis."
RESULTS: One-hundred and twenty-nine relevant articles were found. The articles support the validity and reliability of isokinetic strength testing for patients with knee OA. The responsiveness to various therapeutic interventions has been reported.
CONCLUSIONS: Isokinetic dynamometry is a valid and reliable measure of muscle strength in knee OA.

Keywords: Muscle strength, measurement, knee osteoarthritis

1. Introduction

Knee osteoarthritis (OA) is a common musculoskeletal condition that is responsible for approximately 80% of the global burden related to osteoarthritis at all sites within the body [1]. The individual and societal burden of knee OA is negatively associated with physical activity, disability, morbidity, and mortality levels [2,3]. Muscle strength has been implicated in disease severity and highlighted as a target for therapeutic rehabilitation [4–7]. There are several options for assessing lower extremity muscle strength in the presence of knee OA including manual muscle testing, hand-held dynamometry, and isokinetic dynamometry. The purpose of this review was to highlight procedures and results of isokinetic testing utilized for the measurement of knee strength in the presence of knee OA.

2. Methods

PubMed was searched for articles potentially related to isokinetic testing and knee arthritis on July 7, 2019. The search string included "isokinet* AND knee osteoarthritis." Article titles and abstracts were initially reviewed for relevance and if warranted the full text was then examined to determine if the articles addressed isokinetic strength testing for individuals with knee OA. Articles were excluded if published in a language other than English, were review articles, failed to provide procedural specifics or presented no findings relevant to the clinimetric properties of isokinetic testing. Articles retained for this review were mined for information on the sample tested, procedural specifics (e.g., speed and movement tested), and clinically relevant findings.

3. Results and discussion

The PubMed search identified 312 potentially relevant articles. After review, 183 articles were excluded leaving 129 articles for inclusion in this report. Rele-

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Table 1
Summary of studies describing the isokinetic measurement of strength in knee osteoarthritis (OA)

Authorship (year)	Participants	Isokinetic procedures	Findings
Aily (2019) [8]	Brazilians with knee OA (n = 40; mean age = 59.8 y) & without knee OA (n = 40; mean age = 59.9 y).	Biodex System 3 Pro dynamometer measured knee extensor strength (PT & body weight normalized PT) @ 60°/s & isometric extensor strength (PT & body weight normalized PT).	Validity: knee extensor strength in middle-aged without knee OA SGNF > older-aged without knee OA. Knee extensor strength in middle-aged with knee OA SGNF > older-aged with knee OA. No difference in knee extensor strength between middle-aged with knee OA & older-aged without knee OA.
Akyol et al. (2010) [9]	Turkish females with bilateral knee OA assigned to isokinetic strength training with short-wave diathermy (n = 20; mean age = 57.8 y) or isokinetic strength training without short-wave diathermy (n = 20; mean age = 56.6 y).	Cybex Human Norm dynamometer measured concentric flexor & extensor strength (PT) @ 60, 120, & 180°/s.	Responsiveness: no difference in knee strength between groups at 4 weeks. 3-month improvements in right knee flexor strength @ 60°/s & right knee extensor strength @ 60 & 120°/s for group receiving short-wave diathermy SGNF > group without short-wave diathermy. No between group difference in left limb or other speeds.
Alencar et al. (2007) [10]	Brazilians with knee OA with a history of falling (n = 15; mean age = 74.2 y) or without a history of falling (n = 5; mean age = 71.7 y).	Biodex System 3 measured concentric knee flexor & extensor strength (body weight adjusted PT, work, & power) @ 60, 120, & 180°/s.	Validity: No difference in concentric knee flexor or extensor strength between groups.
Alkatan et al. (2015) [11]	Americans with knee OA assigned to receive cycling (n = 24; mean age = 61 y) or swimming (n = 24; mean age = 59 y).	Biodex dynamometer measured knee flexor & extensor strength (PT) @ 60 & 120°/s.	Reliability: test-retest reliability in knee strength measurement (ICC = 0.88 to 0.97). Responsiveness: SGNF ↑ knee flexor & extensor strength in both groups.
Almosnino et al. (2012) [12]	Canadians with knee OA (n = 35; mean age = 62.1 y).	Biodex System 3 dynamometer measured concentric knee extensor strength (bodyweight adjusted PT) @ 60, 90, & 120°/s.	Validity: concentric knee extensor strength @ 60° SGNF > @ 90 & 120°/s. No difference in pain between test speeds.
Altubasi et al. (2018) [13]	Jordanians with knee OA (n = 160; mean age = 63.6 y).	Biodex System 3 measured isokinetic knee extensor strength (PT) @ 60°.	Validity: height, weight, age, gender, & isometric knee extensor strength partially explained variability in Get Up and Go Test (r^2 = 0.41) and WOMAC physical function subscale (r^2 = 0.21). Reliability: test-retest knee extensor strength (ICC = 0.96).
Amin et al. (2009) [14]	Americans with knee OA (n = 265; mean age = 67 y).	Cybex dynamometer measured isokinetic knee extensor strength (bodyweight adjusted PT) @ 60°/s.	Responsiveness: no relationship between knee extensor strength & cartilage loss. Highest tertile of knee extensor strength had SGNF ↓ risk of patellofemoral cartilage loss (OR = 0.4), better WOMAC physical function scores, & less pain.
An et al. (2008) [15]	Chinese females with knee OA assigned to Baduanjin-traditional Chinese exercise (n = 14; mean age = 65.4 y) or control (n = 14; mean age = 64.6 y).	Biodex System 3 measured isokinetic knee extensor strength (PT) @ 60°/s.	Responsiveness: SGNF ↑ knee extensor strength for exercise group.
An et al. (2013) [16]	Chinese with knee OA (n = 22; mean age = 65.2 y) assigned to Baduanjin exercise.	Biodex System 3 Pro dynamometer measured knee flexor & extensor strength (PT) @ 60°/s.	Responsiveness: SGNF ↑ in knee flexor & extensor strength.
Anandkumar (2014) [17]	Indians with knee OA assigned to receive kinesiotape with tension (n = 20; mean age = 55.7 y) or kinesiotape without (n = 20; mean age = 55.9 y) tension.	Cybex Humac NORM dynamometer measured concentric & eccentric knee extensor strength (PT) @ 90 & 120°/s.	Reliability: test-retest concentric knee extensor strength (ICC = 0.87 to 0.92; MDC = 0.03 to 0.05 Nm/kg) & eccentric knee extensor strength (ICC = 0.72 to 0.86; MDC = 0.14 to 0.19 Nm/kg). Responsiveness: concentric knee extensor strength in group receiving kinesiotape with tension SGNF > group without tension, no between group difference in eccentric knee extensor strength.

Table 1, continued

Authorship (year)	Participants	Isokinetic procedures	Findings
Bacon et al. (2018) [18]	Americans with knee OA (n = 834; mean age = 62.9 y).	Cybex 350 dynamometer measured knee extensor strength (PT & bodyweight adjusted PT) @ 60°/s.	Validity: knee extensor strength females SGNF < males. Females with knee extensor strength < 38 Nm was associated with larger ↑ difficulty rising from a chair & getting off toilet. Females with knee extensor strength < 0.74 Nm/kg associated with larger ↑ 20m walk test time.
Baert et al. (2013) [19]	Belgians with established knee OA (n = 24; mean age = 64.0 y), early knee OA (n = 21; mean age = 65.5 y) or healthy controls (n = 20; mean age = 62.9 y).	Biodex System 3 Pro dynamometer measured knee flexor & extensor strength (body weight adjusted PT) @ 60 & 240°/s & isometric knee flexor & extensor strength (body weight adjusted PT) @ 60 & 90°.	Validity: knee extensor strength in OA groups was SGNF < healthy group. Knee flexor strength in established OA group SGNF < early knee OA or healthy groups. Reliability: test-retest strength (ICC = 0.75 to 0.98).
Baert et al. (2014) [20]	Belgian females (mean age = 65.2 y) with knee OA (n = 45) & asymptomatic controls (n = 42).	Biodex System 3 Pro dynamometer measured knee extensor strength (body weight adjusted PT) @ 60 & 240°/s & isometric knee flexor & extensor strength (body weight adjusted PT) @ 60 & 90°.	Validity: High correlation between all strength measures ($r > 0.70$). SGNF association between Kellgren-Lawrence grade & isokinetic extensor strength ($\beta = -0.331$) but not isometric flexor or extensor strength. Variability in isometric extensor strength was partially explained ($r^2 = 0.28$) by patellofemoral cartilage integrity & pain. Variability in isokinetic extensor strength was partially explained ($r^2 = 0.38$) by amount of cartilage lesions, loose bodies & pain. Variability in isometric knee flexor strength was partially explained ($r^2 = 0.34$) by synovitis/effusion, patellofemoral cartilage integrity & pain. Reliability: test-retest all strength measures (ICC = 0.75 to 0.98).
Baert et al. (2017) [21]	Belgian females with knee OA (n = 68; mean age = 65.6 y) & healthy controls (n = 56; mean age = 65.0 y).	Biodex System 3 measured isometric flexor & extensor strength (bodyweight adjusted PT) @ 60 & 90°, & isokinetic extensor strength(bodyweight adjusted PT) @ 60 & 240°/s.	Validity: knee strength (all measures) in knee OA SGNF < control group. SGNF inverse correlation of pain catastrophizing with isometric flexor strength @ 60 & 90° ($r = -0.31$ to -0.26). SGNF inverse correlation of kinesiophobia & isometric extensor strength @ 90° ($r = -0.26$). No relationship between psychological factors & knee strength.
Barker (2018) [22]	Americans with knee OA (n = 29; mean age = 49 y).	Biodex System 4 dynamometer measured concentric flexor & extensor strength (bodyweight adjusted PT) @ 60°/s & isometric extension strength (PT) @ 60°.	Validity: SGNF correlation of knee strength on limb with knee OA & superoxide dismutase but not cytokines.
Batista et al. (2018) [23]	Brazilian females with knee OA (n = 11; median age = 62 y) & healthy controls (n = 10; median age = 65 y).	Biodex System 4 measured knee flexor & extensor strength (bodyweight adjusted PT) @ 90 & 240°/s.	Validity: OA group knee extensor strength @ 90 & 240°/s, & flexor strength @ 90°/s SGNF < control group.
Bayramoğlu et al. (2003) [24]	Turks with knee OA assigned to physiotherapy (n = 15; mean age = 60.7 y), physiotherapy with low molecular weight hyaluronic acid (n = 15; mean age = 61.5 y), or physiotherapy with higher molecular weight hyaluronic acid (n = 16; mean age = 62.6 y).	Cybex 770 Norm dynamometer measured flexor & extensor strength (PT) @ 60 & 90°/s.	Responsiveness: no difference in isokinetic strength within or between groups over time.
Bayramoglu et al. (2007) [25]	Turks with bilateral knee OA (n = 50; mean age = 60.2 y) & age matched controls (n = 30; mean age = 57.9 y).	Cybex 770 Norm dynamometer measured isometric flexor & extensor strength (PT) @ 90°.	Validity: OA group isometric knee flexor & extensor strength SGNF < control group.
Bily (2019) [26]	Austrians with knee OA (n = 75; mean age = 67.5 y).	S2P dynamometer measured isometric knee extensor strength (PT) @ 60°.	Validity: SGNF inverse correlation of isometric knee extension strength with Timed Up and Go Test ($r = -0.41$ to -0.39) & stair climb test ($r = -0.46$).

Table 1, continued

Authorship (year)	Participants	Isokinetic procedures	Findings
Bokaeian et al. (2016) [27]	Iranians with knee OA assigned to strength training with whole body vibration ($n = 15$; mean age = 51.8 y) or strength training without whole body vibration ($n = 13$; mean age = 54.0 y).	Biodex System 4 Pro dynamometer measured concentric knee flexor & extensor strength (PT, power, & work) @ 90 & 120°/s.	Responsiveness: ↑ knee extensor strength in group receiving whole body vibration training SGNF > group without whole body vibration.
Börjesson et al. (1996) [28]	Swedes with knee OA assigned to physiotherapy ($n = 34$; mean age = 64 y) or control ($n = 37$; mean age = 64 y).	Cybex II dynamometer measured isokinetic flexor & extensor strength (PT) at 30°/s.	Responsiveness: no difference in knee extensor or flexor strength after physiotherapy compared to control.
Brandt et al. (1999) [29]	Americans with knee OA ($n = 79$; mean age = 71.6 y).	KIN-COM 500H dynamometer measured knee flexor & extensor strength (body weight adjusted PT) @ 60 & 120°/s.	Validity: no difference in knee flexor & extensor strength between females with progressive or stable knee OA. Body weight adjusted knee extensor strength was inversely correlated with body weight ($r = -0.60$ to -0.39) in females. Reliability: test-retest knee strength (ICC = 0.90).
Brandt et al. (2000) [30]	Americans with radiographic knee OA ($n = 35$; mean age = 71.7 y) & without radiographic knee OA ($n = 171$; median age = 70.3 y).	KIN-COM 500H dynamometer measured knee flexor & extensor strength (PT & bodyweight adjusted PT) @ 60°/s.	Validity: knee extensor strength with knee OA SGNF < without knee OA. Knee extensor strength with knee pain without radiographic OA SGNF < healthy controls. No difference in knee extensor strength between females with knee OA & females without radiographic knee OA but with knee pain. Knee flexor strength in females with knee pain without radiographic knee OA SGNF < compared to those with knee OA or controls. In females with knee pain, individuals with radiographic knee OA had SGNF ↓ flexor strength than those without radiographic knee OA. No difference in flexor strength between radiographic knee OA & controls for knee flexor strength.
Bülow et al. (1994) [31]	Danes with knee OA (median age = 74 y) assigned to low power laser ($n = 14$) or placebo ($n = 7$).	Kin-Com dynamometer measured knee extensor strength (PT) @ 60°/s.	Responsiveness: no between group differences in knee extensor strength.
Carpenter et al. (2006) [32]	Americans with mild knee OA ($n = 18$; mean age = 54.1 y).	Biodex Multi-joint System B2000 measured extensor & flexor isokinetic strength (bodyweight adjusted PT, work, power, & fatigue) @ 60 & 180°/s, & isometric extensor strength (maximum average torque, maximum repetition work) @ 30, 45, & 80°.	Reliability: test-retest isometric strength (ICC = 0.81 to 0.96) & isokinetic strength (ICC = 0.60 to 0.95).
Cavanellas et al. (2018) [33]	Brazilians with mild knee OA ($n = 20$; mean age = 56.3 y), severe knee OA ($n = 20$; mean age = 66.1 y), 6 months post TKA ($n = 20$; mean age = 69.1 y), 12 months post TKA ($n = 20$; mean age = 65.8 y), & healthy controls ($n = 20$; mean age = 67.9 y).	CSMI dynamometer measured maximal knee flexion & extension strength (bodyweight adjusted PT) @ 60°/s.	Validity: severe knee OA or post-TKA knee extensor & flexor strength SGNF < control or mild knee OA groups.

Table 1, continued

Authorship (year)	Participants	Isokinetic procedures	Findings
Cetin et al. (2008) [34]	Turks with bilateral knee OA assigned to isokinetic exercise with receive short-wave diathermy & hot packs (n = 20; mean age = 59.8 y), isokinetic exercise with transcutaneous electric stimulation & hot packs (n = 20; mean age = 61.9 y), isokinetic exercise with ultrasound & hot packs (n = 20; mean age = 57.6 y), isokinetic exercise with hot packs (n = 20; mean age = 61.1 y), or isokinetic exercise only (n = 20; mean age = 58.9 y).	Cybex 770 Norm measured concentric knee flexor & extensor strength (PT) @ 60, 120, & 180°/s.	Responsiveness: knee extensor strength SGNF ↑ in all groups, with strength ↑ in groups receiving short-wave diathermy & hot packs, transcutaneous electric stimulation & hot packs, or ultrasound & hot packs > control group. Knee flexor strength ↑ for all groups SGNF > control group.
Chen et al. (2008) [35]	Taiwanese with mild to moderate knee OA assigned to wear magnetic knee wrap (n = 21; mean age = 64.2 y) or sham wrap (n = 21; mean age = 66.1 y).	Biodex System 3 measured concentric knee extensor strength (bodyweight adjusted PT) @ 30 & 60°/s.	Responsiveness: knee extensor strength SGNF ↑ in magnetic knee wrap group.
Cherian et al. (2015) [36]	Americans with knee OA (n = 5; mean age = 69 y) assigned to neuromuscular electrical stimulation.	Biodex dynamometer measured knee flexor & extensor strength (PT & body weight normalized PT) @ 60°/s.	Responsiveness: no difference in knee strength.
Cherian et al. (2015) [37]	Americans with knee OA assigned to standard care (n = 10; mean age = 54 y) or transcutaneous electrical stimulation (n = 13; mean age = 55 y).	Biodex dynamometer measured knee flexor & extensor strength (bodyweight adjusted PT) @ 60°/s.	Responsiveness: SGNF ↑ knee flexor & extensor strength in group receiving transcutaneous electrical stimulation.
Conroy et al. (2012) [38]	Americans with knee OA (n = 858; mean age = 73.5 y).	Kin-Com dynamometer measured concentric knee extensor strength PT) @ 60°/s.	Validity: no difference in knee extensor strength with or without radiographic knee OA & with or without pain. Radiographic knee OA group knee extensor strength per unit of muscle area SGNF < group without radiographic knee OA. Knee extensor strength per unit of muscle area for radiographic knee OA & pain group SGNF < group without radiographic knee OA or pain.
Cornish and Peeler (2018) [39]	Canadians with knee OA with creatine supplementation (n = 9; mean age = 57.5 y) or without creatine supplementation (n = 8; mean age = 56.7 y).	Biodex System 3 measured isometric knee flexor & extensor strength (PT) @ 0, 45, & 90°.	Responsiveness: SGNF ↓ in isometric knee extension @ 0° for both groups. No difference between groups in isometric flexor or extensor isometric strength.
Cudejko et al. (2017) [40]	Dutch with knee OA (n = 689; mean age = 62.2 y).	EnKnee isokinetic dynamometer measured isokinetic knee flexor & extensor strength(bodyweight adjusted PT) @ 60°/s.	Validity: SGNF association of muscle strength with proprioception ($\beta = -0.48$ to -0.40) & systemic inflammation ($\beta = -0.42$ to -0.24).
de Zwart et al. (2015) [41]	Dutch with knee OA (n = 301; mean age = 61.5 y).	EnKnee dynamometer measured knee flexor & extensor strength (bodyweight adjusted PT) @ 60°/s.	Validity: knee flexor & extensor strength in those reporting falls within previous 3 months SGNF < those without falls. SGNF association of knee flexor (OR = 0.2) & extensor (OR = 0.3) strength with lower falls history.

Table 1, continued

Authorship (year)	Participants	Isokinetic procedures	Findings
Dias et al. (2017) [42]	Brazilian females with knee OA assigned to hydrotherapy ($n = 36$; mean age = 70.8 y) or control ($n = 37$; mean age = 71.0 y).	Biodex System 3 measured isokinetic flexor & extensor strength (bodyweight adjusted PT), power, & fatigue index at 180°/s.	Responsiveness: SGNF ↑ in flexor & extensor strength, flexor power, & extensor fatigue index in group receiving hydrotherapy.
Diracoglu et al. (2005) [43]	Turkish females with knee OA assigned to strength training with kinesthesia/ balance exercises ($n = 30$) or without kinesthesia/ balance exercises ($n = 30$).	Biodex System 3 measured knee flexor & extensor strength (bodyweight adjusted PT) @ 60, 180, & 240°/s.	Responsiveness: SGNF ↑ in isokinetic knee extensor strength for both groups. Kinesthesia/balance group SGNF ↑ knee extensor strength @ 180, & 240°/s while the group without kinesthesia/balance SGNF ↑ knee extensor strength @ 60 & 180°/s.
Diracoglu et al. (2009) [44]	Turks with knee OA assigned to hyaluronan injection ($n = 40$; mean age = 59.4 y) or control placebo injection ($n = 20$; mean age = 56.2 y).	Biodex System 3 Pro measured knee flexor & extensor strength (PT, & agonist/antagonist ratio) @ 60, 180, & 240°/s.	Responsiveness: ↑ in flexor & extensor strength @ 60°/s in the hyaluronan group SGNF > control group. No between group differences in knee strength @ 180 & 240°/s.
Diraçoglu et al. (2009) [45]	Turks with bilateral knee OA ($n = 51$; mean age = 55.6 y) & healthy controls ($n = 43$; mean age = 52.4 y).	Biodex System 3 Pro measured knee flexor & extensor strength (bodyweight adjusted PT) @ 60, 180, & 240°/s.	Validity: knee flexor & extensor strength in OA group @ all speeds SGNF < control group. Knee flexor & extensor muscle strength for Kellgren-Lawrence stage I SGNF > stage II @ all speeds.
Edelaar et al. (2017) [46]	Dutch with knee OA ($n = 562$; mean age = 62.1 y).	EnKnee isokinetic dynamometer measured flexor & extensor strength (PT & bodyweight adjusted PT) @ 60°/s.	Validity: SGNF correlation of knee strength between sides ($r = 0.81$). SGNF association between knee strength & Get Up and Go Test ($\beta = -6.45$; $r^2 = 0.32$ to 0.43). SGNF association between knee strength & Stair climb test ($\beta = -7.53$; $r^2 = 0.31$ to 0.45). SGNF association between knee strength & Stair descent test ($\beta = -9.02$; $r^2 = 0.30$ to 0.39).
Eyigör et al. (2004) [47]	Turks with bilateral knee OA assigned to isokinetic exercise ($n = 21$; mean age = 53.1 y) or progressive resistance exercise ($n = 18$; mean age = 51.9 y).	Cybex Norm Dynamometer measured knee flexor & extensor strength @ 60, 90, 120, & 180°/s.	Responsiveness: SGNF ↑ isokinetic flexor & extensor strength in both groups without between group differences.
Germanou et al. (2013) [48]	Greeks with knee OA ($n = 10$; mean age = 58.9 y) & age-weight matched controls ($n = 10$; mean age = 62.4 y) assigned to isokinetic exercise.	Cybex 6000 dynamometer measured concentric flexor & extensor (PT) @ 90, 120, & 150°/s.	Validity: knee flexor & extensor strength in knee OA group SGNF < control group.
Gkrilias et al. (2018) [49]	Greeks with knee OA ($n = 40$; mean age = 61.7 y).	Biodex System 3 measured isokinetic flexor & extensor strength (bodyweight adjusted PT) @ 120 & 180°/s.	Validity: SGNF correlation between isokinetic flexor & extensor strength @ both speeds with 6 minute Walk Test ($r = 0.618$ to 0.666), Timed Up and Go Test ($r = -0.625$ to -0.530), 30 second Chair Stand Test ($r = 0.509$ to 0.557), & 12 Stair Climb Test ($r = -0.671$ to -0.624). Functional measures predicted isokinetic strength ($r^2 = 0.497$ to 0.607).
Glass et al. (2013) [50]	Americans with knee OA or risk factors for knee OA ($n = 2404$; mean age = 62.2 y).	Cybex 350 dynamometer measured knee flexor & extensor strength (PT) @ 60°/s.	Validity: knee strength in males SGNF > females. Responsiveness: lower knee extensor strength SGNF > risk (RR = 1.23 to 1.28) of worsening knee pain in females but not males.
Gökçen et al. (2016) [51]	Turks with knee OA ($n = 152$; mean age = 57.3 y).	NORM 6000 dynamometer measured knee flexor & extensor strength (PT) @ @ 60°/s & isometric strength (PT) 60°.	Validity: Female knee strength SGNF < males. SGNF inverse correlation of knee strength with pain ($r = -0.33$ to -0.22), comorbidity ($r = -0.32$ to -0.22) & WOMAC score ($r = -0.37$ to -0.21). No difference in knee strength by Kellgren-Lawrence grade.

Table 1, continued

Authorship (year)	Participants	Isokinetic procedures	Findings
Gur et al. (2002) [52]	Turks with knee OA assigned to concentric ($n = 9$; mean age = 56 y), concentric-eccentric ($n = 8$; mean age = 55 y), or no exercise control ($n = 6$; mean age = 57 y).	Cybex 6000 dynamometer measured concentric & eccentric flexor & extensor strength (PT) @ 60, 120, & 180°/s.	Responsiveness: SGNF ↑ concentric extensor strength @ 120, & 180°/s in concentric group only. SGNF ↑ eccentric strength in concentric-eccentric group at all speeds, & concentric group @ 120°/s. SGNF ↑ concentric flexor strength for both exercise groups. SGNF ↑ in eccentric flexor strength @ 60 & 120°/s for both exercise groups but only the concentric-eccentric group @ 180°/s.
Gur and Cakin (2003) [53]	Turkish females with bilateral knee OA ($n = 18$; mean age = 56 y).	Cybex 6000 dynamometer measured concentric & eccentric flexor & extensor strength (PT) @ 60, 120, & 180°/s.	Validity: eccentric strength for knee flexors & extensors SGNF > concentric @ all speeds. SGNF correlation of eccentric to concentric strength for flexors ($r = 0.36$ to 0.87) & extensors ($r = 0.73$ to 0.86) @ all speeds. SGNF correlation between concentric flexor & extensor strength ($r = 0.63$ to 0.83) & eccentric flexor & extensor strength ($r = 0.61$ to 0.88). SGNF correlation between quadriceps cross sectional area with concentric & eccentric extensor strength ($r = 0.68$ to 0.78) & hamstrings cross sectional area with concentric & eccentric flexor strength ($r = 0.49$ to 0.73). Variation in strength was partially explained by cross sectional area of flexors ($r^2 = 0.46$ to 0.61) & extensors ($r^2 = 0.24$ to 0.54) respectively. SGNF correlation of stair climbing time with eccentric flexor to concentric extensor ratio ($r = 0.71$ to 0.73) & stair descent time with concentric flexor to eccentric extensor ratio ($r = 0.68$ to 0.77). Stair climbing time was predicted by eccentric flexor to concentric extensor ration ($r^2 = 0.81$), eccentric flexor strength ($r^2 = 0.48$) & concentric flexor to concentric extensor ratio ($r^2 = 0.45$). Stair descent time was predicted by concentric flexor to eccentric extensor ratio ($r^2 = 0.61$) & concentric flexor to concentric extensor ratio ($r^2 = 0.45$). Reliability: test-retest ($r = 0.72$ to 0.95) for all strength measures.
Ha et al. (2018) [54]	Korean females with knee OA assigned to aquatic therapy ($n = 9$; mean age = 60.9 y) or non-exercise control ($n = 8$; mean age = 61.3 y).	Biodex System 3 measured isokinetic knee flexor & extensor strength (bodyweight adjusted PT) @ 60°/s.	Responsiveness: SGNF ↑ knee extensor strength in aquatic therapy group, although no difference between groups.
Hall et al. (2018) [55]	Australians with knee OA assigned to exercise ($n = 49$; mean age = 65.7 y) or control ($n = 48$; mean age = 63.8 y).	KinCom 125-AP measured isometric knee extensor strength (bodyweight adjusted PT) @ 60°.	Responsiveness: knee extensor strength in exercise group SGNF > control group. ↑ in knee extensor strength accounted for 38% & 60% of variability in WOMAC pain & function.
Harper (2019) [56]	Americans with knee OA assigned to moderate intensity ($n = 19$; mean age = 69.1 y) or low load blood flow restriction resistance training ($n = 16$; mean age = 67.2 y).	Biodex system measured knee extensor isokinetic strength (PT) @ 60°, 90°, & 120°/s.	Responsiveness: SGNF ↑ knee extensor strength @ all three speeds for both groups, but no between group differences.
Huang et al. (2003) [57]	Taiwanese with bilateral knee OA (mean age = 62 y) assigned to isokinetic exercise ($n = 33$), isotonic exercise ($n = 33$), isometric exercise ($n = 33$), or non-exercise control ($n = 33$).	Kin-Com 505 dynamometer measured eccentric & concentric flexor & extensor strength (PT) @ 60 & 180°/s.	Responsiveness: SGNF ↑ in strength @ 60°/s in isokinetic & isotonic groups @ 8 weeks & 1 year, & only 1 year for isometric group. SGNF ↑ in strength for isokinetic group only @ 180°/s @ 8 weeks & 1 year.

Table 1, continued

Authorship (year)	Participants	Isokinetic procedures	Findings
Huang et al. (2005) [58]	Taiwanese with bilateral knee OA (mean age = 65.0 y) assigned to isokinetic exercise ($n = 35$), isokinetic exercise & pulse ultrasound ($n = 35$), isokinetic exercise & pulse ultrasound & hyaluronan injection ($n = 35$), or non-exercise control ($n = 35$).	Kin-Com 505 dynamometer measured concentric & eccentric flexor & extensor strength (PT) @ 60 & 180°/s.	Responsiveness: SGNF ↑ in concentric & eccentric flexor & extensor strength @ 60 & 180°/s in all exercise groups @ 8 weeks & 1 year, with group receiving exercise, pulse ultrasound & hyaluronan SGNF > other groups.
Huang et al. (2005) [59]	Taiwanese with knee OA ($n = 120$; mean age = 62.0 y) assigned to control group, isokinetic exercise, or isokinetic exercise with continuous, or isokinetic exercise with pulsed ultrasound.	Kin-Com 505 dynamometer measured concentric & eccentric knee flexion & extension strength (PT) @ 60 & 180°/s.	Responsiveness: SGNF ↑ flexor & extensor strength @ 60°/s after treatment & @ follow-up for groups receiving isokinetic exercise & either pulsed or continuous ultrasound compared to other groups. SGNF ↑ flexor & extensor strength @ 60°/s @ follow-up in isokinetic only compared to control group. ↑ knee flexor & extensor strength @ 180°/s in group receiving isokinetic exercise & pulsed ultrasound SGNF > other groups.
Hurley and Newham (1993) [60]	British with knee OA ($n = 10$; mean age = 56 y) assigned to exercise including isokinetic training.	Cybex System II + dynamometer measured extensor strength (PT) @ 30, 60, 90, 120 & 180°/s & isometric extensor strength (PT) @ 90°.	Validity: isometric knee extensor strength in knee OA SGNF < age predicted norms & contralateral knee without OA. Responsiveness: SGNF ↑ knee extensor strength @ 30°/s in knees without OA. SGNF improvement in knee extensor strength deficits in knee with OA compared to contralateral knee @ 30, 60, 90, & 120°/s. SGNF ↑ in isometric knee extensor strength to achieve predicted normative values. SGNF < knee extensor strength compared to contralateral knee without OA @ all speeds remained after training. No difference in isometric knee extensor strength between knee OA & contralateral knee.
Jadelis et al. (2001) [61]	Americans with knee OA ($n = 480$; mean age = 71.8 y).	Kin-Com 125E dynamometer measured concentric & eccentric knee flexor & extensor strength (PT) @ 30% velocity.	Validity: correlation of knee flexor & extensor strength ($r = 0.97$), & knee strength with ankle strength ($r = 0.54$ to 0.68). Knee strength in males SGNF > females. Knee strength partially explained the variance in anterioposterior balance ($r^2 = 18.4\%$).
Kean et al. (2010) [62]	Canadians with knee OA ($n = 20$; mean age = 53.6 y).	Biodex System 3 dynamometer measured concentric knee extensor strength (bodyweight adjusted PT & body size adjusted PT) @ 60°/s & isometric extensor strength (bodyweight adjusted PT & body size adjusted PT) @ 90°.	Reliability: test-retest isokinetic knee extensor strength (ICC = 0.93; MDC = 33.90 Nm) & isometric knee extensor strength (ICC = 0.98; MDC = 25.02 Nm).
Kim et al. (2018) [63]	Taiwanese females with bilateral knee OA & no swelling ($n = 40$; mean age = 68.3 y).	CSMI isokinetic dynamometer measured maximal knee flexion & extension strength (PT) @ 60 & 180°/s.	Validity: knee extensor strength in painful knees SGNF < non-painful knees. SGNF inverse correlation for knee extensor strength with dynamic balance stability ($r = -0.58$ to -0.44). No correlation between knee strength & proprioception.
King et al. (2008) [64]	Canadians with knee OA & varus malalignment ($n = 14$; mean age = 48.4 y) assigned to isokinetic resistance training.	Biodex System 3 measured concentric knee flexor & extensor strength (PT & work) @ 60, 90, 120, & 180°/s.	Validity: knee strength in affected limb SGNF < unaffected at all time points. Responsiveness: SGNF ↑ in knee flexor & extensor strength at all speeds at week 3, no further ↑ afterward.
Koeckhoven et al. (2016) [65]	Dutch with knee OA ($n = 319$; mean age = 60.5 y).	En-Knee dynamometer measured knee flexor & extensor strength (body weight adjusted PT) @ 60°/s.	Validity: SGNF correlation between right & left limb strength ($r > 0.75$). Individuals with serum 25-hydroxy vitamin D levels < 50 nmol/l had SGNF ↓ strength. SGNF association for strength with 25-hydroxy vitamin D levels ($\beta = 0.03$), & BMI ($\beta = -0.448$).

Table 1, continued

Authorship (year)	Participants	Isokinetic procedures	Findings
Kumar et al. (2014) [66]	Americans with radiographic knee OA ($n = 30$; mean age $= 57.7$ y) or without radiographic knee OA ($n = 66$; mean age $= 50.7$ y).	Primus RS dynamometer measured knee flexor & extensor strength (bodyweight adjusted PT) @ 120°/s, & isometric knee flexor & extensor strength (bodyweight adjusted PT) @ 70°.	Validity: knee extensor strength in knee OA group SGNF $<$ control group. No difference between groups for knee flexor strength. SGNF inverse correlation between isometric knee extensor strength & age ($r = -0.36$), Kellgren-Lawrence grade ($r = -0.23$), & total cartilage ($r = -0.16$).
Lankhorst et al. (1985) [67]	Dutch with knee OA ($n = 39$; mean age $= 62.4$ y).	Cybex System II dynamometer measured knee flexor & extensor strength (PT) @ 30, 60, 120, & 180°/s & isometric knee extension strength (PT) @ 90°.	Validity: knee strength on affected knee SGNF $<$ unaffected contralateral knee (65–83%). SGNF correlation between isometric & isokinetic strength @ all speeds ($r = 0.80$ to 0.95). SGNF inverse correlation of walking time with knee extensor strength @ 30°/s ($r = -0.46$) & isometric knee extensor strength ($r = -0.41$). Variability in walking time, functional capacity score, stair climb test, & mean pain score were partially explained by a combination of knee extensor strength & pain ($r^2 = 0.23$ to 0.38).
Lee et al. (2015) [68]	Koreans with knee OA ($n = 35$; mean age $= 57.8$ y).	Biodex System 4 dynamometer measured knee flexor & extensor strength (bodyweight adjusted PT & work) @ 60 & 180°/s.	Validity: SGNF correlation of knee flexor ($r = 0.43$) & extensor ($r = 0.43$) work @ 180°/s with adduction moment. No correlation between knee flexor or extensor PT with adduction moment.
Levinger et al. (2018) [69]	Australians with knee OA ($n = 24$; mean age $= 68.6$ y).	Biodex System 2 measured isokinetic knee extensor strength (bodyweight & height adjusted PT) @ 90 & 180°/s, & flexor strength (bodyweight & height adjusted PT) @ 120°/s.	Validity: individuals with multiple stepping strategy after induced forward fall had SGNF ↓ isokinetic knee extensor strength @ 180°/s than those with fewer steps. No difference in other strength measures by stepping strategy.
Lim et al. (2010) [70]	Obese Koreans with knee OA assigned to aquatic exercise ($n = 26$; mean age $= 65.7$ y), land-based exercise ($n = 25$; mean age $= 67.7$ y), or control ($n = 24$; mean age $= 63.3$ y.	Biodex dynamometer measured knee flexor & extensor strength (PT) @ 60°/s.	Responsiveness: No change in knee strength for any group.
Lim et al. (2015) [71]	Koreans with knee OA ($n = 40$; mean age $= 56.7$ y).	Primus RS dynamometer measured isometric extensor strength (bodyweight adjusted PT) @ 60°.	Validity: no difference in isometric knee extension strength by radiographic knee alignment.
Madsen et al. (1996) [72]	Danish with knee OA awaiting knee arthroplasty ($n = 23$; median age $=$ 69 y).	Cybex 6000 dynamometer measured knee flexor & extensor strength (PT) @ 30 & 120°/s & isometric knee flexor & extensor strength (PT) @ 75°.	Validity: knee extensor strength SGNF $>$ flexor strength. Knee extensor strength @ 120°/s SGNF $<$ 30°/s or isometric strength. Reliability: test-retest knee flexor strength @ 120°/s (ICC $= 0.81$ to 0.92).
Malas et al. (2013) [73]	Turks with knee OA assigned to isokinetic ($n = 20$; mean age $= 56.2$ y), isometric ($n = 22$; mean age $= 61.2$ y), or isotonic exercise ($n = 19$; mean age $= 59.1$ y).	Biodex System 3 dynamometer measured concentric flexor & extensor strength (body weight adjusted PT) @ 60°/s.	Responsiveness: SGNF ↑ knee extensor strength in trained & contralateral knee for isometric group only. No within group differences for knee flexor strength. No difference in knee strength between groups after training.
Maly et al. (2006) [74]	Canadians with knee OA ($n = 54$; mean age $= 68.3$ y).	Biodex System 3 measured concentric flexor & extensor strength (PT) @ 60°/s.	Validity: SGNF correlation of Functional Self Efficacy scores with knee extensor strength ($r = 0.35$) & flexor strength ($r = 0.39$). SGNF correlation of flexor with extensor strength ($r = 0.79$). Variance in Functional Self Efficacy scores is partially explained by stiffness, flexor strength, age, & depression ($r^2 = 0.51$).
Maly et al. (2008) [75]	Canadians with knee OA ($n = 53$; mean age $= 68.5$ y).	Biodex System 3 measured knee extensor strength (PT) @ 60°/s.	Validity: muscle strength did not contribute to explanation of pain variability.
Matsuno et al. (1997) [76]	Japanese with knee OA ($n = 20$; mean age $= 76.6$ y) assigned to knee bracing.	KIN-500-HX dynamometer measured knee extensor strength (PT) @ 30°/s.	Responsiveness: SGNF ↑ in knee extensor strength with knee brace.

Table 1, continued

Authorship (year)	Participants	Isokinetic procedures	Findings
Matsuse et al. (2017) [77]	Japanese with knee OA ($n =$ 11; mean age = 74.0 y) assigned to electrical stimulation with walking.	Biodex System 3 measured isokinetic knee flexor & extensor strength (bodyweight adjusted PT) @ 60°/s.	Responsiveness: SGNF ↑ extensor & flexor strength.
Maurer et al. (1999) [78]	Americans with knee OA assigned to an educational intervention ($n = 49$; mean age = 64.5 y) or isokinetic exercise ($n = 49$; mean age = 66.3 y.	Biodex dynamometer measured knee extensor strength (PT) @ 90 & 120°/s, & isometric knee extensor strength (PT) @ 90°.	Responsiveness: SGNF ↑ knee extensor isometric strength & isokinetic strength @ 90°/s in both the exercise & education groups, with only the exercise group ↑ @ 120°/s. SGNF association of ↑ knee extensor strength @ 120°/s with ↓ WOMAC pain, function, & total score.
Messier et al. (1992) [79]	Americans with knee OA (n = 15; mean age = 58.7 y) or without knee OA ($n = 15$; mean age = 58.1 y).	Cybex II + dynamometer measured knee flexor & extensor strength (bodyweight adjusted PT & peak flexor-extensor ratio) @ 60°/s.	Validity: knee flexor & extensor strength in OA group SGNF < control group. Non-dominant leg flexor & extensor strength SGNF < dominant leg in the OA group.
Messier et al. (2000) [80]	Obese Americans with knee OA assigned to exercise & diet ($n = 13$; mean age = 69 y) or exercise alone (n = 11; mean age = 67 y).	Kin-Com 125E isokinetic dynamometer measured flexor & extensor strength (mean torque) @ 30°/s.	Responsiveness: SGNF ↑ in flexor & extensor strength in both groups without between group differences.
Messier et al. (2002) [81]	Older Americans with knee OA ($n = 480$; mean age 71.8 y).	Kin-Com 125E dynamometer measured concentric & eccentric knee flexor & extensor strength (PT) @ 30°/s.	Validity: SGNF association between knee & ankle strength @ baseline. Responsiveness: SGNF ↓ in knee flexor & extensor strength. SGNF association between knee & ankle strength @ 30 months. Greater knee strength at baseline was SGNF associated with less decline in balance @ 30 months.
Mikesky et al. (2006) [82]	Older Americans assigned to strength training ($n = 113$; mean age = 69.4 y) or range of motion ($n = 108$; mean age = 68.6 y).	Kin-Com III dynamometer measured concentric flexor & extensor strength (PT) @ 60 & 120°/s.	Validity: knee extensor strength in males without knee OA SGNF > males with knee OA, no difference in knee flexor strength. Knee flexor & extensor strength in females without pain SGNF > females with pain. Responsiveness: SGNF ↓ in flexor & extensor strength @ 30 months. SGNF larger↓ in extensor strength @ 30 months in range of motion group @ 120°/s, & with baseline knee OA @ 60°/s, & larger ↓ if painful at baseline @ 120°/s. SGNF larger ↓ in flexor strength @ 30 months in range of motion group @ 60°/s. SGNF correlation between exercise session adherence & flexor (r = 0.32 to 0.37) & extensor (r = 0.32 to 0.35) strength @ 60°/s for the strength training group.
Miltner et al. (2002) [83]	Germans with bilateral knee OA ($n = 43$; mean age = 67.0 y) assigned to unilateral hyaluronic acid injections.	Cybex 6000 dynamometer measured flexor & extensor strength (PT & work) @ 60, 90, 120, 150, & 180°/s.	Responsiveness: SGNF ↑ in knee flexor & extensor strength in treatment group but not the control group.
Öğüt (2018) [84]	Turk females with knee OA assigned to Kinesiology Taping ($n = 31$; mean age = 53.8 y) or Sham Taping (n = 30; mean age = 53.1 y) to the extensor muscles.	Humac Norm isokinetic dynamometer measured knee extensor strength (PT) @ 60 & 180°/s.	Responsiveness: SGNF ↑ in knee extensor strength in both groups, although no difference between groups.
Park et al. (2013) [85]	Korean females with knee OA assigned to home based exercise with whole body vibration ($n = 11$; mean age = 62.5 y) or home based exercise without ($n = 11$; mean age = 60.0 y).	Biodex 900-240 dynamometer measured knee extensor isokinetic strength (PT) @ 60°/s & isometric strength (PT) @ 60°.	Responsiveness: no difference in strength change between groups. SGNF ↑ right & not left knee extensor strength @ 60°/s. SGNF ↑ knee extensor isometric strength in both knees for both groups.
Patsika et al. (2014) [86]	Greek females with knee OA ($n = 12$; mean age = 60.3 y) & healthy controls (n = 11; mean age = 56.5 y).	Cybex dynamometer measured concentric & eccentric knee flexor & extensor strength (flexor/extensor ratio) @ 60, 120, & 150°/s.	Validity: females with knee OA flexor/extensor ratio SGNF > healthy controls.

Table 1, continued

Authorship (year)	Participants	Isokinetic procedures	Findings
Peeler and Ripat (2018) [87]	Canadians with knee OA (n = 31; mean age = 64.2 y) assigned to low-intensity exercise.	Biodex System 3 measured maximal isokinetic knee extensor strength (bodyweight adjusted PT) @ 60, 180, & 240°/s.	Validity: no difference in strength between affected & unaffected limbs at baseline. Responsiveness: females had SGNF ↑ in knee extensor strength @ 60, 180 & 240°/s.
Peixoto et al. (2011) [88]	Older Brazilian females with unilateral or bilateral knee OA ($n = 35$; mean age = 73.3 y).	Biodex System 3 Pro dynamometer measured concentric knee flexor & extensor strength (bodyweight adjusted PT) @ 60 & 180°/s.	Validity: SGNF inverse correlation of knee extensor strength @ 180°/s & age ($r = -0.34$), but not @ 60°/s. No correlation with proprioceptive acuity & strength.
Pelletier et al. (2013) [89]	Canadian females with knee OA ($n = 17$; mean age = 60.3 y) assigned power training.	Biodex System 3 dynamometer measured knee extensor strength (power & work) @ 180°/s & isometric knee extensor strength (PT) @ 30°.	Responsiveness: SGNF ↑ knee extensor power & work but no difference in isometric strength.
Peloquin et al. (1999) [90]	Canadians with knee OA assigned an exercise program ($n = 59$; mean age = 65.6 y) or educational control (n = 65; mean age = 66.4 y).	Isokinetic dynamometer measured knee flexor & extensor strength (PT) @ 30 & 90°/s & isometric flexor & extensor strength (PT) @ 30 & 60°.	Responsiveness: improvement in isometric knee extensor, & isokinetic & isometric knee flexor strength in exercise group was SGNF > control group. No between group differences in isometric knee flexor strength.
Petrella et al. (2017) [91]	Brazilians with knee OA (n = 24 mean age = 52.4 y) & healthy controls ($n = 20$; mean age = 51.4 y).	Biodex System 3 measured concentric & eccentric knee extensor strength (bodyweight adjusted PT) @ 90°/s, & isometric knee extensor strength (bodyweight adjusted PT) @ 60°.	Validity: knee OA group eccentric knee extensor strength < control group, but not concentric or isometric strength.
Pua et al. (2011) [92]	Singaporeans with knee OA awaiting total knee replacement ($n = 104$; mean age = 67 y).	Biodex dynamometer measured isometric knee extensor strength (body weight adjusted PT) @ 75°.	Validity: variation in SF36 physical function & gait speed were partially explained (r^2 = 0.32 to 0.55) by knee extensor strength, center of pressure displacement, & covariates.
Pua et al. (2013) [93]	Singaporeans with knee OA awaiting total knee replacement ($n = 67$; mean age = 67.2 y).	Biodex dynamometer measured isometric knee extensor strength (body weight adjusted PT) @ 75°.	Validity: individuals with slower gait speeds (< 1.0 m/s) had SGNF ↓ knee extensor strength.
Robbins et al. (2011) [94]	Canadians with symptomatic knee OA of medial compartment ($n = 38$; mean age = 54 y).	Biodex System 3 Pro dynamometer measured concentric knee extensor strength (PT) @ 60°/s.	Validity: SGNF correlation of knee extensor strength with KOOS pain score ($r = 0.49$). Variation in KOOS pain score was partially explained ($r^2 = 0.49$) by BMI, knee extensor strength, external knee adduction moment, & steps/day.
Rodrigues-da-Silva et al. (2017) [95]	Brazilians with knee OA (n = 130; mean age = 64.3 y) pre & post-familiarization to isokinetic testing.	Biodex System 3 measured flexor & extensor isokinetic strength (PT, body weight adjusted PT, total work, coefficient of variation, & agonist-antagonist ratio) @ 60°/s.	Responsiveness: SGNF ↑ strength (PT, body weight adjusted PT, & total work) with ↓ coefficient of variation post-familiarization to isokinetic testing. No difference in agonist-antagonist ratio.
Rodrigues da Silva (2019) [96]	Brazilians with knee OA (n = 136; mean age = 66.3 y) assigned interdisciplinary exercise education program.	Biodex System 3 dynamometer measured concentric knee flexor & extensor strength (PT, bodyweight adjusted PT, total work, coefficient of variation, & agonist-antagonist ratio) @ 60°/s.	Responsiveness: SGNF ↑ knee flexor & extensor strength (all measures) & ↓ coefficient of variation after training. No difference in agonist-antagonist ratio or strength between legs.
Røgind et al. (1998) [97]	Danes with knee OA assigned to exercise (n = 11; mean age = 69.3 y) or control ($n = 12$; mean age = 73.0 y).	Cybex 6000 dynamometer measured knee flexor & extensor strength (PT) @ 30, 60, 90 & 120°/s & isometric @ 90°.	Responsiveness: SGNF ↑ knee flexor & extensor strength @ 30°/s & isometric for exercise group.
Samut et al. (2015) [98]	Turks with knee OA assigned to isokinetic exercise ($n = 15$; mean age = 62.5 y), aerobic exercise ($n = 14$; mean age = 57.6 y), or control ($n = 13$; mean age = 60.9 y).	Biodex System 3 Pro dynamometer measured concentric knee flexor & extensor strength (bodyweight adjusted PT) @ 60 & 180°/s.	Responsiveness: SGNF ↑ in right knee extensor strength in aerobic exercise group, but not other groups or the left knee for all groups. SGNF ↑ in left knee flexor strength @ 60°/s in isokinetic group, & @ 180°/s in aerobic exercise group, with no difference in right knee strength in all groups.

Table 1, continued

Authorship (year)	Participants	Isokinetic procedures	Findings
Sanchez-Ramirez et al. (2013) [99]	Dutch with knee OA (n = 284; mean age = 61.5 y).	EnKnee dynamometer measured knee flexor & extensor strength (body weight adjusted PT) @ 60°/s.	Validity: SGNF association in one leg stance time (> 30 s) with knee strength (β = 0.1 to 0.23).
Sanchez-Ramirez et al. (2013) [100]	Dutch with knee OA (n = 285; mean age = 61.7 y).	EnKnee dynamometer measured knee flexor & extensor strength (body weight adjusted PT) @ 60°/s.	Validity: SGNF association of lower muscle strength with elevated C-reactive protein ($\beta = -0.10$) & erythrocyte sedimentation rate ($\beta = -0.12$) which was no longer SGNF after controlling for BMI.
Sanchez-Ramirez et al. (2014) [101]	Dutch with knee OA (n = 186; mean age = 61.0 y).	EnKnee dynamometer measured knee flexor & extensor strength (bodyweight adjusted PT) @ 60°/s.	Responsiveness: group with elevated c-reactive protein @ baseline & 2y had SGNF < strength improvements ($\beta = -0.21$ to -0.17) @ 2-years.
Sanchez-Ramirez et al. (2015) [102]	Dutch with knee OA (n = 186; mean age = 61.2 y).	EnKnee dynamometer measured knee flexor & extensor strength (bodyweight adjusted PT) @ 60°/s.	Responsiveness: SGNF ↑ in mean knee muscle, & flexor & extensor strength @ 2-years. SGNF association between knee extensor strength & WOMAC physical function score ($\beta = -2.8$), Get Up and Go Test ($\beta = -0.08$), & 12-Stairs Step Test ($\beta = -2.7$).
Santos et al. (2011) [103]	Brazilian females with knee OA (n = 80; mean age = 71.2 y).	Biodex System 3 Pro dynamometer measured concentric knee flexor & extensor strength (bodyweight adjusted PT) 60 & 180°/s.	Validity: SGNF inverse correlation of Interleukin-6 with knee flexor strength ($r = -0.23$) & hamstring to quadriceps ratio ($r = 0.25$) @ 180°/s. No correlation of knee extensor strength with I'nterleukin-6.
Schilke et al. (1996) [104]	Americans with knee OA assigned to isokinetic exercise (n = 10; mean age = 64.5 y) or control (n = 10; mean age = 68.4 y).	Cybex II dynamometer measured flexor & extensor strength (PT) @ 90°/s.	Responsiveness: SGNF ↑ flexor & extensor strength in exercise group, & right flexors & left extensors in control group. Strength ↑ for exercise group in left flexor strength SGNF > control group. No other between group differences in knee strength.
Segal et al. (2009) [105]	Americans (mean age = 62.4 y) with knee OA (n = 2078) & without knee OA (n = 1617).	Cybex 350 dynamometer measured concentric knee flexor & extensor strength (PT) @ 60°/s.	Validity: knee extensor strength in males SGNF > females. Responsiveness: knee strength was not predictive of incident radiographic OA @ 30 months. SGNF ↓ risk of incident symptomatic knee OA for highest tertile in females (OR = 0.4) & males (OR = 0.5).
Segal et al. (2009) [106]	Americans with knee OA or at risk for knee OA (n = 1269 female knees & 1006 male knees; mean age = 62.2 y).	Cybex 350 dynamometer measured concentric knee flexor & extensor strength (PT) @ 60°/s.	Reliability: knee strength test-retest (ICC = 0.94). Responsiveness: concentric knee extensor strength does not predict development of knee symptoms @ 15 or 30 months.
Segal et al. (2010) [107]	Americans with knee OA or risk factors for knee OA (n = 2856; mean age = 62.2 y).	Cybex 350 dynamometer measured knee flexor & extensor strength (PT) @ 60°/s.	Validity: male knee flexor & extensor strength SGNF > females. Reliability: test-retest knee strength (ICC = 0.94). Responsiveness: females in the lowest tertile of extensor strength @ baseline SGNF > risk of joint space narrowing @ 30 months for the whole knee (OR = 1.66) or tibiofemoral joint (OR = 1.69). No difference in joint space narrowing based upon strength for males.
Segal et al. (2011) [108]	Americans who were non-obese (n = 113: mean age = 55.0 y), obese (n = 101; mean age = 54.7 y), or moderate to severely obese (n = 89; mean age = 55.2 y).	Biodex System 3 dynamometer measured knee extensor strength (PT) @ 60°/s.	Validity: No difference in strength by BMI or presence of knee OA.
Serrão et al. (2012) [109]	Brazilians with knee OA (n = 27; mean age = 51.8 y).	Biodex System 3 dynamometer measured concentric & eccentric knee extensor strength (body weight adjusted PT) @ 90°/s.	Validity: SGNF inverse correlation of concentric & eccentric extensor strength with WOMAC pain ($r = -0.70$ & $r = -0.56$), stiffness ($r = -0.62$ & $r = -0.44$), & physical function ($r = -0.54$ & -0.52).
Serrão et al. (2015) [110]	Brazilian males with knee OA (n = 22; mean age = 51.9 y) or without knee OA (n = 18; mean age = 52.0 y).	Biodex System 3 dynamometer measured concentric & eccentric knee flexor & extensor strength (bodyweight adjusted PT) @ 90 & 180°/s.	Validity: eccentric knee extensor strength in group without knee OA SGNF > knee OA group. OA group knee extensor strength to Type 2b & Type 1 fiber cross sectional area SGNF < control group. No between group difference in concentric knee strength or muscle fiber cross sectional area.

Table 1, continued

Authorship (year)	Participants	Isokinetic procedures	Findings
Shakoor et al. (2017) [111]	Americans with knee OA or at high risk for knee OA (n = 1803; mean age = 67.6 y).	Cybex 350 dynamometer measured isokinetic extensor strength (bodyweight adjusted PT) @ 60°/s.	Responsiveness: ↑ Strength associated with SGNF ↓ risk of incident (RR = 0.48) & worsening (RR = 0.64) of slipping & shifting symptoms; ↓ incident (RR = 0.86) & worsening (RR = 0.85) of buckling, ↓ instability symptoms (RR = 0.53) & worsening (RR = 0.73).
Silva et al. (2018) [112]	Brazilians with knee OA & sleep apnea (n = 15; mean age = 55.4 y), sleep apnea without knee OA (n = 15; mean age = 54.9 y), knee OA without sleep apnea (n = 15; mean age = 53.2 y), or control (n = 15 mean age = 52.6 y).	Biodex System 3 measured isometric knee extensor strength (bodyweight adjusted PT) @ 60°, & concentric & eccentric knee extensor strength (bodyweight adjusted PT) @ 90 & 180°/s.	Validity: concentric knee extensor strength @ 90 & 180°/s in group with knee OA & sleep apnea SGNF < participants without knee OA, & group with knee OA without sleep apnea SGNF < groups without knee OA. Isometric knee extensor strength in group with knee OA & sleep apnea SGNF < participants without knee OA, & group with knee OA without sleep apnea SGNF < groups without knee OA. No differences in eccentric knee extensor strength between groups.
Skou et al. (2016) [113]	Americans with knee OA (n = 1257; mean age = 62.2 y).	Cybex 350 dynamometer measured knee extensor strength (PT) @ 60°/s.	Validity: no difference in risk for TKA by knee extensor strength when adjusted for radiographic severity.
Slemenda et al. (1997) [114]	Americans with knee OA (n = 112; mean age = 72.4 y) or without knee OA (n = 350; mean age = 72.1 y).	Kin-Com 500H dynamometer measured concentric & eccentric knee flexor & extensor strength (PT) @ 60 & 120°/s.	Validity: knee extensor strength in knee OA group SGNF < group without knee OA. Knee extensor strength in females with knee OA but no pain group SGNF > knee OA with pain group. Risk of radiographic (OR = 0.80) & symptomatic (OR = 0.71) knee OA SGNF ↓ per 10 lb/ft of knee extensor strength.
Slemenda et al. (1998) [115]	Elderly Americans (mean age = 70.8 y) with knee OA (n = 99) or without knee OA (n = 237).	Kin-Com 500H dynamometer measured concentric knee flexor & extensor strength (PT, body weight adjusted PT, & lower extremity muscle mass adjusted PT) @ 60°/s.	Validity: knee strength (body weight adjusted) in females with knee OA SGNF < controls. No difference in relative strength by knee OA status for males. SGNF correlation between body weight & knee extensor strength in male controls (r = 0.22) but not females. Responsiveness: SGNF correlation between knee extensor strength & body weight (r = −0.74) among females with incident knee OA. SGNF correlation between body weight & knee extensor strength (adjusted for lower extremity muscle mass) in females controls (r = −0.21), with incident knee OA (r = −0.83), & those with knee OA who did not develop contralateral knee OA (r = −0.46). No correlation between knee extensor strength (adjusted for lower extremity muscle mass) & body weight in males. No between group difference in knee flexor strength for controls or incident knee OA.
Stefanik et al. (2011) [116]	Americans with knee OA or at risk for knee OA (n = 807 knees; mean age = 62 y).	Cybex 350 dynamometer measured concentric knee extensor strength (bodyweight adjusted PT & BMI adjusted PT) @ 60°/s.	Validity: individuals in the lowest tertile of knee extensor strength had SGNF ↑ medial & lateral patellofemoral joint cartilage damage & lateral patellofemoral bone marrow lesions. Reliability: concentric knee extensor strength test-retest (ICC = 0.94).
Tan et al. (1995) [117]	Turkish females with radiographic knee OA & knee pain (n = 30; mean age = 63.0 y), knee pain without radiographic knee OA (n = 30; mean age = 51.9 y), & healthy controls (n = 30; mean age = 50.6 y).	Cybex-350 dynamometer measured knee flexor & extensor strength (PT, & agonist/antagonist ratio) @ 60 & 180°/s, & isometric flexor & extensor strength (PT & agonist/antagonist ratio) @ 30 & 60°.	Validity: knee flexor & extensor isometric & isokinetic strength in both OA groups SGNF < healthy controls. No between group differences in agonist/antagonist ratio.
Tang et al. (2005) [118]	Taiwanese with bilateral knee OA (n = 25; mean age = 61.3 y) assigned hyaluronan injection to each knee.	Kin-Com dynamometer measured knee flexor & extensor strength (bodyweight adjusted PT) @ 80 & 240°/s.	Responsiveness: SGNF ↑ concentric & eccentric flexor & extensor strength @ 80 & 240°/s, except non-SGNF ↑ in concentric flexor strength @ 240°/s.

Table 1, continued

Authorship (year)	Participants	Isokinetic procedures	Findings
Tok et al. (2011) [119]	Turks with knee OA assigned to receive conventional physical therapy with combined continuous passive motion & electrical stimulation ($n = 20$; mean age = 61.8 y) or conventional physical therapy with isometric exercise ($n = 20$; mean age = 66.6 y).	Cybex 6000 dynamometer measured concentric & eccentric flexor & extensor strength (PT & work) @ 60°/s.	Responsiveness: SGNF improvement in right flexor strength but not left or knee extension strength for group receiving continuous passive motion & electrical stimulation.
Tuna and Balcı (2014) [120]	Turkish females with knee OA ($n = 117$; mean age = 57.9 y).	Cybex NORM 6000 measured knee flexor & extensor strength (PT, work) @ 90 & 180°/s.	Validity: no difference in extensor strength @ 90°/s based upon presence or absence of radiographic knee OA. Knee flexor work on left limb only SGNF < right limb.
Tuna et al. (2016) [121]	Turks with knee OA ($n = 40$, mean age = 52.03 y) undergoing strength training protocol.	Cybex NORM 6000 measured knee flexor & extensor strength (PT & work) @ 60 & 180°/s, & isometric strength (PT) @ 30 & 60°.	Validity: SGNF correlation between cartilage thickness & isometric knee flexor ($r = 0.25$ to 0.30) & extensor ($r = 0.25$) strength @ 30° & isokinetic work @ 180°/s ($r = 0.25$ to 0.32) at baseline. No correlation between cartilage thickness & isokinetic PT or isometric strength @ 60° at baseline. Responsiveness: knee flexor & extensor PT @ 30 & 60°/s & total work @ 180°/s SGNF ↑ @ 1 & 3 months. No correlation between cartilage thickness & strength @ 1 month. SGNF correlation between cartilage thickness & isometric knee flexor strength ($r = 0.39$), isokinetic knee flexor ($r = 0.47$) & extensor strength ($r = 0.49$) @ 60°/s & knee flexor ($r = 0.38$ to 0.40) & extensor ($r = 0.40$ to 0.42) work @ 180°/s.
Valtonen et al. (2015) [122]	Finns with late stage knee OA ($n = 56$; mean age = 65.7 y).	Humac NORM dynamometer measured knee flexor & extensor strength (PT & power) @ 60 & 180°/s.	Validity: knee strength on affected knee SGNF < unaffected knee. Variability in maximal walking speed ($r^2 = 0.41$ to 0.53) & stair ascension time ($r^2 = 0.58$ to 0.59) was partially explained by asymmetry in knee extensor power, contralateral or ipsilateral knee flexor & extensor power, & WOMAC pain subscale.
van der Esch et al. (2006) [123]	Dutch with knee OA ($n = 86$; mean age = 63.6 y).	EnKnee dynamometer measured knee flexor & extensor strength (bodyweight adjusted PT) @ 60°/s.	Validity: SGNF correlation between knees for extensor strength ($r = 0.79$), flexor strength ($r = 0.83$), & average flexor/extensor strength ($r = 0.85$). SGNF correlation for joint laxity with total muscle strength ($r = -0.34$). SGNF correlation for total muscle strength with walking time ($r = -0.50$), & WOMAC physical function score ($r = -0.61$). Variation in walking time ($r^2 = 0.35$) & WOMAC physical function score ($r^2 = 0.43$) were partially explained by muscle strength, & joint laxity.
van der Esch et al. (2007) [124]	Dutch with symptomatic knee OA ($n = 63$; mean age = 60 y).	EnKnee dynamometer measured knee flexor & extensor strength (bodyweight adjusted PT) @ 60°/s.	Validity: SGNF correlation between limbs for knee extensor ($r = 0.80$) & flexor ($r = 0.90$) strength, & average of flexor & extensor strength ($r = 0.94$). Variation in walking time can be partially explained ($r^2 = 0.54$) by knee muscle strength, proprioception, & their interaction. Muscle strength is SGNF associated with walking time, Get Up and Go Test, & WOMAC physical function subscale.
van der Esch et al. (2008) [125]	Dutch with knee OA ($n = 63$; mean age = 60 y).	EnKnee dynamometer measured knee flexor & extensor strength (bodyweight adjusted PT) @ 60°/s.	Validity: No correlation of varus-valgus range of motion or mid-stance position with muscle strength.

Table 1, continued

Authorship (year)	Participants	Isokinetic procedures	Findings
van der Esch et al. (2008) [126]	Dutch with knee OA ($n =$ 63; mean age = 60 y).	EnKnee dynamometer measured knee flexor & extensor strength (bodyweight adjusted PT) @ 60°/s.	Validity: Variation in walking time, Get Up and Go Test, & WOMAC physical function scores were partially explained ($r^2 =$ 0.36 to 0.54) by mid-stance varus-valgus position, muscle strength, & their interaction.
van der Esch et al. (2012) [127]	Dutch with knee OA ($n =$ 248, mean age = 61.0 y).	EnKnee dynamometer measured knee flexor & extensor muscle strength (body weight adjusted PT) @ 60°/s.	Validity: knee strength & pain do not moderate the association of self-reported knee instability with activity limitations.
Wageck et al. (2016) [128]	Brazilians with knee OA assigned to kinesiotape ($n =$ 38; mean age = 69.6 y) or sham taping ($n =$ 38; mean age = 68.6 y).	Biodex System 4 dynamometer measured knee flexor & extensor strength (bodyweight adjusted PT) @ 60°/s.	Responsiveness: no difference in knee flexor & extensor strength between groups.
Weng et al. (2009) [129]	Taiwanese with bilateral knee OA (mean age = 64.0 y) assigned to non-exercise control ($n =$ 33), isokinetic strengthening ($n =$ 33), isokinetic strengthening with static stretching ($n =$ 33), or isokinetic strengthening with proprioceptive neuromuscular facilitation ($n =$ 33).	Kin-Com 505 dynamometer measured concentric & eccentric knee flexor & extensor strength (PT) @ 60 & 180°/s.	Responsiveness: SGNF ↑ in knee flexor & extensor strength with isokinetic exercise (proprioceptive neuromuscular facilitation > static stretching > isokinetic training alone).
Wessel et al. (1996) [130]	Canadian females with knee OA ($n =$ 17; mean age = 60.8 y) or without ($n =$ 17; mean age = 63.8 y) knee OA.	Kin-Com dynamometer measured isokinetic knee extensor strength (PT) @ 30, 60, & 90°/s.	Validity: knee extensor strength in worse knee SGNF < less affected limb in presence of OA. Knee extensor strength @ 60°/s SGNF > 30 & 90°/s, & 90°/s SGNF > 30°/s for individuals with & without knee OA. Reliability: test-retest knee extensor strength (ICC = 0.83 to 0.95).
White et al. (2010) [131]	Americans with knee OA or at risk for knee OA ($n =$ 1801; mean age = 62.7 y).	Cybex 350 dynamometer measured knee extensor strength (PT) @ 60°/s.	Responsiveness: reaching MCID in WOMAC physical function @ follow-up was associated with ↓ radiographic knee OA, medication use, BMI, pain, & depressive symptoms & ↑ walking speed & knee extensor strength @ baseline.
Wu et al. (2008) [132]	Taiwanese with knee OA & normal ($n =$ 11; mean age = 61.1 y) or abnormal patellar alignment ($n =$ 14; mean age = 63.4 y), & healthy controls ($n =$ 10; mean age = 61.4 y).	Cybex Norm dynamometer measured knee extensor strength (body weight adjusted PT) @ 80, 120, & 240°/s.	Validity: knee extensor strength in groups with knee OA SGNF < control, no difference between knee OA groups based on patellar alignment.
Wu et al. (2018) [133]	Taiwanese with bilateral knee OA (mean age = 63.3 y) assigned to platelet rich plasma injection ($n =$ 20) or control ($n =$ 20).	Biodex System 3 measured concentric isokinetic strength (PT) of knee flexors & extensors @ 60 & 180°/s.	Responsiveness: SGNF ↑ in all strength @ 60°/s @ 2 week through 6 months post injection in both groups, although no difference between groups.
Yázigi (2018) [134]	Portuguese with obesity & knee OA ($n =$ 48; mean age = 55 y).	Biodex System 3 measured bilateral isokinetic & isometric knee flexor & extensor strength (bodyweight adjusted PT).	Validity: SGNF correlation between all strength measures & 6 minute Walk Test ($r =$ 0.505 to 0.655).
Yilmaz et al. (2010) [135]	Turks with knee OA assigned strength training with EMG-biofeedback ($n =$ 20; mean age = 55.6 y) or strength training without EMG-biofeedback ($n =$ 20; 59.4 y).	Cybex dynamometer measured knee flexor & extensor strength (PT) @ 60 & 180°/s, & isometric knee extensor strength (PT) @ 65°.	Responsiveness: SGNF ↑ in all knee strength measures in both groups, no between group differences.

Table 1, continued

Authorship (year)	Participants	Isokinetic procedures	Findings
Yoon et al. (2018) [136]	Japanese females with knee OA assigned whole body vibration therapy & maslinic acid supplementation ($n = 11$; mean age = 69.5 y) or whole body vibration therapy & placebo ($n = 15$; mean age = 71.0 y).	Biodex System 4 measured maximal isometric knee extensor strength (bodyweight adjusted PT) @ 60° of flexion, & isokinetic knee flexion & extension strength (bodyweight adjusted PT) @ 60°/s.	Responsiveness: knee with Kellgren-Lawrence grade $\leqslant$ 2 had SGNF ↑ in strength measures for both groups. Knees with Kellgren-Lawrence grade $\geqslant$ 3 had SGNF ↑ for both groups on isokinetic flexor strength & only masclinic acid group for extensor strength.

*OA = osteoarthritis, PT = peak torque, SGNF = significant/significantly, BMI = body mass index, ICC = intraclass correlation coefficient, MDC = minimal detectable change, OR = odds ratio, r = Pearson correlation, β = standardized regression coefficient, r^2 = variance, RR = relative risk, KOOS = Knee Injury Osteoarthritis Outcome Score, WOMAC = Western Ontario McMaster Universities Osteoarthritis Index, TKA = total knee arthroplasty.

vant information from these articles are summarized in Table 1 [8–136].

The summarized information demonstrates that isokinetic dynamometry is frequently utilized to measure strength of the knee flexor and extensor muscles in the presence of OA. Testing has been reported throughout the world with Asia, Europe, North America, and South America producing the bulk of published work. Various dynamometers have been used although Biodex, Cybex, En-Knee, and Kin-Com are most frequently reported. Most protocols have measured concentric contractions, with a primary outcome of peak torque (PT) or PT adjusted for body weight while fewer studies have reported work, power, fatigue, and agonist/antagonist ratio. Isokinetic test velocities range from 30 to 240°/s, with most studies utilizing 60°/s – which appears to produce larger PT values than higher or lower velocities [12,72,130].

Isokinetic knee strength measurements have demonstrated convergent validity with several related factors. Knee flexor and extensor strength have been shown to be strongly correlated ($r = 0.79$ to 0.97) [61,67,74,123, 124], with knee extensor testing producing larger torque values than flexor testing [72]. Concentric and eccentric measurements have been reported to be highly correlated ($r = 0.61$ to 0.88), eccentric efforts demonstrating larger torque values than concentric efforts for both the knee flexor and extensor muscles [53]. A strong correlation exists between the right and left lower extremities for knee flexor and extensor ($r = 0.80$ to 0.90) strength [46,124]. Isokinetic strength has demonstrated strong correlations between testing velocities for the knee extensors [20]. Muscle cross-sectional area and isokinetic strength ($r = 0.49$ to 0.78) have been found to be positively correlated with cross-sectional area-partially explaining the variability in isokinetic strength performance [53]. Body mass index (BMI) may or may not be associated with lower knee strength in the presence of knee OA [65,108].

The clinimetric properties of isokinetic knee strength measurement have been supported via known groups or conditions validity in various ways. Dominant limb strength is larger than non-dominant limb strength [79] and strength measurements in the lower extremity affected with knee OA tend to be lower than in the unaffected limb [64,67,122,130] but no difference has also been reported [87]. Knee extensor strength tends to be greater in individuals without knee OA than with knee OA [8], younger adults have greater strength than older adults [8,66,88], and middle-aged adults with knee OA have similar strength to older adults without knee OA [8]. Knee flexor and extensor strength also tends to be greater in males than females [18,50,51,61,105,107]. Body weight is inversely correlated with knee extensor strength more frequently in females than males [29,115], and those who develop incident knee OA [115].

Healthy adults tend to have stronger knee flexors [23, 30,33,45,48,79,115,117] and extensors [19,21,23,30, 33,38,45,48,66,79,82,91,110,114,115,117,132] than individuals with knee OA, however some studies have reported no difference in the flexors [30,66] and extensors [38,120] based upon presence or absence of knee OA. Knee flexor [19,33,45] and extensor [20,33,45] strength tends to be larger in the early stages of OA than later in the natural course, although some studies have reported no strength differences based upon disease severity [29,51]. Isometric knee strength is reportedly lower in the presence of knee OA [21,25,60,117] and worsens with disease severity [66] with few exceptions [20,91]. A correlation appears to exist between knee cartilage integrity and isometric knee flexor and extensor strength [66,121], but not isokinetic strength [121]. The variability in knee extensor isokinetic and isometric strength may be partially explained by patellofemoral cartilage integrity, extent of cartilage lesions, loose bodies, synovitis or effusion, and pain [20]. Significantly higher medial and lateral patellofemoral joint cartilage damage and lateral patellofemoral bone marrow lesions have been found in those in the lowest tertile of knee extensor strength [116].

Pain appears to be negatively correlated with knee strength ($r = -0.33$ to -0.22) [51] with individuals experiencing knee pain demonstrating lower strength than pain free controls or pain free knee OA participants [30,38,63,82,114]. An inverse correlation between pain catastrophizing and isometric knee flexor strength has been reported [21]. Muscle strength may not contribute to pain variability [75]. An inverse correlation of pain catastrophizing with isometric knee flexor strength and kinesiophobia with isometric knee extensor strength have been reported [21]. Functional self-efficacy has demonstrated a correlation with knee flexor and extensor strength, with the variability in self-efficacy partial explained by knee stiffness, flexor strength, age, and depression [74].

Functional measurements have been associated with knee strength measurement utilizing isokinetic dynamometers. Knee strength has been identified as inversely associated with functional ambulation measures including the Get Up and Go Test [13,46,102,124,126], Timed Up and Go Test [26,49], 6 minute Walk Test [49, 134], 100-meter walk test [123,124], 20-meter walk test [18], gait speed [92,93,122], and walking time [67]. Difficulty rising from a chair has been associated with lower knee extensor strength in females [18]. Functional performance on the 30-second Chair Stand Test has been correlated with knee flexor and extensor strength ($r = 0.51$ to 0.56) [49]. Stair ambulation time tends to be inversely correlated to knee strength [26,46,49, 53,67,102,122]. Knee extensor strength has been associated with lower levels of impairment on the Knee Injury and Osteoarthritis Outcome Score (KOOS) [94], Western Ontario McMaster Universities Osteoarthritis Index (WOMAC) [13,14,51,102,109,123,124,126] and Short Form-36 [92] physical function subscales. There may [40] or may not [63,88] be an association between knee strength and proprioception. An association between knee strength and balance may also be present [61,63].

Other contributing factors association with knee strength have been reported in patients with knee OA. An inverse correlation may be present between markers of systemic inflammation [40,103] or vitamin D levels [65] and knee strength in participants with knee OA [40,103]. Knee strength appears to be negatively influenced by comorbidity [51] and sleep apnea [112]. A history of falling may [41] or may not [10] be associated with lower knee strength values. Levinger et al. [69] have reported fewer steps after an induced forward fall in individuals with higher knee extensor strength performance.

The relative reliability of isokinetic dynamometry in measuring knee strength in the presence of knee OA has been characterized using intraclass correlation coefficients (ICCs). Test-retest reliability for knee isokinetic strength measurement has been noted as strong with ICCs $\geqslant 0.72$ in all studies [11,13,17,19,20,29, 32,53,62,72,106,107,116,130] except that of Carpenter et al. [32], who reported a range of ICCs from 0.60 to 0.95. Despite strong test-retest reliability, strength values may significantly increase in novice individuals after familiarization with isokinetic measurement suggesting a learning effect [95]. Minimal detectable change (MDC) values have been reported for concentric knee extensor strength PT (33.9 Nm) [62] and body weight adjusted PT for concentric knee extensor (0.03 to 0.05 Nm/kg) and eccentric knee extensor strength = 0.14 to 0.19 Nm/kg [17].

Numerous studies have documented significant increases in knee strength after exercise interventions [11,15,16,27,42,43,47,52,54–60,64,73,78,80,82, 85,87,89,90,96–98,121,129,135] including strength-/power training [27,47,55,56,80,82,85,89,90,121,135], isokinetic exercise [47,52,57–59,64,73,78,98,129], aerobic exercise [11,80,87,90], stretching [85,90], kinesthesia and balance exercises [43], physical therapy/ physiotherapy [24,60,97], hydro/aquatic therapy [42, 54], Baduanjin [15,16], and exercise education [96]. Two studies reported no difference in knee strength subsequent to physiotherapy [28] or aquatic or land-based exercise [70] both however conflicting with the positive effects of exercise reported in the majority of studies.

Thermal modalities including short wave diathermy [9,34], hot packs [34], laser [31], and ultrasound [34,58,59] have reportedly been associated with additional improvements in knee strength over exercise interventions alone. Electric modalities including transcutaneous electric stimulation [37], neuromuscular electric stimulation [77,119], and biofeedback [135] have also been reported to produce improvements in knee strength when combined with exercise interventions. Whole body vibration training in combination with exercise may [27] or may not [85] produce larger increases in knee strength than exercise training alone, or maslinic acid supplementation [136].

Kinesiotape tends to produce no difference in knee strength compared with sham taping [84,128]; conflicting results have been reported relative to control applications [17]. Although sparsely reported, knee extensor strength may improve with application of a magnetic knee wrap [35] or knee brace [76]. Intraarticular hyaluronic acid injections tend to increase knee strength measures [44,58,83,118] with one study reporting no difference [24]. Wu et al. [133] reported increased knee strength after platelet rich plasma injections although no difference was identified compared to placebo injection.

The available evidence of isokinetic measurement of knee strength the presence of knee OA is extensive, dating to at least the work of Lankhorst et al. [67] in 1985. Numerous studies have evaluated the association of knee strength and the presence and severity of knee OA, age, gender, and body type. Isokinetic dynamometry has been shown to be a valid and reliable measure of knee flexor and extensor muscle strength. In the presence of knee OA, change in knee strength over time and with various interventions have been reported.

This review utilized only one database (PubMed) which may have limited the pool of available articles meeting the search and inclusion criteria. It is unlikely, however, that the inclusion of additional databases would substantially alter the summary provided in this review.

4. Conclusion

Isokinetic measurement of knee strength is well-supported for individuals with knee OA. The evidence supports utilization of isokinetic measurement for the identification of strength impairments and subsequent responsiveness to therapeutic interventions.

Conflict of interest

The author declares no conflict of interest.

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