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Review Article

Isokinetic testing of muscle strength of older individuals post-stroke: An integrative review

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Abstract.
BACKGROUND: Muscle weakness is a common impairment accompanying stroke.
OBJECTIVE: Describe isokinetic testing procedures and clinimetric findings associated with the testing of older individuals with weakness following stroke.
METHODS: Relevant articles were identified by an electronic PubMed search using the search string "isokinet* AND stroke."
RESULTS: Seventy-six relevant articles were found. The articles largely support the validity and reliability of isokinetic strength testing of older patients with stroke. Little data are available that provides specific information on the responsiveness for such measures.
CONCLUSIONS: Isokinetic dynamometry is a valid and reliable measure of muscle strength after stroke. However, it is not particularly practical and information is lacking regarding its responsiveness.

Keywords: Muscle strength, measurement, clinimetrics

1. Introduction

Stroke is the most common neurological disorder in the world today. The World Stroke Organization has estimated that the worldwide incidence of stroke is 15 million per year and that stroke is the second leading cause of death for adults older than 60 years [1]. Although numerous impairments can result directly from stroke, muscle weakness is probably the most common and obvious [2]. Several options are available for measuring muscle strength after stroke, among them are self-report [3] manual muscle testing [4], field tests such as sit-to-stand [5], hand-held dynamometry [6], hand-grip dynamometry [7], and isokinetic dynamometry [8]. This review focuses on isokinetic dynamometry. Specifically, it seeks to describe the isokinetic testing procedures that have been applied to older individuals with stroke and the findings obtained using the procedures.

2. Methods

Potentially relevant articles were identified by a search of PubMed on February 10, 2019. The search string used was "isokinet* AND stroke." A hand-search was also conducted. Article titles and abstracts, and where warranted full text, were examined to determine whether articles identified by the searches addressed the isokinetic testing of muscle strength of individuals with stroke. Review articles and articles in languages other than English were excluded. Articles were also excluded if they failed to provide procedural specifics (e.g., dynamometer used), used a custom isokinetic dynamometer, 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., muscle groups tested and speed of testing), and clinimetrically relevant findings (e.g., information on validity, reliability, and responsiveness).

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Table 1
Summary of studies describing the isokinetic measurement of strength after stroke

Study	Participants	Procedures	Findings
Abdollahi et al. (2015) [8]	Iranians with chronic stroke ($n = 40$, mean age = 59.3 y)	Cybex Model 770 dynamometer measured concentric strength (PT normalized against nonparetic side & bodyweight) of knee extension @ 90°/s & ankle plantarflexion @ 30°/s.	Validity: paretic side strength normalized against nonparetic side correlated SGNF (τ-b $\geqslant$ 0.36) with Modified Ashworth, but paretic side strength normalized against weight was not correlated SGNF (τ-b $\leqslant -0.20$) with Modified Ashworth. Reliability: test-retest (1 wk apart) – knee extension strength ICC = 0.94 (weight normalized) & ICC = 0.86 (nonparetic side normalized); ankle plantarflexion strength ICC = 0.80 (weight normalized) & ICC = 0.70 (nonparetic side normalized).
An and Jo (2017) [9]	Koreans with chronic stroke assigned to ankle mobilization group ($n = 13$, mean age = 48.5y) or control group ($n = 13$, mean age = 48.3 y)	Biodex dynamometer measured Ⓑ concentric paretic ankle dorsiflexion & plantarflexion strength (PT normalized against body weight) @ 30°/s.	Responsiveness: ankle strength ↑ SGNF in the mobilization group but not the control group.
Andersen et al. (2011) [10]	Danish with chronic stroke ($n = 11$, mean age = 51.0 y)	KinCom dynamometer measured Ⓑ knee flexion & extension strength (normalized average torque) concentrically @ 30 & 240°/s & eccentrically @ 30°/s.	Validity: paretic side strength < nonparetic side strength. Responsiveness: 12 weeks of intensive rehabilitation associated with SGNF ↑ in all normalized paretic strength measures.
Avila et al. (2013) [11]	Brazilians with chronic stroke ($n = 22$, mean age = 65.5 y) & healthy controls ($n = 22$, mean age = 64.4 y)	Biodex Multi-joint System 3 dynamometer measured Ⓑ concentric shoulder abduction strength (PT, total work, average power) @ 60°/s.	Validity: all paretic side strength measures < nonparetic side measures, torque & work of paretic side SGNF < nonparetic side. All strength measures of the nonparetic and paretic sides < controls with all paretic side measures SIGN < controls and nonparetic work & power SGNF < controls.
Barbic and Brouwer (2008) [12]	Canadians with chronic stroke ($n = 10$, mean age = 60.6 y), healthy old group ($n = 10$, mean age = 62.1 y) & healthy young group ($n = 10$, mean age = 20.7 y) controls	Biodex System 3 dynamometer measured Ⓑ concentric hip flexion & extension strength (gravity normalized PT) @ 60°/s.	Validity: strength of patients with stroke < controls & strength of paretic side < that of nonparetic side.
Bohannon (1992) [13]	Americans with subacute stroke ($n = 20$, mean age = 63.7 y)	Lido Active Rehabilitation System measured Ⓑ knee extension strength (maximum velocity, isometric PT & power). Speed was set @ 400°/s for velocity & power. Isometric torque was measured at 90°.	Validity: strength of paretic side SGNF < nonparetic side. All strength measures were correlated SGNF with comfortable and maximum gait speed, but correlations with paretic side measures ($r = 0.63$ to 0.75) > nonparetic side measures ($r = 0.45$ to 0.65).
Bohannon (1987) [14]	Americans with subacute stroke ($n = 27$, mean age = 64.1 y)	Cybex II measured Ⓑ knee extension strength (torque) @ 30, 60, 120, & 189°/s.	Validity: strength of paretic side < that of nonpatretic side at every speed. Strength correlated SGNF ($r = 0.74$ to 0.94) between measurements @ different speeds of paretic and nonparetic sides.
Brogårdh et al. (2012) [15]	Swedes with chronic stroke assigned to vibration group ($n = 16$, mean age = 61.3 y) or control group ($n = 15$, mean age = 63.9 y)	Biodex Multi-Joint System 3 PRO dynamometer measured Ⓑ isokinetic concentric knee extension & flexion strength (PT) @ 60°/s & isometric knee extension strength (peak torque) @ 90°.	Validity: strength of paretic side < that of nonparetic side.
Calmels et al. (2011) [16]	French with subacute or chronic stroke ($n = 14$, mean age = 53.7 y)	Cybex 6000 dynamometer measured Ⓑ knee extension strength (body weight normalized PT) concentrically @ 60 & 120°/s & isometrically @ 30 & 60°.	Validity: strength of paretic side < nonparetic side. Responsiveness: strength after ergometer training. ↑ SGNF in 5 of 8 nonparetic measures and 3 of 8 paretic measures.

Table 1, continued

Study	Participants	Procedures	Findings
Carvalho et al. (2013) [17]	Swedes with chronic stroke ($n = 41$, mean age = 59 y) & healthy reference group ($n = 144$, age range = 40–79 y)	Biodex Multi-Joint System 3 PRO dynamometer measured concentric Ⓑ knee flexion & extension strength (maximum torque) @ 60°/s & isometric ankle dorsiflexion and plantarflexion strength (torque) @ 0°. A strength index was calculated using all 8 measures.	Validity: mean strength of paretic side of patients was < controls. Mean strength of nonparetic side < controls. Mean strength index for stroke group < that of control group. For patients with stroke, strength index correlated SGNF with self-selected gait speed ($r^2 = 0.37$), maximum gait speed ($r^2 = 0.63$) & 6MWT distance ($r^2 = 0.44$).
Chen et al. (2015) [18]	Taiwanese with subacute stroke assigned to isotonic training ($n = 12$, mean age = 67.1 y) or isokinetic training ($n = 12$, mean age = 64.7 y)	Biodex dynamometer measured Ⓑ isometric knee flexion & extension strength (PT) @ 90° & isokinetic knee flexion & extension strength (PT) @ 60 & 120°/s.	Responsiveness: knee strength ↑ in both groups after strength training, ↑ in isokinetic group were all SGNF.
Clark et al. (2006) [19]	Americans with chronic stroke ($n = 17$, mean age = 57.5 y) & nondisabled controls ($n = 13$, mean age = 63 y)	Biodex System 3 Pro dynamometer measured paretic knee extension strength (torque & power) isometrically @ 0° concentrically @ 30, 60, 90, 120, 150, 180, 210, & 240°/s & eccentrically @ 30, 60, 90, 120, 150 & 180°/s.	Validity: knee extension strength (as % of maximum capacity) of paretic knee extensors < controls. Reliability: test-retest 48 hr apart – ICC (torque) = 0.86 to 0.97 & ICC (power) = 0.83 to 0.97. Responsiveness: smallest real difference (%) 39.0 to 72.7 (torque) & 38.7 to 78.1 (power).
Cohen et al. (2018) [20]	Canadians with subacute stroke ($n = 75$, mean age = 61.1 y)	Biodex System 3 Pro dynamometer measured Ⓑ concentric knee & hip flexion & extension strength (PT & power) @ 60°/s & ankle dorsiflexion and plantarflexion strength (PT & power) @ 30°/s on both sides. Strength measures of each side were summed & normalized against body weight.	Validity: strength of the nonparetic lower limb was SGNF > strength of the paretic lower limb. Strength measures were correlated SGNF with the physical component of the SIPSO ($r = 0.42$ to 0.59) & the physical component summary of the SF-36 ($r = 0.29$ to 0.47).
Coroian et al. (2018) [21]	French with chronic stroke assigned to isokinetic strengthening ($n = 10$, mean age = 63.6 y) or passive mobilization ($n = 10$, mean age = 63.6 y)	CON-TREX dynamometer measured elbow flexor & extensor strength (PT) @ 30°/s & wrist flexor & extensor strength (PT) @ 15°/s.	Responsiveness: strength ↑ over 45 days in wrist & elbow muscle groups (effect sizes 0.11 to 0.44).
Dehkordi et al. (2008) [22]	Iranians with chronic stroke ($n = 42$, mean age = 61.5 y)	Biodex dynamometer measured Ⓑ concentric knee flexion & extension strength (PT & normalized PT) @ 60 & 120°.	Validity: strength of the affected side SGNF < unimpaired side. Reliability: test-retest (1 day apart) – ICC (torque) = 0.88 to 0.99 & ICC (normalized torque) = 0.85 to 0.98. Responsiveness: smallest real difference (%) 18.7 to 85.1 (torque) & 22.3 to 76.3 (normalized torque).
Dias et al. (2017) [23]	Brazilians with chronic stroke ($n = 15$, mean age = 56 y) or healthy controls ($n = 15$, mean age = 59 y)	Biodex dynamometer measured isometric ankle plantar flexion strength (PT normalized against body mass) at maximum dorsiflexion, 0° & 30°.	Validity: strength of affected limb SGNF < unaffected limb which was SGNF < control limb.
Ekiz et al. (2015) [24]	Turks with subacute/ chonic stroke assigned to kinesio tape ($n = 12$, mean age = 48.8 y) or control group ($n = 12$, mean age = 50.9 y)	Biodex System 3 Pro Multijoint System dynamometer measured Ⓑ knee flexion and extension strength (PT) @ 60 & 180°/s.	Responsiveness: after 4 weeks of training, paretic side & nonparetic side strength ↑ SGNF in all measures in both groups.

Table 1, continued

Study	Participants	Procedures	Findings
Ekstrand et al. (2015) [25]	Swedes with chronic stroke ($n = 45$, mean age = 65 y)	Biodex System 3 PRO dynamometer measured Ⓑ shoulder isometric abduction strength (torque) @ 15° of shoulder abduction, isometric elbow flexion strength (torque) @ 30° of elbow flexion), & isokinetic elbow flexion & extension strength (PT) @ 60°/s.	Reliability: test-retest (1 week apart) – ICC (less affected/more affected) isometric shoulder abduction = 0.97/0.97, isometric elbow flexion = 0.97/0.97, isokinetic elbow flexion = 0.95/0.95, isokinetic elbow extension = 0.92/0.92. Responsiveness: SRD% (less affected/more affected) isometric shoulder abduction = 16.0/26.1, isometric elbow flexion = 15.5/21.2, isokinetic elbow flexion = 20.6/25.5 isokinetic elbow extension = 25.9/34.8.
Ekstrand et al. (2016) [26]	Swedes with chronic stroke ($n = 45$, mean age = 65 y)	Biodex System 3 PRO dynamometer measured Ⓑ isometric shoulder abduction @ 15° & elbow flexion @ 90° strength (PT) & isokinetic elbow flexion & extension strength (PT) @ 60°/s.	Validity: grip strength was correlated SGNF with other strength measures of both sides: isometric shoulder abduction ($r = 0.82$ & 0.80) & elbow flexion ($r = 0.77$ & 0.82) strength & isokinetic elbow flexion ($r = 0.76$ & 0.81) & elbow extension ($r = 0.65$ & 0.77).
Eng et al. (2002) [27]	Canadians with chronic stroke ($n = 20$, mean age = 60 y)	Kim-Com dynamometer measured Ⓑ concentric hip, knee, & ankle flexion & extension strength (PT & average torque) @ 60°/s.	Validity: all strength measures of non-involved side SGNF > paretic side. Reliability: test-retest (2–4 days apart) – ICC (PT) = 0.97 to 0.99 paretic side & 0.95–0.98 non-involved side. ICC average torque = 0.96 to 0.98 paretic side & 0.88 to 0.96 non-involved side.
Eng et al. (2009) [28]	Canadians with chronic stroke ($n = 18$, mean age = 64.9 y) & neurologically healthy ($n = 18$, mean age = 63.3 y)	Kin-Com dynamometer measured Ⓑ concentric & eccentric hip, knee, & ankle flexor & extensor strength (PT) @ 30°/s.	Validity: strength of controls > strokes and strength of nonparetic side > paretic side of strokes. Physical activity correlated SGNF with concentric torque preservation ($r = 0.51$ & 0.64) but not eccentric torque preservation.
Engardt et al. (1995) [29]	Swedes ambulatory after stroke assigned to concentric training ($n = 10$, mean age = 64.6 y) or eccentric training ($n = 10$, mean age = 62.2 y)	Kin-Com 500H dynamometer measured Ⓑ concentric and eccentric strength (average torque) @ 60, 120, & 180°/s.	Responsiveness: concentric & eccentric strength ↑ SGNF in the concentric & eccentric training groups.
Fernandez-Gonzalo et al. (2014) [30]	Swedes with chronic stroke ($n = 12$, mean age = 63.3 y)	IsoMed 2000 dynamo-meter measured Ⓑ concentric and eccentric knee extension strength (PT over 1 s window) @ 30, 60, & 90°/s.	Validity: all strength measures of affected limb SGNF < nonaffected limb. Responsiveness: all strength measures of the affected knee ↑ after 8 weeks of flywheel resistance training. Some (4 of 7) strength measures of the nonaffected knee ↑ after training.
Flansbjer et al. (2006) [31]	Swedes with chronic stroke ($n = 50$, mean age = 58 y)	Biodex Multi-joint System II dynamometer measured Ⓑ concentric knee extension & flexion strength (PT) @ 60°/s.	Validity: strength of paretic knee extension & flexion < nonparetic knee extension & flexion. Nonparetic knee extension & flexion strength for men was SGNF > for women. Paretic knee extension strength for men was SGNF > for women. Paretic knee flexion strength was not SGNF different for men and women. Paretic knee extension strength, unlike nonparetic knee extension strength, was correlated SGNF with Timed up & Go ($r = -0.65$), comfortable gait speed ($r = 0.61$, fast gait speed ($r = 0.67$), stair climb ascent ($r = -0.58$), stair climb descent ($r = -0.61$), & 6 min walk test ($r = 0.70$). Paretic knee flexion strength, unlike nonparetic knee flexion strength, was correlated SGNF with timed up & go ($r = -0.64$), comfortable gait speed ($r = 0.61$, fast gait speed ($r = 0.65$), stair climb ascent ($r = -0.61$), stair climb descent ($r = -0.61$), & 6 min walk test ($r = 0.71$).

Table 1, continued

Study	Participants	Procedures	Findings
Flansbjer et al. (2005) [32]	Swedes with chronic stroke ($n = 50$, mean age = 58 y)	Biodex Multijoint System II dynamometer measured Ⓑ knee strength (torque) at 60° & 120° concentrically & 60° eccentrically.	Reliability: test-retest 7 days apart – ICC = 0.89 to 0.96. Responsiveness: smallest real difference 22–55%.
Flansbjer et al. (2012) [33]	Swedes with chronic stroke (mean age = 66 y) assigned to strength training group ($n = 11$) or control group ($n = 7$)	Biodex Multijoint System 3 PRO dynamometer measured Ⓑ knee flexion & extension strength (torque) @ 60°/s.	Validity: strength of nonparetic side SGNF > that of paretic side. Responsiveness: strength ↑ after strength training.
Flansbjer et al. (2008) [34]	Swedes with chronic stroke assigned to resistance training ($n = 15$, mean age = 61 y) or usual activity ($n = 9$, mean age = 60 y)	Biodex Multi-Joint System 3 PRO dynamometer measured Ⓑ concentric knee flexion & extension strength (PT) @ 60°/s.	Validity: strength of paretic knee muscles < that of nonparteic knee muscles. Responsiveness: strength ↑ over course of intervention in training group.
Freire et al. (2017) [35]	Brazilians with chronic stroke ($n = 12$, mean age = 59.6 y) or healthy controls ($n = 12$, mean age = 59.8 y)	Biodex Medical System 3 dynamometer measured Ⓑ isometric ankle plantarflexion strength (normalized torque) @ 0° & maximum dorsiflexion.	Validity: maximum plantarflexion strength and strength @ 0° SGNF < on the paretic than nonparetic side & on nonparetic side than healthy controls.
Gray et al. (2017) [36]	Americans with chronic stroke ($n = 18$, mean age = 61.4 y)	Biodex System Pro4 dynamometer measured Ⓑ isokinetic ankle dorsiflexion & plantarflexion strength & hip abduction & adduction strength (PT) @ 30°/s.	Validity: all strength measures of paretic limb < nonparetic limb.
Hameau et al. (2014) [37]	French with chronic stroke ($n = 14$, mean age = 54 y)	ConTrex – MJ dynamometer measured paretic isokinetic knee flexion & extension strength (PT) @ 30, 60, & 90°/s & isometric knee flexion & extension strength (PT) @ 40° & 60°.	Responsiveness: all strength measures except knee flexion @ 90°/s ↑ SGNF after botulinum toxin injection.
Hamrin et al. (1982) [38]	Swedes with chronic stroke assigned to special activation ($n = 23$, mean age = 69.9 y) or routine activation ($n = 14$, mean age = 69.7 y) or healthy controls ($n = 13$, age = not stated)	Cybex II dynamometer measured knee extension & flexion strength & elbow extension and flexion strength (torque) @ 45 & 60° during knee testing @ 30 & 90°/s & @ 90° during elbow testing @ 30 & 90°/s.	Validity: paretic limb strength < nonparetic limb strength. Both paretic and nonparetic limb strength < that of controls. All paretic knee strengths correlated SGNF with locomotion ($r = 0.71$ to 0.90). All but 2 nonparetic knee strengths were correlated SGNF with locomotion ($r = 0.47$ to 0.67). Of 48 correlations between elbow strength and 3 activities (e.g., dressing), 8 involving paretic elbow muscles were significant ($r = 0.48$ to 0.77) & 2 involving nonparetic elbow muscles were significant ($r = 0.63$ & 0.68).
Hsu et al. (2003) [39]	Taiwanese with chronic stroke ($n = 26$, mean age = 54.2 y)	Cybex 6000 dynamometer measured Ⓑ hip flexor, knee extensor, & ankle plantarflexor strength (normalized PT & total work) @ 30°/s (hip & ankle), 90°/s (knee).	Validity: affected limb strength < unaffected limb strength. All affected side strength measures correlated SGNF with comfortable speed ($r = 0.39$ to 0.57) and fast speed ($r = 0.40$ to 0.71) gait. Affected side strength measures correlated SGNF with some measures of gait asymmetry ($r = -0.25$ to -0.57).
Hsu et al. (2002) [40]	Taiwanese with chronic stroke ($n = 9$, mean age = 55.6 y)	Cybex 6000 dynamometer measured Ⓑ hip flexor, knee extensor, & ankle plantarflexor strength (normalized PT, total work & average power) @ 30°/s (all 3 muscle groups), 90°/s (hip flexors & knee extensors) & 15°/s (ankle plantarflexors).	Validity: affected limb strength < unaffected limb strength, usually SGNF. Reliability: test-retest 1 week apart – ICC = 0.62 to 0.96. ICC for strength deficits = 0.13 to 0.91.

Table 1, continued

Study	Participants	Procedures	Findings
Hyun et al. (2015) [41]	Koreans with subacute stroke ($n = 53$, mean age = 62.6 y)	Humac Norm measured Ⓑ isometric knee flexion & extension strength (gravity-corrected PT) @ 60° of knee flexion.	Validity: paretic limb strength < nonparetic limb strength. Strength of household ambulators SGNF < community ambulators. Paretic knee extensor strength related to 6 min walk test (adjusted $R^2 =$ 0.67).
Karatas et al. (2004) [42]	Turks with acute stroke ($n = 38$, mean age = 59.1 y) or healthy controls ($n = 40$, mean age = 62.6 y)	Cybex 770 NORM dynamometer measured concentric & isometric trunk flexion & extension strength (PT) @ 60, 90, 120 & 0°/s. Isometric strength measured at trunk flexion angle of 60°.	Validity: strength measures of healthy controls > patients. Strength measures SGNF higher except for isometric flexion & extension & concentric extension @ 120°/s. Of 64 correlations between trunk strength & Functional Independence scores ($r = 0.01$ to 0.51) and Berg Balance scores ($r =$ 0.10 to 0.64), 26 were SGNF.
Kim and Eng (2003) [43]	Canadians with chronic stroke ($n = 20$, mean age = 61.2 y)	Kin-Com measured Ⓑ hip, knee, and ankle flexors & extensor strength (average torque normalized to body mass) @ 60°/s.	Validity: paretic side strength < nonparetic side strength. Of 6 correlations between paretic side strength & self-selected gait speed ($r = 0.33$ to 0.84), 3 were significant. Of 6 correlations between nonparetic side strength & self-selected gait speed ($r = 0.29$ to 0.62), 2 were significant. Of 6 correlations between paretic side strength & stair speed ($r = 0.27$ to 0.71), 3 were significant. Of 6 correlations between nonparetic side strength & stair speed ($r = 0.29$ to 0.48), 2 were significant.
Kim et al. (2001) [44]	Canadians with chronic stroke assigned to isokinetic strength training ($n = 10$, mean age = 60.4 y) or passive range of motion ($n =$ 10, mean age = 61.9 y)	Kin-Com dynamometer measured Ⓑ hip flexion & extension, knee flexion & extension, & ankle dorsiflexion & plantarflexion strength (average torque normalized against body mass) @ 60°/s.	Validity: strength of paretic side < that of nonparetic side. Responsivenes: composite strength of training group ↑ over course of intervention.
Kim et al. (2005) [45]	Americans with chronic stroke ($n = 10$, mean age = 62.2 y)	Biodex System 3.0 measured Ⓑ elbow flexion & extension & shoulder flexion strength (torque, speed, power) at 30, 75 & 120°/s.	Validity: strength of paretic side < nonparetic side. Reliability: test-retest session 1, day 7, week 6 – ICC = 0.73 to 0.99 on nonparetic side & 0.64 to 0.99 on the paretic side.
Kim et al. (2016) [46]	Koreans with chronic stroke assigned to ankle biofeedback training ($n = 14$, mean age = 51.2 y) or ankle strengthening ($n = 13$, mean age = 52.8 y)	Biodex dynamometer measured isometric affected ankle dorsiflexion & plantar flexion strength (PT) with ankle @ 60°.	Responsiveness: strength ↑ SGNF in both biofeedback & ankle strengthening groups.
Knorr et al. (2010) [47]	Canadians with chronic stroke ($n = 44$, mean age = 62.6 y)	Biodex dynamometer measured Ⓑ concentric hip & knee flexion & extension strength (body-weight normalized PT) @ 60°/s & ankle dorsiflexion and plantarflexion strength (PTue) @ 30°/s.	Validity: strength of paretic lower limb SGNF < strength of nonparetic lower limb. Strength of paretic limb correlated SGNF with Community Balance & Mobility Scale, ($r_s = 0.67$), Berg Balance Scale ($r_s = 0.50$) & Timed Up & Go ($r_s =$ −0.71). Strength of nonparetic limb correlated, albeit not always SGNF, with Community Balance & Mobility Scale, ($r_s = 0.46$), BBS ($r_s = 0.28$) & Timed Up & Go ($r_s = -0.44$).
Kwong et al. (2017) [48]	Chinese with chronic stroke ($n = 105$, mean age = 61.0 y)	Cybex 6000 dynamometer measured paretic concentric knee extensor and flexor strength (PT) @ 90°/s.	Validity: strength measures correlated SGNF with one another ($r_p = 0.60$) & with 6 minute walk test ($r_p = 0.40$ & 0.46). Knee extension strength correlated SGNF with BBS ($r_p = 0.31$) but knee flexor strength did not ($r_p = 0.25$). Neither strength measure correlated significantly with the SIPSO ($r_p = 0.23$ & 0.29).

Table 1, continued

Study	Participants	Procedures	Findings
Lau et al. (2012) [49]	Hong Kongese with chronic stroke assigned to whole body vibration ($n = 41$, mean age = 57.3 y) or control group ($n = 41$, mean age-57.4)	Cybex dynamometer measured paretic side isometric knee flexion & extension strength (body mass normalized PT) @ 70°.	Responsiveness: strength ↑ SGNF but minimally over course of vibration training.
Lee et al. (2015) [50]	Koreans with stroke assigned to overground treadmill walking ($n = 16$, mean age = 50.9 y) or underwater treadmill walking ($n = 16$, mean age = 49 y)	Biodex dynamometer measured knee flexion & extension strength (PT) @ 60 & 120°/s.	Responsiveness: After 6 wk of training all strength measures ↑ SGNF except knee flexion strength @ 120°/s in overground group.
Lee and Kang (2013) [51]	Korean inpatients with stroke assigned to isokinetic eccentric strengthening ($n = 10$, mean age = 53.4y) or conventional therapy ($n = 10$, mean age = 53.9 y)	Cybex 770 dynamometer measured hip flexion & extension strength (PT) @ 90°/s.	Responsiveness: after 6 wk the eccentric training group demonstrated a SGNF ↑ flexion & extension strength.
Lee et al. (2018) [52]	Koreans with subacute stroke assigned to hydrotherapy ($n = 19$, mean age = 57.6 y) or conventional rehabilitation ($n = 18$, mean age = 63.7 y)	Humac Norm dynamometer measured Ⓑ isometric knee flexion & extension strength (PT) while knees were @ 60°.	Responsiveness: ↑ in paretic knee flexion and extension strength SGNF greater in the aquatic training group ($p < 0.05$). ↑ in nonparetic knee flexion and extension strength were not SGNF different between groups.
Liao et al. (2016) [53]	Chinese with chronic stroke assigned to low intensity whole body vibration ($n = 28$, mean age = 60.8 y), high intensity whole body vibration ($n = 28$, mean age = 62.9 y), or control group ($n = 28$, mean age = 59.8 y)	Humac NormTM dynamometer measured Ⓑ knee flexion & extension strength (body mass normalized torque) isometrically while knees were at 30 & 70°, & concentrically & eccentrically @ 60°/s.	Responsiveness: most strength measures stayed the same or increased. SGNF ↑ (without reference to group) were found in 5 of 16 strength measures.
Lindmark et al. (1995) [54]	Swedes with subacute stroke ($n = 34$, median age = 74 y men & 72 y women)	Cybex II dynamometer measured Ⓑ knee flexion & extension strength (torque) @ 90 & 12°/s.	Validity: strength of nonparetic limb > that of nonparetic limb, SGNF under most test conditions. Most strength measures correlated SGNF with free speed (r = 0.21 to 0.72) & fastest gait speed (r = 0.31 to 0.70).
Lindström et al. (1998) [55]	Swedes with stroke ($n = 10$, mean age = 40 y) & healthy controls ($n = 22$, mean age = 28 y)	Cybex II measured Ⓑ knee flexion and extension strength (PT) @ 90°.	Validity: strength of controls > that of patients with stroke. Strength of paretic side SIGN < nonparetic side.
Lomaglio and Eng (2005) [56]	Canadians with chronic stroke ($n = 22$, mean age 67.0 y)	Kin-Com measured Ⓑ concentric strength (average body mass normalized torque) of ankle plantar flexion & dorsiflexion @ 30°/s & knee & hip flexion & extension @ 60°/s.	Validity: 3 of 6 strength measures of the paretic lower limb correlated SGNF with self-paced STS ($r = -0.07$ to -0.72) & fast-paced STS ($r = -0.10$ to -0.74). No measure of the nonparetic lower limb correlated SGNF with either STS measure.
Lum et al. (2004) [57]	Americans with chronic stroke ($n = 14$, mean age = 70.6 y)	Biodex System 3 Pro measured Ⓑ elbow flexion & extension strength (isokinetic torque normalized against isometric torque) isometrically @ 90° & concentrically @ 30, 75, & 120°/s.	Validity: strength of paretic limb SGNF < that of unaffected limb.

Table 1, continued

Study	Participants	Procedures	Findings
MacIntyre et al. (2010) [58]	Canadians with subacute stroke ($n = 11$, mean age = 69 y), chronic stroke ($n = 11$, mean age = 72 y), or controls ($n = 11$, mean age = 71 y)	Biodex System 3 measured knee extension and ankle plantarflexion strength (body mass normalized torque) at 60 & 30°/s respectively.	Validity: strength of patients with stroke SGNF < controls.
Maeshima et al. (2003) [59]	Japanese with stroke assigned to conventional training ($n = 18$, mean age = 64.8 y) or self-training with family support ($n = 42$, mean = 65.8 y)	Biodex System 3 measured nonparetic knee extension and flexion strength (body mass normalized PT) @ 60°/s & 180°/s.	Validity: strength of ambulatory patients SGNF > nonambulatory patients.
Marigold et al. (2004) [60]	Canadians with stroke ($n = 40$, mean age = 67.1 y) or controls ($n = 60$, mean age = 67.1 y)	Kin-Com dynamometer measured Ⓑ concentric strength (PT) of the ankle flexors & extensors (30°/s) & knee & hip flexors & extensors (60°/s).	Validity: Muscle strength had SGNF relationships ($r = 0.33$ to 0.53) with only "the most challenging" sensory organization test items.
Marque et al. (1997) [61]	French with acute stroke ($n = 15$, mean age = 65.6 y) or sedentary controls ($n = 16$, mean age = 65 y)	Cybex 600 measured non paretic flexion & extension strength of hip @ 60°/s, wrist @ 120°/s, elbow @ 90°/s & eversion & inversion of the ankle @ 60°/s.	Validity: nonparetic strength of patients was < controls, SGNF so @ hip, ankle, and wrist. Responsiveness: nonparetic strength ↑ SGNF between days 20 & 90 for hip flexion & extension, ankle inversion, elbow extension, & wrist flexion & extension.
Nakamura et al. (1985) [62]	Japanese with chronic stroke ($n = 11$, mean age = 53.8 y)	Cybex II dynamometer measured Ⓑ extension strength (PT) isokinetically @ 30°/s, 90°/s & 180°/s & isometrically at 30°, 60°, & 90°.	Validity: affected side strength measures SGNF < unaffected side. All strength measures correlated SGNF with one another ($r = 0.60$ to 0.99). All paretic side strength measures except isometric (30°) correlated SGNF with walking velocity and rate ($r = 0.60$ to 0.87). No nonparetic side strength measures correlated significantly with walking velocity or rate.
Nascimento et al. (2014) [63]	Brazilians with chronic stroke ($n = 12$, mean age = 52 y) & healthy controls ($n = 12$, mean age = 52 y)	Biodex Medical System 3 Pro dynamometer measured Ⓑ shoulder internal & external rotation, shoulder flexion & extension, & scapular protraction & retraction strength (PT & work expressed as % of control group) @ 60°/s.	Validity: all strength measures of patients with stroke < measures of controls and all measures of paretic side of patients with stroke < nonparetic side.
Novak and Brouwer (2012) [64]	Canadians with chronic stroke ($n = 10$, mean age = 60.1 y) & controls ($n = 10$, mean age = 59.4 y)	Biodex System 3 measured Ⓑ concentric & eccentric strength (body mass normalized torque) of ankle plantarflexion @ 30°/s, knee extension @ 60°/s, and hip extension @ stair-climbing velocity.	Validity: strength of controls SGNF > patients with stroke. Concentric & eccentric strength of ankle plantarflexors & knee extensors of less affected side SGNF > more affected side.
Pang et al. (2013) [65]	Chinese with chronic stroke assigned to a whole body vibration group ($n = 41$, mean age = 57.3 y) or control group ($n = 41$, mean age = 57.4 y)	Cybex NUMAC dynamometer measured concentric and eccentric knee extension & flexion strength (peak power normalized to body mass) @ 60°/s.	Responsiveness: most strength measures ↑, some SGNF.
Ploutz-Snyder et al. (2006) [66]	Americans with chronic stroke ($n = 6$, mean age = 55.9 y)	Biodex System 3 dynamometer measured Ⓑ isometric elbow flexion and extension strength (torque) @ 90°.	Validity: strength of affected side SGNF < that of unaffected side in both flexors & extensors.

Table 1, continued

Study	Participants	Procedures	Findings
Pohl et al. (2000) [67]	Americans with stroke ($n = 10$, mean age = 64.0 y) & controls ($n = 10$, mean = 68.7 y)	Cybex II dynamometer measured Ⓑ knee extension & flexion strength (PT & average torque) @ 60°/s & ankle extension & flexion strength (PT & average torque) @ 30°/s.	Validity: affected side strength < unaffected side & < controls. Reliability: test-retest reliability (1 week apart) – ICC = 0.75 to 0.97 (less affected side) & 0.44 to 0.90 (more affected side).
Quintino et al. (2018) [68]	Brazilians with stroke ($n = 18$, mean age = 59.8 y) & healthy controls ($n = 18$, mean age = 57 y)	Biodex dynamometer measured concentric trunk flexion & extension strength (PT, torque @ 90°, total work & total work normalized against trunk mass) @ 60°/s & 120°/s.	Validity: all strength measures of patients with stroke were SGNF < for healthy individuals.
Rabelo and Fachin-Martins (2018) [69]	Brazilians with chronic stroke ($n = 13$, mean age = 57.0 y) & able-bodied ($n = 13$, mean age = 63.0 y)	Biodex System 3 Pro measured trunk flexion and extension strength (PT, PT normalized to body weight, power & total work) @ 60°/s & 120°/s.	Reliability: inter-rater reliability – ICC = 0.61 to 0.96; test-retest reliability (1 week apart) – ICC = 0.84 to 0.98.
Ryan et al. (2011) [70]	Americans with chronic stroke ($n = 70$, mean age = 63 y)	Kin-Com 125AP measured Ⓑ knee concentric & eccentric strength (PT) @ 90 & 120°/s.	Validity: strength of paretic knee SGNF < non-paretic knee. 6MWT correlated SGNF with paretic ($r = 0.55$) & nonparetic ($r = 0.33$) eccentric strength & nonparetic concentric strength ($r = 0.34$).
Şen et al. (2015) [71]	Turks with subacute-chronic stroke assigned to isokinetic exercise ($n = 25$, mean age = 51.3 y) or control group ($n = 25$, mean age = 55.4 y) or & healthy individuals ($n = 30$, mean age = 49.9 y)	Biodex System 3 Pro Multijoint System dynamometer measured Ⓑ knee extension and flexion strength (PT) @ 60°/s & 180°/s & ankle dorsiflexion and plantarflexion strength (PT) @ 60°/s & 120°/s.	Validity: strength of nonparetic strength measures all SGNF < control group. Responsiveness: strength of all paretic and nonparetic muscle groups (exercise & control) ↑ SGNF.
Sharp et al. (1997) [72]	Canadians with chronic stroke ($n = 15$, mean age = 67 y)	Cybex 2 dynamometer measured Ⓑ knee extension and flexion strength (PT) @ 30, 60, & 120°/s.	Validity: strength of the paretic side SGNF < non-paretic side. Responsiveness: strength ↑ SGNF with isokinetic training over time on paretic side.
Shimodozono et al. (2010) [73]	Japanese with subacute stroke assigned to isokinetic training + anabolic steroid group ($n = 14$, mean age = 66.6 y) or control group ($n = 11$, mean age = 62.3 y)	Cybex 6000 dynamometer measured nonparetic knee flexion & extension strength (bodyweight normalized PT) isometrically, isotonically & @ 60, 120 & 180°/s.	Responsiveness: strength of nonparetic side ↑ over course of 6 week training with anabolic steroid.
Silva et al. (2015) [74]	Brazilians with stroke ($n = 18$, mean age = 59.8 y) & healthy controls ($n = 18$, mean age = 59.7 y)	Biodex dynamometer measured concentric trunk flexion & extension strength (PT & total normalized work) @ 60°/s.	Validity: all strength measures of patients with stroke were SGNF < healthy individuals. Flexion strength correlated SGNF with 5 times STS test ($r = -0.52$ & -0.56). Extension strength correlated SGNF with 5 times STS test ($r = -0.62$ & -0.63).
Sunnerhagen and Mattsson (2005) [75]	Swedes with chronic stroke ($n = 29$, mean age = 53 y)	Kin-Com dynamometer measured Ⓑ knee flexion & extension strength (torque) isometrically @ 60° & concentrically @ 60°/s.	Validity: strength of paretic limb < nonparetic limb.
Suzuki et al. (1999) [76]	Japanese with subacute stroke ($n = 34$, mean age = 54.2 y)	Cybex II dynamometer measured Ⓑ knee extension strength (PT) @ 30°/sec.	Validity: strength correlated SGNF with most balance measures: sway path ($r = -0.21$ to -0.67), weight shifting ($r = 0.37$ to 0.73). Responsiveness: Strength ↑ SGNF over 4 & 8 week of gait training.

Table 1, continued

Study	Participants	Procedures	Findings
Suzuki et al. (1990) [77]	Japanese with stroke ($n = 29$, mean age = 57.8 y)	Cybex II dynamometer measured Ⓑ knee extension strength (PT) @ 30°/s.	Validity: strength of paretic side < nonparetic side. Strength of paretic side correlated SGNF with that nonparetic side. Strength of paretic side correlated SGNF with maximum walking speed ($r = 0.85$) & sway path (−0.63). Strength of nonparetic side correlated SGNF with maximum walking speed ($r = 0.43$) & sway path ($r = -0.51$)
Tanaka et al. (1997) [78]	Japanese men with stroke ($n = 25$, mean age = 61.3 y) or healthy controls ($n = 25$, mean age = 59.7 y)	Cybex trunk Extension-Flexion dynamometer measured trunk flexion & extension strength (PT) @ 0, 60, 120, & 150°/s.	Validity: strength of men with stroke SGNF < controls except for flexion @ 0°/s.
Tanaka et al. (1997) [79]	Japanese men with stroke ($n = 65$, mean age = 59.3 y males & 60.0 y females) & age-matched controls ($n = 80$, mean age = 60.9 y males & 59.3 y females).	Cybex Torso Rotation dynamometer measured left & right rotation strength (PT & best work) @ 60, 120, & 150°/s.	Validity: strength of men SGNF > women. Strength of controls SGNF > individuals with stroke.
Tankisheva et al. (2014) [80]	Belgians with chronic stroke assigned to vibration training ($n = 7$, mean age = 57.4 y) or control ($n = 8$, mean age = 65.3 y) group	Biodex dynamometer measured Ⓑ isometric knee flexion & extension strength (torque) at 60° & concentric knee flexion & extension strength (torque) @ 60°/s & 240°/s.	Responsiveness: all strength measures ↑, some SGNF, after 6 weeks vibration training.
Teixeira-Salmela et al. (1999) [81]	Canadians with chronic stroke assigned to exercise group ($n = 6$, mean age = 65.9 y) or control group ($n = 7$, mean age = 69.4 y)	Cybex II dynamometer measured hip & knee flexion & extension & ankle plantarflexion & dorsiflexion strength (total PT) @ 30 & 60°/s.	Validity: torques generated at 2 speeds correlated SGNF ($r = 0.77$ to 0.98). Responsiveness: total PT of affected lower limb ↑ with training.
Tyson et al. (2013) [82]	British with stroke receiving electrical stimulation via a sock electrode ($n = 29$, mean age = 64.5 y)	Biodex dynamometer measured Ⓑ dorsiflexion & plantarflexion strength (mean torque) @ 60°/s.	Responsiveness: strength ↑ after stimulation with the ↑ SGNF for ankle plantarflexion.
Wang et al. (2014) [83]	Taiwanese with chronic stroke ($n = 35$, mean age = 57.1 y)	Biodex dynamometer measured Ⓑ concentric knee extension strength (torque) @ 60°/s & 90°/s.	Validity: all strength measures correlated SGNF with walking speed ($r = 0.45$ to −0.66) and VO_2 ($r = 0.48$ to 0.61).

*Ⓑ = bilateral, PT = peak torque, SIPSO = Subjective Index of Physical and Social Outcome, SF-36 = Short Form Health Survey, SGNF = significant/significantly, BBS = Berg Balance Scale, r = Pearson correlation, r_p = partial correlation, ICC = intraclass correlation coefficient. SRD = smallest real difference, τ-b = tau-b, STS = sit-to-stand.

3. Results and discussion

The PubMed search identified 161 potentially relevant articles. An additional 3 possibly relevant articles were identified by hand searches. Ultimately, 76 articles were found that met inclusion and exclusion criteria. Relevant information from those articles is summarized alphabetically by author in Table 1 [8–83].

The summarized information shows that isokinetic dynamometers have been used extensively to measure strength in individuals with stroke, most often older adults (mean/median age of 48.3 to 74.0 years) with chronic stroke. Isokinetic testing of individuals with stroke has been conducted in at least 15 different countries, but testing is reported most widely in North America and Europe. Utilization of some model of 7 different dynamometers has been described in the literature, with some type of Biodex described most frequently, followed by some model of Cybex or Kin-Com. Most articles that specified the type of measurement obtained documented concentric torque. Some articles however were inspecific or reported the measurement of eccentric or isometric torque with isokinetic dynamometers. A few articles reported torque normalized against body weight, the nonparetic side, or healthy controls [8,9,11,16,20,22,23,35,40,43,44,53,56, 58,64,65,69,73], or measures of work, power, or velocity [13,40,45,63,68,69,79]. The speed of concentric and eccentric testing ranged from 15 to 240°/s, but testing was most commonly reported to be at

60°/s [11,12,14,16–22,24–27,29–34,37,42–44,47,50, 53,56,58,60–69,71–75,78–83]. Testing at higher speeds was intentionally avoided in some studies as individuals with severe weakness following stroke can have difficulty producing torque at higher speeds on their paretic side [14,57]. Most research reports bilateral isokinetic testing of limb muscles [9–18,20,22,24–36,39–41,43–45,47,52–57,60,62–64,66,67,70–72,75–77,80–83], particularly the knee flexors and extensors, but some articles limit testing to the paretic [19,37] or nonparetic limb muscles. Additional research focuses on the testing of the trunk muscles [42,65,78,79].

The clinimetric properties of isokinetic testing of individuals with stroke is generally well-supported. Validity has been demonstrated most often by differences in known groups and known conditions. Specifically, numerous studies have demonstrated that individuals with stroke are weaker, often significantly (SGNF), than controls in both the paretic [11,17,19,28,38,55,63,64] and nonparetic [11,17,23,28,35,38,55,61,63,71,74,78] limbs, that individuals with stroke are weaker (almost always SGNF) on their paretic side than on their nonparetic side [10,13–16,20,22,23,27,28,30,31,33–36, 38,40,41,43,45,47,54,55,67,68,70,72,75,77], that men tend to be SGNF stronger than women [79], that ambulatory individuals tend to be SGNF stronger than nonambulatory individuals [59], and that community ambulators are SGNF stronger than household ambulators [41]. Validity is also supported by correlations between isokinetically measured strengths of different muscle actions [26,48] and between isokinetic strength measures at different speeds [14,62,81]. Most studies examining the correlation between isokinetic measurements of the lower limbs and mobility [13,17,31,38,39,43,47,48,54,56,62,70,74,76,77,83] and other important variables [20,60] have also reported SGNF results.

Numerous studies have used intraclass correlation coefficients (ICCs) to describe the relative reliability of strength measures obtained from individuals with stroke tested with isokinetic dynamometers. One study reported ICCs for inter-tester reliability of 0.61 to 0.96 [69]. All other studies addressing reliability focused on the test-retest consistency of measures obtained over periods of 1 day to 6 weeks. With the exception of a few results reported by Hsu et al. [40] and Kim et al. [45] virtually all test-retest ICCs reported exceeded 0.80 [8,19,22,25,27,32,40,45,67,69]. The absolute reliability of isokinetic measures obtained from patients with stroke has received little attention. However, a few studies have reported a wide range of smallest real differences of 1.5 to 85.1% [15,19,25,32], which also reflect on responsiveness. No studies were found that used minimal detectable changes or minimal clinically important differences to reflect responsiveness. What was found in abundance were studies showing a wide range of increases in isokinetic strength, some SGNF in response to strengthening and other interventions as well as the natural course of stroke recovery [11,16,18,21,24,29,30,33,34,37,44,46,49–53, 61,65,71–73,76,80–82]. Whether described using ICCs, smallest real difference or some other indication of reliability the magnitude of summary descriptions is dependent on the sensitivity of the isokinetic measurement, the time between measurements, the natural course of stroke recovery, and the effectiveness of any intervention applied between measurements.

In spite of precedence and evidence supporting the use of isokinetic testing of strength following stroke, the information in this nonsystematic review is limited. Most notably, a single bibliographic database (PubMed) was used. While it is doubtful that the inclusion of additional databases would have markedly altered the results, such expansion may have added to the evidence for the conclusions presented herein. A more systematic review may have also allowed for a meta-analysis of some variables and for a quality assessment of included articles.

4. Conclusion

There is considerable research support for measuring the isokinetic strength of older individuals who have experienced a stroke. That noted, the data are mostly limited to the young old and information on responsiveness is limited.

Conflict of interest

The author declares no conflict of interest.

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