JSES International 7 (2023) 2349–2355

Contents lists available at ScienceDirect

JSES International

journal homepage: www.jsesinternational.org

Concordance of shoulder strength assessments using a spring balance and isometric dynamometer in patients before and after arthroscopic rotator cuff repair

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ARTICLE INFO

Keywords:
Shoulder
Strength assessment
Spring balance
Isometric dynamometer
Constant Score
Rotator cuff repair

Level of evidence: Basic Science Study; Validation of Outcome Assessment

Background: Shoulder strength is an essential assessment to monitor the outcome of treatment interventions. Isometric strength assessment in the Constant Score (CS) was initially measured with a cable tensiometer or spring balance (SB). Some authors have questioned the validity of this strength assessment and the resulting CS. The purpose of this study was to investigate the concordance of strength measurements using an unsecured SB vs. isometric dynamometer and outline the impact of these methods on the CS.

Methods: In the context of routine clinical examination as well as participation in a Swiss national cohort study, shoulder strength was measured to calculate baseline (before surgery) and 6-month postoperative CS in adult rotator cuff tear patients who had undergone primary arthroscopic rotator cuff repair. Measurements of each of the operated and contralateral shoulders were made per patient routinely using an unsecured SB and study-specific using an isometric dynamometer in patients with the shoulder at 90° abduction in the scapular plane. Absolute and change values of strength and CS data were presented in scatter plots and assessed using concordance correlation coefficients (CCCs) and Bland-Altman plots.

Results: Between June 2020 and October 2021, baseline strength measurements from the operated shoulder of 78 patients ranged from 0.0 to 13.6 kg with a CCC of 0.64 ($P < .001$) and a mean difference of 0.81 kg between the SB and dynamometer methods. There were 89 measurements of the contralateral healthy shoulder that ranged from 3.6 to 15.6 kg; CCC and mean strength difference were 0.76 ($P < .001$) and 0.70 kg, respectively. At 6 months postsurgery, strength measurements of the operated shoulder ranged from 1.4 to 12.0 kg with a CCC of 0.66 ($P < .001$) and mean strength difference of 0.9 kg ($n = 68$). Respective 6-month measurements of the contralateral side ($n = 52$) ranged from 2.0 to 15.9 kg with a CCC of 0.73 ($P < .001$) and mean strength difference of 0.03 kg.

Conclusion: Absolute and change values in shoulder strength assessments using an unsecured SB and isometric dynamometer are fairly concordant with mean differences of less than 1 kg between methods. With the variability of strength differences among patients, interpretation of these values for individual patients may be challenging. Nonetheless, unsecured SB and dynamometer methods share only slight and clinically unimportant differences that can provide similar group mean values for use in research along with the calculation of the CS.

Institutional review board/Ethics committee approval was granted by the following institutions: The study was performed in accordance with the standards of the ethics committee of Zurich (Kantonale Ethikkommission [KEK], Stampfenbachstrasse 121, 8090 Zurich, Switzerland; KEK-ZH-Nr. 2014-0483) for the local Schulthess Klinik register, the ethics committee of Northwest and Central Switzerland (Ethikkommission Nordwest- und Zentralschweiz (EKNZ), Hebelstrasse 53, 4056 Basel, Switzerland; ID: 2019-02076) for the Swiss ARCR_Pred cohort study and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

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https://doi.org/10.1016/j.jseint.2023.06.017

The objective quantification of shoulder strength is an essential tool for diagnosing patients with degenerative or traumatic shoulder pathologies. This is important to evaluate the patient's current functional status and extent of disability as well as monitor the outcome of surgical or therapeutic procedures.[7,19,24] Among others, the Constant Score (CS) is an established tool for measuring outcome after shoulder surgery.[15-17] This score has been adopted by the European Society for Surgery of Shoulder and Elbow as the primary functional outcome score for clinical research of the upper extremities. From a total CS of 100 points, a maximum of 25 points is accredited to the strength assessment.[4,7-10,16] The isometric strength assessment of the CS was originally measured with a cable tensiometer or spring balance (SB) held at arm's length in 90° abduction in the scapular plane.[16,21] This measurement technique was later modified by adding a cuff to the patient's wrist,[9,10] which led to criticism concerning the reliability of the unsecured SB[9]; an unsecured device may deliver inaccurate results compared to those achieved on fixed equipment. There is also a lack of clear definitions outlining the exact maneuver required during measurement, the location and angulation of the test arm and duration in which patients should resist the SB.[9] To resolve the assessment deficiencies of the SB, the Isobex isometric dynamometer was developed to electronically measure the isometric force of the supraspinatus tendon.[13] While the handheld dynamometer measurements have proven reliability,[3,6,16,22] many institutions still employ the unsecured SB for routine clinical evaluation and research. The use of SB by multiple clinicians/assessors is a more cost- and time-efficient method to measure muscle strength in a routine register documentation setting.

At our institution, patients with arthroscopic rotator cuff repair (ARCR) were routinely documented in a local clinical register[12] whereby an unsecured SB is used; part of these patients participated in a Swiss national cohort project with the requirement that an isometric dynamometer be used for strength assessment.[2] The purpose of this study was to investigate the concordance between these two strength measurements and outline the impact of these methods on monitoring the CS of ARCR patients as documented in our local register and database of our research group. We hypothesized that measurements using the SB would be significantly higher compared to isometric dynamometer strength values and result in clinically relevant changes in estimated CSs.

Materials and methods

This prospective analysis of consecutive patients documented in our clinic registry and as part of a multicenter study was approved by the local ethics committee of Zurich (Kantonale Ethikkommission [KEK], Stampfenbachstrasse 121, 8090 Zurich, Switzerland; KEK-ZH-Nr. 2014-0483) for the local Schulthess Klinik register, the ethics committee of Northwest and Central Switzerland (Ethikkommission Nordwest- und Zentralschweiz (EKNZ), Hebelstrasse 53, 4056 Basel, Switzerland; ID: 2019-02076) for the Swiss ARCR_Pred cohort study and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Study reporting was performed according to relevant items of the STrengthening the Reporting of OBservational studies in Epidemiology statement.[11]

Study population

Between June 2020 and October 2021, adult patients with a partial- or full-thickness rotator cuff tear who underwent primary ARCR were documented routinely as part of a clinic local register[12] and enrolled in a multicenter cohort study[2] after giving their informed consent to participate. For this analysis of strength measurements, patients with complete preoperative shoulder strength measurement data for both the operated and contralateral healthy shoulders were included. Patients with any concomitant pathology affecting the arm on the operated side were excluded. Concomitant pathology is any observed lesions/pathology diagnosed in the affected shoulder during the operation. This may include biceps lesions, superior labrum from anterior to posterior tear lesions, humeral avulsion of the glenohumeral ligament lesions, Bankart lesions, humeral cartilage lesions, glenoidal cartilage lesions, acromioclavicular joint degeneration, and other concomitant injuries/pathologies.

Clinical evaluation

Patients were evaluated clinically before surgery (baseline) and 6 months postoperatively using the CS,[9] which involves objective assessment of shoulder range of motion in abduction, adduction, and internal rotation as well as muscle strength in 90° abduction. For the latter, measurements could only be performed when the arm could be held actively in position.

Measurement procedures

For routine documentation in the local ARCR register, patient recruitment and 6-month clinical examinations were completed either by the treating surgeons or supporting physicians. Preoperative muscle strength was initially measured using a calibrated unsecured SB device with a cuff attachment for the wrist for both the operated and contralateral shoulders. (Fig. 1*A*). Measurements were made with the arm positioned in 90° abduction in the scapular plane, the elbow extended, and forearm pronated while the patient was standing. The patient was instructed to resist a force generated by the examiner pulling the device down with progressively increasing force. The maximum force at which the patient could resist this generated force while holding the arm position during a series of three successive measurements was documented separately for each side.

After patients signed the informed consent for study participation, isometric dynamometer measurements were completed by research staff member on the same day using the IsoForceControl Evo 2 dynamometer 10-400N (MDS Herkules Kunststoff, Oberburg, Switzerland). All clinical study staff were instructed on how to document isometric dynamometer strength with the support of the manufacturer's instruction manual and video. All patients were instructed to stand with their feet straight and shoulder-width apart and to position the arm in 90° abduction in the scapular plane with the wrist pronated and elbow extended (Fig. 1*B*). The dynamometer strap was placed around the distal end of the ulna. Patients were then instructed to abduct the shoulder in this position for a maximum of 3 seconds with short breaks in between each measurement. Three measurements each were made for both the operated and contralateral shoulders. The mean value of the three measurements was calculated and documented separately for each side. Between the SB and isometric dynamometer assessments, patients were allowed to rest for a minimum of 30 minutes to minimize the effects of muscle fatigue.

Both strength measurement devices were calibrated, and all assessors were trained in using them, before the start of the study. When patients were unable to fulfill the correct position for strength testing, measurements were considered incomplete and 0 points were automatically allocated to the CS calculation. In addition, we excluded data for any patients who were unable to sufficiently recover between the SB and isometric dynamometer strength measurements completed on the same examination day.

Data management and statistical analysis

Sample size was determined by the subgroup of 161 ARCR patients who were consecutively recruited at our site in the context of

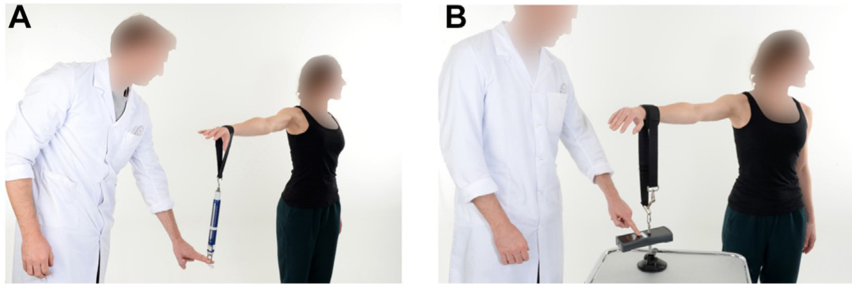

Figure 1 (**A**) Image of the unsecured spring balance in scapular plane (Pesola Präzisionswaagen AG, Schindellegi, Schweiz). (**B**) Image of the isometric dynamometer in scapular plane (IsoForceControl Evo 2 dynamometer 10-400N; MDS Herkules Kunststoff, Oberburg, Switzerland).

the multicenter cohort study. Registry and study data were managed using the REDCap Electronic Data Capture system[14] and exported for statistical analysis using Intercooled Stata version 14 (StataCorp LP, College Station, TX, USA).

Baseline patient demographics were tabulated using standard descriptive statistics. From our local registry, the clinical parameters of range of motion, SB strength on both sides and CS were also tabulated at baseline and 6 months. From the multicenter study, isometric dynamometer strength measures were described and used for the calculation of respective CS values. There was no missing patient examination at baseline, and therefore missing strength measurements were only occurring in patients who could not hold their arm at 90° of arm abduction as instructed. At 6 months, examined patients were also similarly documented.

SB and isometric dynamometer strength measures were assessed on scatter plots. Concordance was evaluated using the concordance correlation coefficient (CCC)[20] and Bland-Altman plots[5] to characterize the differences between measurements obtained by each device.[5,25] CCC above 0.60 is considered acceptable in this study.[1] These analyses were performed for the operated shoulder at each time point (ie, baseline and the 6-month follow-up); the same analyses were made for the healthy contralateral side after excluding patients with reported pathologies at baseline. 95% limits of agreement are calculated as well. All analyses were explorative with a significance level set at 0.05.

Results

Patient population

One hundred and twenty-three ARCR patients (67% male) with a mean age of 58 years (range: 22-79) were included in this analysis after excluding seven patients who did not have complete strength measurement data and 31 with conditions affecting the ipsilateral elbow (n = 6) or wrist/hand (n = 25). Overall, baseline strength measurements could be correctly performed in 78 patients for the operated arm and in 89 patients for the healthy contralateral side (Fig. 2). The majority of rotator cuff tears requiring surgical repair were full tears in either a single tendon (n = 51, 41%) or involving two or three tendons (with only one full tear) (n = 48, 39%); the remainder were characterized as partial (n = 18, 15%) or massive (full in at least two tendons) (n = 6, 5%). At 6 months post-ARCR, three patients dropped out of the study and seven were lost to follow-up at the time of the analyses. There were 69 patients with fully documented strength measurements of the operated side.

Concordance of strength measurements

The CCC for baseline strength measurements on the operated side was 0.64 ($P < .001$) with a mean difference of 0.8 kg between the SB and isometric dynamometer (Table I and Fig. 3). The limits of agreement were −3.5 kg and 5.1 kg for SB and isometric dynamometer measurements, respectively. The correlation between the difference in strength and mean strength was −0.023 ($P = .84$, Fig. 3).

For the healthy contralateral side measurements at baseline, the CCC was 0.76 ($P < .001$) with a mean difference of 0.7 kg between the devices; respective limits of agreement were −3.2 kg and 4.6 kg (Fig. 3). A negative correlation of −0.24 was noted between the difference in strength and mean strength ($P = .025$, Fig. 3).

The CCC for 6-month strength measurements on the operated side was 0.66 for absolute SB and isometric dynamometer measurements ($P < .001$) with a mean difference of 0.9 kg and respective limits of agreement of −2.3 and 4.1 kg (Fig. 4). The change in muscle strength between baseline and 6 months showed concordance between the measurement methods with a CCC of 0.53 ($P < .001$, Fig. 4). The mean difference was 0.1 kg with respective limits of agreement of −4.3 and 4.5 kg; there was no significant correlation between difference in change strength and mean change strength ($r = 0.09$, $P = .58$).

At baseline and the 6-month follow-up, the CCCs for absolute CSs using SB and isometric dynamometer strength measurements were 0.94 and 0.93, respectively ($P < .001$, Fig. 5). The respective mean differences were 1.7 points (limits of agreement: −6.9 and 10.2 kg) and 1.9 points (limits of agreement: −4.5 and 8.3 kg). There was a CCC of 0.90 for the change in CSs to 6 months ($P < .001$) with a mean difference of 0.1 points (limits of agreement: −8.6 and 8.8 kg, Fig. 5).

Discussion

In our prospective analysis, we analyzed the reliability of two frequently used shoulder strength assessment methods and its effect on the CS evaluation. Both methods show acceptable concordance in their measurements with coefficients above 0.60 and only slightly influence baseline and 6-month postoperative CS in ARCR patients with, on average, a maximum of 2 points higher when using the SB. There was no significant difference between the strength measurement methods when considering change values from baseline to 6 months. The large variability among patients at both time points was noted as illustrated by the reported limits of agreement.

Muscle strength assessment plays an important role in the evaluation of patient functional status and outcome measurement. Constant et al proposed the application of either an isometric dynamometer or a defined SB technique and rejected the unsecured SB because of its complexity and lack of definition.[4,9] Also, the technique of measurement is important and it was suggested to use a maximum of three repetitions, each separated by at least 1 minute and to use the highest value because those were the most reproducible values.[9,23] In routine register documentation, we primarily

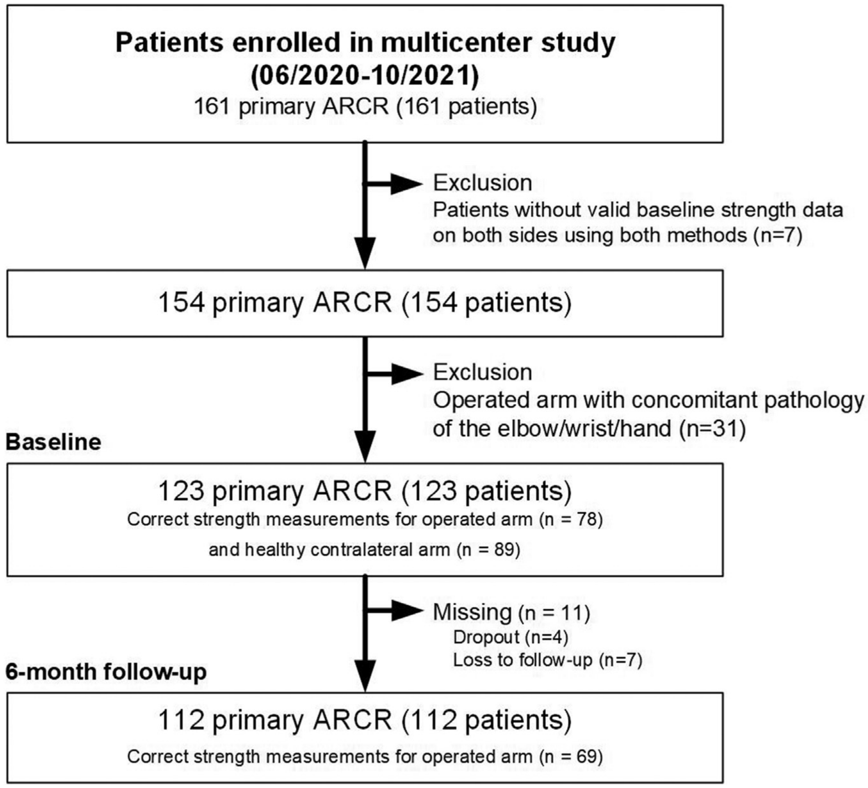

Figure 2 Patient selection flowchart. *ARCR*, primary arthroscopic rotator cuff repair.

Table I
Strength and Constant Score differences between SB and isometric dynamometer measurement methods.

Sides, parameters, and time points	N	Unsecured spring balance	Isometric dynamometer	Difference	*P* value
		Mean (SD)	Mean (SD)	Mean (95% CI)	
Operated					
Strength (kg)					
Preoperative	79	5.9 (2.7)	5.1 (2.7)	−0.8 (−1.3 to −0.3)	.002
6 months	70	6.5 (2.2)	5.5 (2.3)	−1.0 (−1.4 to −0.6)	<.001
Change to 6 months	40	0.8 (2.4)	0.6 (2.2)	−0.2 (−0.9 to 0.5)	.596
Constant Score (0-100)					
Preoperative	79	61.5 (12.8)	59.8 (13.0)	−1.6 (−2.6 to −0.7)	.001
6 months	70	74.5 (9.5)	72.5 (10.3)	−2.0 (−2.8 to −1.2)	<.001
Change to 6 months	40	13.1 (10.6)	12.8 (10.3)	−0.3 (−1.8 to 1.1)	.649
Contralateral					
Strength (kg)					
Preoperative	87	10.1 (2.8)	9.4 (3.2)	−0.7 (−1.1 to −0.3)	.001

N, number of patients with measured parameters using both methods; *SD*, standard deviation; *CI*, confidence interval.

used an unsecured SB to evaluate bilateral shoulder strength in patients undergoing ARCR and as a follow-up after 6 months. Compared to the SB, the isometric dynamometer is not as practical in providing timely measurement of strength during routine clinical examinations, due to factors such as costs for each assessor, time efficiency, and availability in daily clinical activities. We did adhere to systematic measurements made at 90° abduction in the scapular plane with the wrist in pronation and a strap attached at the level of the wrist,[9] and secondary examinations were completed using a standardized isometric dynamometer.[13] However, our results revealed only slightly higher SB values over that of the dynamometer regardless of the high interpatient variability of each procedure. The CS was barely influenced by either of the methods and was, on average, only 1.7 points higher when measured with an unsecured SB. This is well below the reported minimal important difference of 10.4 points for the CS.[18] Based on this established threshold, the measured difference of 1.7 points between measurement techniques will most likely go unnoticed by the patient.

To our knowledge, there are only two other working groups that have compared the concordance between an unsecured or secured SB and isometric dynamometer device of any kind.[7,25] A recent study compared a weighing machine with an isometric dynamometer in 80 healthy subjects and published similar results for both measurement techniques.[7] The second study compared maximum and mean shoulder strength with a myometer and maximum strength with a secured SB in 108 patients aged over 50 years as well as the effect on the CS.[25] Maximum strength measurements were very similar regardless of the device used and so too the CSs.

Mean strength measurement values are known to be lower and it is suggested that the technique of choice be uniformly applied or correction factors must be considered depending on the method(s)

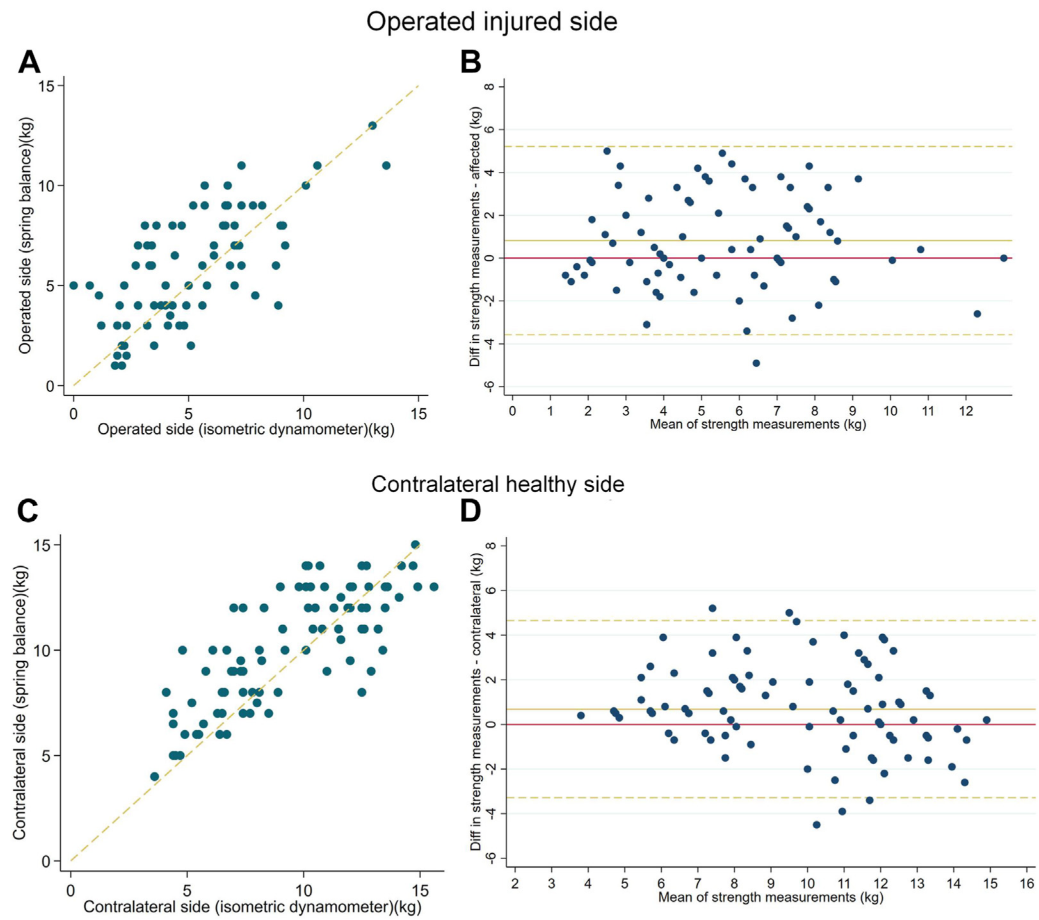

Figure 3 Scatter and Bland-Altman plots of preoperative SB and isometric dynamometer strength measurements and the correlation between difference in strength and mean strength on the operated (**A** and **B**) and contralateral healthy sides (**C** and **D**). The dashed line represents the line of perfect concordance; *Diff*, difference; *SB*, spring balance.

used.[25] The reliability of isometric dynamometers is good when the maximum of three values is considered rather than the mean value.[4,13,19] This fact may provide clarification for the differences in strength values observed in our analysis. The SB method measures the mean of three maximum values, whereas isometric dynamometer measurements comprise the mean strength of three strength values. Therefore, values between these measurement techniques might be even more similar than in our analysis. Nevertheless, you could argue that each maximum value measurement of the SB is held for a few seconds and therefore could be regarded as a mean value. Johansson et al reported good intraobserver and interobserver reliability as well as similar measurement values for unsecured SB vs. handheld digital dynamometer strength assessments in 30 patients.[16] A very early comparative study compared an unsecured SB, secured SB, and Isobex isometric dynamometer[4] and suggested the usage of a standardized method in a small patient collective (n = 50, respectively, n = 26). In this study, the mean values of the unsecured SB were significantly higher over those of the secured SB and dynamometer, where the latter measurements resembled one another. While Bankes et al advised against measurements with an unsecured SB, their small cohort markedly limits the strength of this recommendation.[4] A further study testing manual muscle capacity compared unsecured SB against handheld dynamometer measurements in eight and nine study participants, respectively.[13] The final outcome defined both devices as reliable tools to assess shoulder strength with a slight advantage of the dynamometer in reliability.

The strength of this study is the larger patient cohort compared to previously published work as well as the assessment of measurement change over time. Nonetheless, limitations do exist and must be highlighted. Firstly, our study participants did not have a full recommended break of 1 minute between individual measurements with either the SB or isometric dynamometer.[9] Therefore, mean measurement values might be too low in general. Secondly, there were a number of measurement assessors potentially contributing to the higher variability among the patients and methodologies; our data, however, may better reflect the reality and differences known of clinical practice. Thirdly, isometric dynamometer measurements were completed around 30 minutes after the SB measurements. For the affected arm in particular, some patients may not have fully recovered after the initial SB tests, leading to systematically lower dynamometer strength values. We estimated from our clinical experience however that 30 minutes were sufficient for the vast majority of patients to recover and provide valid dynamometer data. One preferred study methodology to address this limitation would have been to randomize the order of measurement implementation using the two techniques, however, that was not practical and possible at our institution given the recruitment process required to foster a successful implementation of the cohort study. Lastly, while both measurement techniques showed good concordance in absolute values with little deviation, our study cannot show which of the measurement techniques was more reliable. The demonstration of reliability would nonetheless be challenging because a shoulder pathology

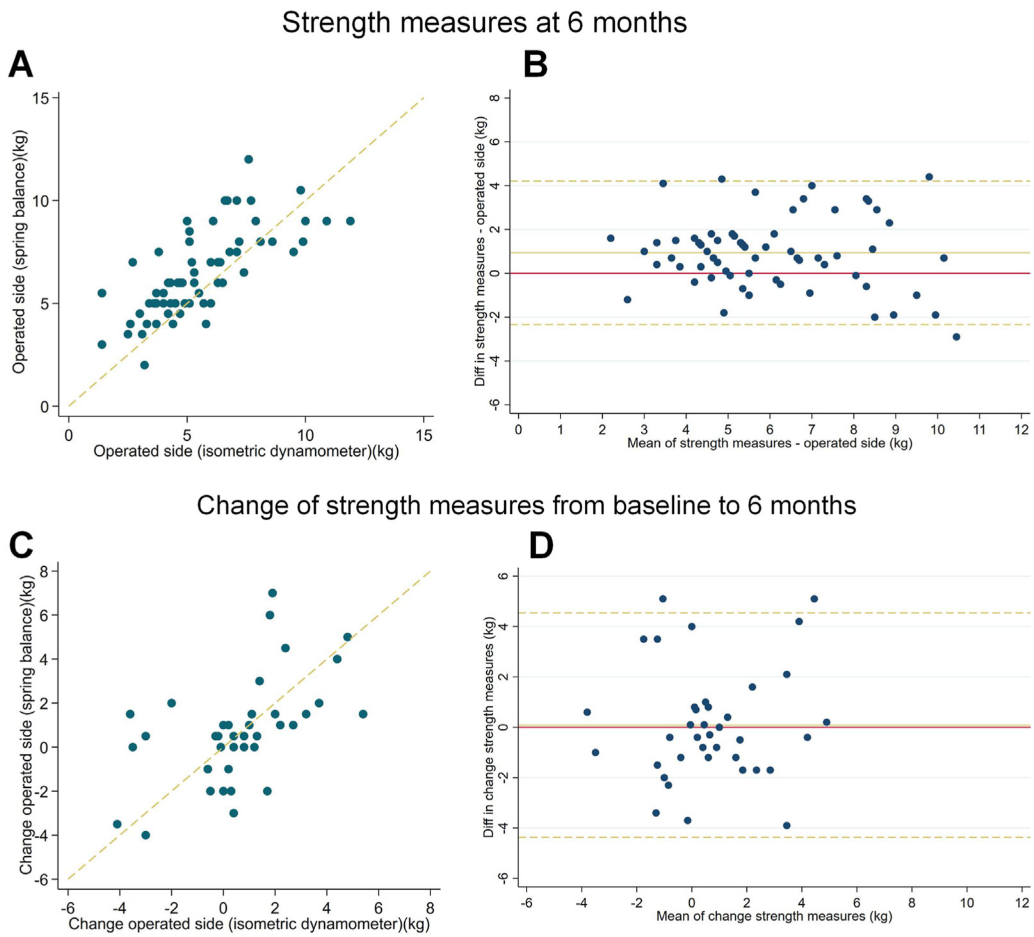

Figure 4 Scatter and Bland-Altman plots of 6-month SB and isometric dynamometer strength measures and the correlation between difference in strength and mean strength on the operated side (**A** and **B**). Change in muscle strength between baseline and 6 months (**C** and **D**). The dashed line represents the line of perfect concordance; *Diff*, difference; *SB*, spring balance.

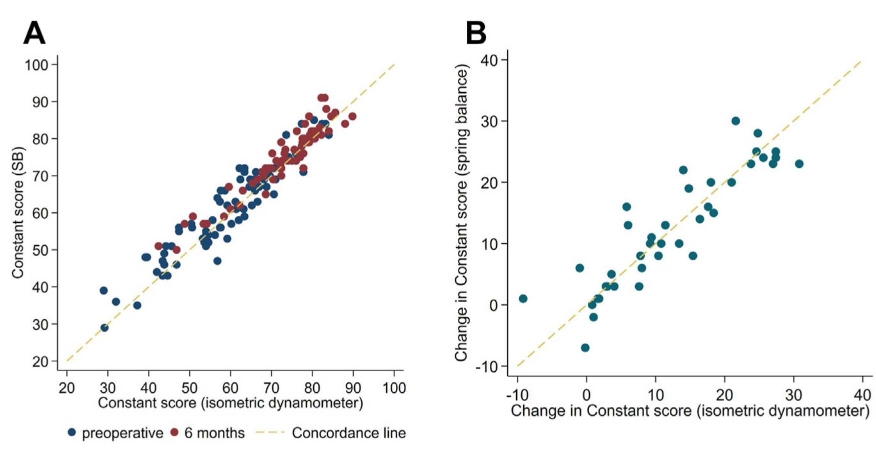

Figure 5 Scatter and Bland-Altman plots of absolute (**A**) and change (**B**) SB and isometric dynamometer Constant Score on the operated side. The dash line represents the line of perfect concordance; *SB*, spring balance.

may fundamentally affect the consistency of the patient's own performance.[4]

Conclusion

Absolute and change values in shoulder strength assessments using an unsecured SB and isometric dynamometer are fairly concordant with mean differences of less than 1 kg between methods. With the variability of strength differences among patients, interpretation of these values for individual patients may be challenging. Nonetheless, unsecured SB and dynamometer methods share only slight and clinically unimportant differences that can provide similar group mean values for use in research along with the calculation of the CS.

Acknowledgments

The authors thank M. Wilhelmi, PhD (medical writer at Schulthess Clinic), for the editing and final preparation of this manuscript.

Disclaimers:

Funding: Support for this research was provided by Schulthess Clinic. Part of the data was collected in the context of a project funded by the Swiss National Science Foundation (SNF Project ID 320030_184959, https://www.snf.ch/en/X5jbA5udARKhcIk8/page/aboutus/contact).

Conflicts of interest: The authors, their immediate families, and any research foundation with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

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