

Research Article



Assessing the Reliability of the Dynamic-Index of Inspiratory Muscle Strength in Cardiac Surgery Candidates

Bahareh Mehregan Far¹ , Sedigheh Sadat Naimi^{2*} , Seyed Ahmad Raeissadat³ , Mohsen Abedi² , Mahmood Beheshti Monfared³ , Alireza Akbarzadeh Baghban⁴

1. Department of Physiotherapy, Student Research Committee, School of Rehabilitation, Shahid Beheshti University of Medical Sciences, Tehran, Iran.
2. Department of Physiotherapy, Physiotherapy Research Center, School of Rehabilitation, Shahid Beheshti University of Medical Sciences, Tehran, Iran.
3. Clinical Research Development Center, Shahid Modarres Educational Hospital, Shahid Beheshti University of Medical Sciences, Tehran, Iran.
4. Department of Biostatistics, Proteomics Research Center, School of Allied Medical Sciences, Shahid Beheshti University of Medical Sciences, Tehran, Iran.



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ABSTRACT

Introduction: Inspiratory muscle strength (IMS) is a crucial predictor of the development of pulmonary complications after cardiac surgery. The strength index (S-index), a novel non-invasive tool, dynamically assesses inspiratory muscles and is associated with lower risks for heart patients than static tests. This study aims to investigate the reliability of the S-index in patients scheduled for cardiac surgery.

Materials and Methods: This study included 20 preoperative cardiac surgery candidates (11 men and 9 women; mean age, 56 ± 13 years). The S-index, peak inspiratory flow (PIF) and vital capacity (VC) were evaluated using a power breath K5 Electronic respiratory device. An examiner conducted these measurements at two distinct intervals, one hour apart. Each index's average and best values were evaluated for reliability using the intra-class correlation coefficient (ICC).

Results: The study revealed excellent ($ICC > 0.9$) and good ($ICC > 0.8$) intra-examiner reliability for the best and average values of the S-index and PIF, respectively. Also, the results of the present study showed excellent intra-examiner reliability for the best and average values of the VC ($ICC > 0.9$).

Conclusion: The ICC results of the present study showed that the S-index can be used to determine the dynamic strength of the inspiratory muscles with acceptable repeatability in cardiac surgery candidates. One of its advantages is the ability to determine the appropriate load for inspiratory muscle training (IMT) exercises during the hospitalization phase of these patients dynamically without breath-holding.

Keywords:

Dynamic inspiratory strength;
Heart surgery; Reliability

* Corresponding Author:

Sedigheh Sadat Naimi, Professor.

Address: Department of Physiotherapy, Physiotherapy Research Center, School of Rehabilitation, Shahid Beheshti University of Medical Sciences, Tehran, Iran.

Tel: +98 (912) 3720617

E-mail: naimi.se@gmail.com



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Introduction

Coronary artery bypass grafting (CABG) surgery, the main treatment for coronary artery diseases, can lead to post-operative pulmonary complications (POPC) in the intensive care unit due to the anesthesia process and disruption of normal ventilation function [1-3]. Chest-related surgical interventions can alter the efficiency and length-tension relationship of the respiratory muscles [4]. A 27% and 62% decrease in maximal inspiratory pressure (MIP) has been reported following the first week of CABG and heart valve replacement surgeries, respectively [5, 6]. It has been demonstrated that performing inspiratory muscle training (IMT) with threshold loading, before and after heart surgery significantly reduces the risk of POPCs through improvements in pulmonary function tests and inspiratory muscle strength (IMS) [7, 8]. Recently, following the use of IMT exercises in the inpatient phase of cardiac surgeries, positive changes have been reported in the dynamic inspiratory strength or strength index (S-index) and the MIP or static strength of these muscles [9].

The MIP, commonly used to measure IMS, captures the pressure plateau created after maximal inspiration through a closed valvular system, thus measuring the static strength of the inspiratory muscles [10, 11]. In contrast, the novel tool S-index offers a dynamic assessment of IMS and is non-invasive, resistance-free (through an open valve system), and easy to use [11, 12]. The recent method likely poses fewer risks to patients with prior vascular conditions [13]. A strong correlation has been reported between the MIP and S-index in measuring IMS in healthy individuals but with different muscle contractions [11]. In the S-index, the maximum pressure generated during a deep breath and against linear resistance (without breath-holding) is measured by converting flow to pressure [11]. Due to the role of the patient in maximal voluntary effort in mouth pressure tests, there may be variations in the results of multiple measurements [14].

The reliability of measuring dynamic IMS using the S-index in cardiac surgery candidates has not yet been reported. This study assessed the reliability of measuring the S-index using an electronic respiratory device (Powerbreathe K5) in patients scheduled for heart surgery.

Materials and Methods

This study was conducted at the Cardiac Surgery Center of [Shahid Modares Hospital](#) in Tehran Province, Iran, between July 2024 and September 2024. It was

a single-blind clinical trial (participants) and repeatability tests were conducted by an experienced physiotherapist with a decade of clinical practice involving cardiovascular patients.

After the initial assessment, the inclusion criteria included:

- 1) Patients aged between 30 and 70 years who were identified as potential candidates for heart surgery were admitted to the hospital for pre-operative assessments;
- 2) The ability to perform and complete respiratory tests;
- 3) An ejection fraction (EF) above 40% [15];
- 4) Cardiac classification one or two, based on the New York Heart Association (NYHA) classification [15].

The exclusion criteria were as follows:

- 1) History of prior heart surgery [6];
- 2) Suffering from chronic obstructive pulmonary disease [16];
- 3) Use of medications impacting neuromuscular function or cause cognitive confusion [17];
- 4) Prior engagement in IMT exercises or respiratory muscle tests [17].

Patients demonstrating non-cooperation, a lack of willingness to participate in the research, inability to complete breathing tests, failure to comprehend the technique employed or signs of hemodynamic instability during the tests were also excluded [18, 19].

[Figure 1](#) shows the consort flow diagram of the inclusion and exclusion of participants in this study.

Respiratory tests

To assess the intra-examiner reliability for breathing tests, measurements were taken at precisely an hour interval and under identical conditions. An electronic respiratory device (Power Breath K5, 2010 HaB International Ltd, UK) was used in this study to assess respiratory muscle function, providing linear resistance during inhalation. The evaluation focused on the dynamic strength of the inspiratory muscles using the S-index parameter. Additionally, the device automatically recorded peak inspiratory flow (PIF) and vital capacity (VC) parameters during each assessment, and their reliability was also evaluated in this study. To perform this test, the patient was placed in a chair sitting position without leaning. A nose clip was used to prevent air leakage, and the patient kept the mouthpiece of the device filter tightly with his lips. First, the patient was asked to perform a deep exhalation until the lung was in the residual volume state, and then, following a strong verbal order from the examiner, perform a maximal inhalation. The participant

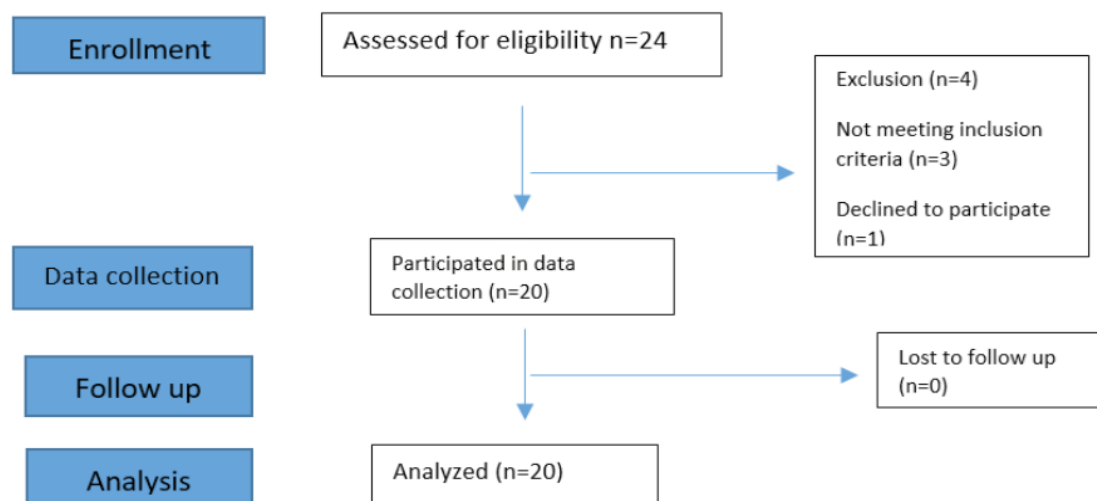


Figure 1. Consort flow diagram

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then exhaled again, and the above process 3 times. The highest point of the pressure curve over time and in each effort was considered the peak in the S-index, which was displayed in the Breath-Link software connected to the device.

This entire process was replicated an hour later under the same conditions without the patient engaging in physical exercise, drug intervention, or laboratory examination. The same examiner carried out the evaluation as in the initial session. Thus, for each of the mentioned indices, including the S-index, PIF and VC, two values, including the best value (best of three efforts) and the average value (average of 3 efforts), in each measurement were recorded and stored.

Statistical analysis

To calculate the intra-rater reliability of the respiratory tests with the electronic device (power breath K5), we calculated the intra-class correlation coefficient (ICC) for the best and average values of S-index, PIF and VC obtained from this device. ICCs <0.5, 0.75-0.5, 0.9-0.75, and >0.9 were considered poor, moderate, good and excellent, respectively.

We also used the Bland-Altman diagram to show the degree of agreement achieved for each indicator between two measurement times. To further assess response stability, the standard error of measurement (SEM) and minimal detectable change (MDC) were also calculated.

The statistical analysis was conducted using SPSS software, version 25 with a significance level of $P < 0.05$.

Results

The patient distribution included seven candidates for heart valve replacement surgery, 12 for CABG, and one for atrial septal defect. Initially, the examiner conducted a thorough physical examination and medical history assessment, and the demographic and medical information of the patients was documented in tables. Table 1 presents an overview of this data. Table 2 summarizes the results of the statistical indicators of the desired values in the first and second tests. Table 3 summarizes the outcomes of the intra-rater reliability assessment between the two tests conducted on targeted variables.

As can be seen in Table 3, the ICC results showed excellent repeatability in all mentioned values ($ICC > 0.9$) and good repeatability for the average values of the S-index and PIF ($ICC > 0.8$). Figure 2 shows the “Bland and Altman” diagram for these values at two mentioned times.

In Figure 2, the limits of agreement are marked as standard deviations (red broken line) from either side of the mean difference (solid blue line). As can be seen, more than 95% of the difference in the two tests for all indices is within these limits, indicating good agreement of the measurements.

Discussion

The primary objective of our study was to assess the intra-examiner reliability of the S-index using an electronic respiratory device (power breath K5), which is also used for TL-IMT exercises in cardiac and respiratory patients. The ICC results were in the good and excellent ranges; therefore, the protocol used in this study facilitated both best and average measurements across three consecutive breaths.

Table 1. Demographic characteristics and comorbidities of the subjects

Characteristic	Mean±SD	Min-max
Age (y)	56±13	33-78
Height (cm)	163±10	145-181
Weight (kg)	70±11	53-95
BMI (kg/m ²)	26±4.03	18-35
EF (%)	49±9	25-60
FEV1/FVC	81±9	50-100

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Abbreviations: BMI: Body mass index; EF: Ejection fraction; FEV1: Forced vital capacity in 1 second; FVC: Forced vital capacity.

Table 2. Statistical indicators during the two tests

Indices	Mean±SD		Minimum		Maximum	
	T1	T2	T1	T2	T1	T2
S-index (A)	32.37±16.38	34.64±17.09	10.09	8.83	70.82	72.19
S-index (B)	38.9±21.22	39.67±20.53	10.58	9.08	84.19	80.76
PIF (A)	1.74±1.02	1.87±1.05	0.35	0.28	4.1	4.19
PIF (B)	2.11±1.28	2.18±1.26	0.38	0.29	4.84	4.65
VC (A)	1.69±0.8	1.8±0.82	0.3	0.25	3.33	3.62
VC (B)	2.01±0.81	2.01±0.8	0.32	0.35	3.30	3.68

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Abbreviations: S-index: Strength index; PIF: Peak inspiratory flow; VC: Vital capacity; A: Average values; B: Best values; T1: First test; T2: Second test.

Table 3. Reliability test results

Indices	Intra-class Correlation (ICC)	95% CI		P	SEM	MDC
		Lower Bound	Upper Bound			
S-index (A)	0.86	0.69	0.94	<0.001	6.08	16.87
S-index (B)	0.9	0.78	0.96	<0.001	6.43	17.84
PIF (A)	0.86	0.69	0.94	<0.001	0.3	0.83
PIF (B)	0.9	0.77	0.96	<0.001	0.27	0.75
VC (A)	0.91	0.79	0.96	<0.001	0.29	0.82
VC (B)	0.95	0.89	0.98	<0.001	0.25	0.69

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Abbreviations: S-index: Strength index; PIF: Peak inspiratory flow; VC: Vital capacity; A: Average values; B: Best values; SEM: Standard error of measurement; MDC: Minimal detectable change.

Based on the TK Koo's study, ICCs between 0.9 and 0.75 and >0.9 are considered good and excellent, respectively [20]. We also used the Bland-Altman diagram, and this graphical method with simple calculations can complete the repeatability evaluations [21]. If the points are evenly distributed between the limits in this diagram, it indicates good agreement between the two tests [22].

The effect of performing limb exercises on improving the quality of life in the first phase of cardiac rehabilitation has already been well demonstrated, as well as the effect of performing environmental aerobic exercises on improving cardiac parameters, such as systolic and diastolic blood pressure [23, 24]. In contrast, IMT can affect cardiovascular autonomic modulation, muscle metabolism and vascular function [25]. An emerging trend in recent years, particularly among heart and respiratory patients, is the increased utilization of IMT as a type of breathing exercise [9, 19, 26-28]. In some cases, these exercises commence from the patient's admission to the hospital for surgery and continue until discharge [6].

The MIP index (static measure of IMS) was employed during the Muller maneuver in cardiac studies to measure the maximum strength of inspiratory muscles [10, 11]. A new study extended the evaluation by incorporating the S-index alongside the MIP to measure muscle strength changes following TL-IMT in patients undergoing cardiac surgery [9].

To date, in a small number of studies, different methods have been used to determine the reliability of the S-index. In a study, the reliability of the S-index in patients with heart failure (HF) was examined through 10 breathing maneuvers to obtain the highest values, and an intra-examiner ICC of 0.97 was reported using a two-day interval between two breathing maneuvers [29]. In the present study, the intra-examiner reliability ICC was 0.86 for the average S-index and 0.90 for the best S-index, derived from three consecutive attempts, and it was achieved in the two days before the operation.

Also, the intra-examiner reliability of the same device concerning MIP, PIF and VC parameters was examined in stroke patients, with three trials at two attempts, and the highest values obtained were recorded; in this way, the ICC obtained for the S-index, PIF and VC were 0.98, 0.99 and 0.95, respectively [10].

Conducting more repetitions leads to more reproducible results concerning the S-index. In healthy subjects, a minimum of eight repetitions is necessary to obtain reproducible results of the S-index [12]. Meanwhile,

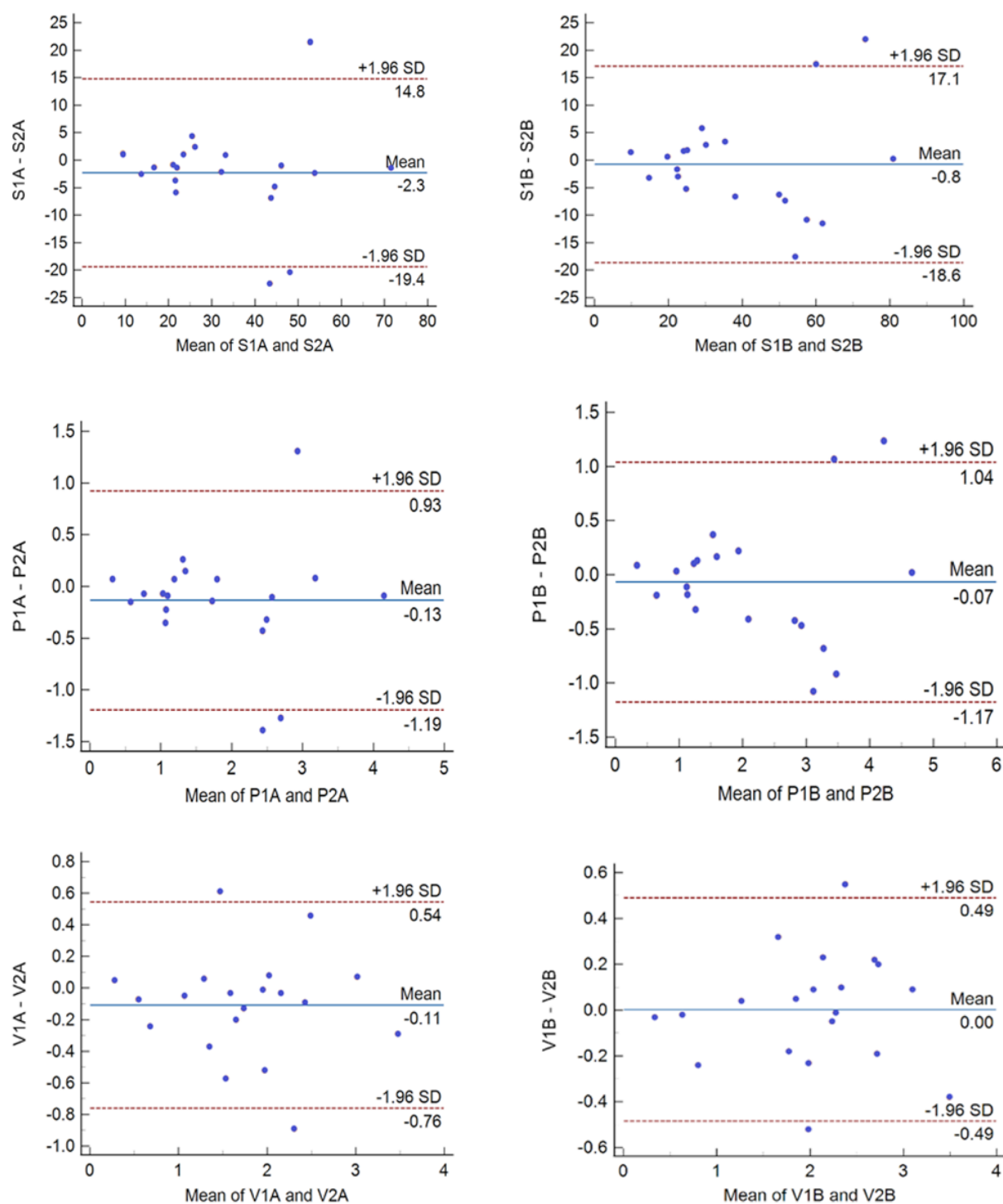
another study reported a linear relationship and good agreement between these two static and dynamic tests using three consecutive maneuvers to obtain the MIP and S-index values [11].

It has been indicated that performing Müller's maneuver during the MIP test can be associated with risks, such as decreased EF and increased heart rate in cardiac patients [13]. Consequently, the dynamic test of respiratory muscle strength (S-index) can be beneficial. As demonstrated in the present study, this test exhibited acceptable reliability in this group of patients, even without a previous respiratory training warm-up before the test and only three repetitions. This is particularly significant when aiming to augment the regulatory load in IMT exercises daily, emphasizing the importance of employing maneuvers involving less risk for heart patients.

Additionally, since IMT exercises follow a flow-pressure type pattern and are based on specificity, which is also pertinent to respiratory muscles, assessing muscle strength through the dynamic S-index pre and post-exercise could offer a more accurate measure. This would aid in determining the appropriate protocol and load considerations [17, 30].

It is better to use 50% of MIP to maximally affect the respiratory muscles and the cardiovascular system by respiratory loading exercises in healthy people and to minimize the effects of hyperventilation and dyspnea [31]. Thus far, various protocols have been utilized to determine the load for IMT exercises in the inpatient phase of cardiac surgeries. For example, in two studies, 40% of MIP was employed [32, 33], while in another study, 15% of MIP was used as a criterion [27]. However, none of these protocols have employed the S-index as a loading criterion.

On the other hand, a study has shown that engaging in IMT exercises post-heart surgery can positively impact both the MIP and S-index of the inspiratory muscles. However, it is noteworthy that the values obtained for these two variables were notably distinct [9]. This can be due to the differences in the neural activation and recruitment of the diaphragm and chest wall muscles during static and dynamic maneuvers due to the changes in the functional residual capacity and muscle length-tension relationship [34]. In the S-index, which is a dynamic maneuver, the airflow is used to determine the amount of pressure; therefore, the way of physiological processing during this maneuver will be different compared to the MIP, which is a static maneuver; however, it has been reported that there is a low difference between these two methods in patients with HF [29]. Since IMT exercises are dynamic maneuvers, determining the load through dynamic indicators is crucial.



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Figure 2. Bland and Altman diagram indicating the obtained difference from S-index, PIF and VC at two measurement times (1 & 2), by one examiner

Abbreviation: A: Average S-index (SA); B: Best S-index (SB); C: Average PIF (PA); D: Best PIF (PB); E: Average VC (VA); F: Best VC (VB).

Note: For each person, the difference between the two measurements was placed on the Y-axis and the average of these two numbers was placed on the X-axis.

In the explanation of the formula for predicting the strength of the IMS by the dynamic method in healthy people, various parameters, such as the results of the spirometry tests and the level of cardiovascular fitness (obtained from a 6-minute walk test), can be effective, which suggests a close relationship between the S-index and lung function level [35]. Also, the amount of electrophysiological activity of respiratory muscles obtained from electromyography during different maneuvers for recording maximum inspiratory pressures, such as MIP and sniffing, is different [36]. In future studies, these cases can be considered in examining the S-index test in cardiac patients to clarify the physiological and biomechanical dimensions.

Conclusion

This study was conducted to determine the intra-examiner reliability of the S-index in patients who are candidates for heart surgery. The outcomes of this study confirm the reliable measurement of this index, along with other indices (PIF and VC), utilizing the electronic respiratory device (power breath K5). This emphasizes the device's credibility and suitability for use in similar studies.

Limitations

In this study, patients were admitted to the hospital one or two days before the operation. In future studies, the S-index test reliability assessment should be performed on two consecutive days instead of one day only.

This study assessed only intra-rater reliability. Future studies should examine the S-index's inter-rater reliability (within two examiners).

Future studies should use a greater number of repetitions to obtain the maximum values of the S-index.

Ethical Considerations

Compliance with ethical guidelines

Informed consent was obtained from all participants. This study was approved by the Ethics Committee of [Shahid Beheshti University of Medical Sciences](#), Tehran, Iran (Code: IR.SBMU.RETECH.REC.1401.058) and the [Iranian Registry of Clinical Trials \(IRCT\)](#) (Code: IRCT20220801055596N1) was obtained.

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Authors' contributions

Conceptualization: Sedigheh Sadat Naimi, Bahareh Mehregan Far and Seyed Ahmad Raeissadat; Methodology: Bahareh Mehregan Far, Sedigheh Sadat Naimi, and Mahmod Beheshti Monfared; Investigation: Bahareh Mehregan Far, Sedigheh Sadat Naimi, and Mohsen Abedi; Data analysis: Alireza Akbarzadeh Baghban, Parsa Salemi, and Hasan Shamsi; Writing the original draft: Bahareh Mehregan Far, Sedigheh Sadat Naimi, and Mohsen Abedi; Review and editing: Bahareh Mehregan Far, Sedigheh Sadat Naimi, Hasan Shamsi, and Parsa Salemi.

Conflict of interest

The authors declared no conflict of interest.

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