Relationship between measures provided by smartwatches and identification of frailty syndrome in older adults: a scoping review

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Abstract

Objective: This scoping review aimed to describe and map the measures provided by smartwatches as a tool for identifying Frailty Syndrome in older adults. *Methods:* Studies published in any language, without publication date restrictions, that described the use of measures provided by smartwatches in evaluating or identifying Frailty Syndrome and/or its criteria in older adults were included. English descriptors for smartwatches, smartbands, Frailty Syndrome and Older Adults were used to develop a comprehensive search strategy, which was then applied to search the following databases: COCHRANE LIBRARY, EMBASE, SCOPUS, PUBMED/MEDLINE, LILACS, WEB OF SCIENCE and PEDRO. *Results:* The initial search identified a total of 156 articles and 2 articles were identified from the manual search in the references of eligible studies. Next, 4 studies that used daily step count measurements for descriptive synthesis were included, and three of the four also used sleep and heart rate data to assess frailty in older adults. The results obtained in this review indicate that parameters derived from smartwatches have been used to identify stages of frailty in different areas, with the majority of studies being associated with other clinical conditions. *Conclusion:* Smartwatches are an excellent frailty monitoring tool through daily measurements of step count, sleep data and heart rate. The results obtained with the use of these devices may suggest a broader evaluation of older adults who face an increased risk of developing Frailty Syndrome.

Keywords: Aging. Frailty Syndrome. Wearable devices.

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INTRODUCTION

Frailty Syndrome is closely related to the aging process, but it is not considered an inevitable condition for the older adult population, because a transience between the frailty stages may occur through appropriate interventions[1]. In view of this, an adequate and early assessment of Frailty Syndrome is an important point to identify which older adults are at increased risk for this condition[2].

Fried's Frailty Phenotype[3] is one of the most widely-used frailty assessment tools which classifies older adults as frail, pre-frail and non-frail according to the presence of the following criteria: muscle weakness, slow gait, exhaustion, unintentional weight loss and low physical activity level[3]. Assessment based on the Frailty index which includes a variety of factors is also widely used for screening this condition resulting in a continuous scale with higher frailty scores for a greater number of conditions present[4] .

Frailty assessment instruments can be classified as: objective when they are not based on direct performance measures; subjective when they are based on self-assessments and/or self-reports; and mixed when they include the two previous types[5]. Although the use of questionnaires is considered a low-cost way to reach larger groups, self-reports can be prone to a variety of biases, such as perception and memory bias[6].

New technologies have been proposed for early screening of frailty, including the use of wearable sensors that can help monitor the risk of developing frailty in the older adult population[7-10]. A systematic review[11] which included 29 observational studies involving older adults who used wearable sensors to identify the presence of frailty and pre-frailty highlighted the heterogeneity of the parameters examined in relation to identifying frailty and the body locations used. Postural transitions, number of steps, percentage of time and intensity of physical activity together were the most frequently measured parameters, closely followed by gait speed. Also, one study demonstrated an association between physical activity and frailty level[11].

Smartwatches are wearable devices worn on the wrist, which, depending on the model and manufacturer, provide various measurements about the number of daily steps, heart rate (HR), sleep quality, and physical activity level, among others[12]. Based on knowledge about these devices and considering that Frailty Syndrome is closely related to the aging process, this review was based on the following guiding question: "Can the measurements provided by smartwatches be used to identify Frailty Syndrome in older adults?". Faced with this question, the objective of this scoping review was to describe and map the measures provided by smartwatches as a tool to identify Frailty Syndrome in older adults.

METHODS

Studies published in any language with no restriction on the publication date, that described the use of measures provided by smartwatches in evaluating or identifying Frailty Syndrome and/or its criteria in older adults were included. The following study designs were considered: prospective and retrospective observational cohort studies, case reports, and cross-sectional studies. Studies that described the evaluation of Frailty Syndrome through measurements provided by wearable devices other than smartwatches/smartbands, used on the wrist, were excluded.

Based on PCC elements[13], which advocates the mnemonic as fundamental elements: P - Population, C - Concept and C - Context, the keywords in English about smartwatches, smartbands, Frailty Syndrome and older adults were used to develop a complete search strategy applied to search in the following databases: COCHRANE LIBRARY, EMBASE, SCOPUS, PUBMED/MEDLINE, LILACS, WEB OF SCIENCE and PEDRO. The database search was carried out between July and September 2023.

The search strategy, including all identified keywords and indexing terms, was adapted for each database and/or information source included. The reference list of all included sources of evidence will be reviewed for further study. The combinations of search strategies used on the platforms are described in Chart 1.

The research protocol was registered and made publicly available on the Open Science Framework (OSF) platform (DOI 10.17605/OSF.IO/42VFJ).

Chart 1. Search strategy/terms used in databases, 2023.

Database	Search strategy
PUBMED/ MEDLINE	(Frailty or Frail or Frailty Syndrome or Frail older adults or Frail Elder* or Functionally-Impaired Elderly or Frail Older Adult*) and (smartwatch, smartband or trackers or fitness trackers) and (Older adult* or older adults or aged) NOT (randomized controlled trial or clinical trial or Controlled Clinical Trial)
SCOPUS	(TITLE-ABS-KEY (Frailty or Frail or 'Frailty Syndrome' or 'Frail older adults' or 'Frail Elder' or 'Functionally-Impaired Elderly' or 'Frail Older Adult' 'Older adult' or 'older adults' or aged) AND TITLE-
EMBASE	('frail syndrome'/exp OR 'frailty syndrome' OR 'frail older adult' OR 'functionally-impaired elderly' OR 'older adult'/exp OR 'older adult' OR 'older adults'/exp OR 'older adults' OR 'aged'/exp OR aged) AND ('smartwatch'/exp OR smartband OR trackers OR 'fitness trackers') AND (observational AND study NOT 'randomized controlled trial'/exp OR 'clinical trial'/exp OR 'controlled clinical trial'/exp)
LILACS	(Frailty or Frail or Frailty Syndrome or Frail older adults or Frail Elder or Functionally-Impaired Elderly or Frail Older Adult) and (smartwatch, smartband or trackers or fitness trackers) and (Older adult or older adults or aged) NOT (randomized controlled trial or clinical trial or Controlled Clinical Trial)
Web Of Science	((ALL=("frail syndrome" OR "frailty syndrome" OR "frail older adult" OR "functionally-impaired elderly")) AND ALL=("smartwatch" OR smartband OR trackers OR "fitness trackers")) NOT ALL=("randomized controlled trial" OR "clinical trial" OR "controlled clinical trial")
PEDro	Frailty Syndrome Smartwatch
COCHRANE LIBRARY	(Frailty or Frail or (Frailty Syndrome) or (Frail older adults) or (Frail Elder) or (Functionally-Impaired Elderly or Frail Older Adult)):ti,ab,kw AND (smartwatch, smartband or trackers or (fitness trackers)):ti,ab,kw NOT ((randomized controlled trial) or (clinical trial) or (Controlled Clinical Trial)):ti,ab,kw" (Word variations have been searched)

Source: The authors.

After the search, all identified citations were grouped and uploaded to Rayyan, a free web application developed by QCRI (Qatar Computing Research Institute). After a pilot test, titles and abstracts were selected by two independent reviewers, in which they were assessed against the eligibility criteria for the review. The reasons for excluding full-text evidence sources which did not meet the inclusion criteria were recorded and reported in this scoping review. Any disagreements that arose between reviewers at each step of the selection process were resolved through discussion with a third reviewer.

Data were manually extracted by two independent reviewers using an "extraction form" developed by the reviewers. Differences were resolved by consensus, and when this was not possible, a third reviewer was called and had the final decision.

The data listed below were extracted from the text, tables or figures of the articles included in the review:

- Study design;
- Study setting (including country where it was conducted);
- Demographics of the population (mean age and gender distribution);
- Frailty assessment criteria and tools;
- Biological signals derived from the smartwatch used in the evaluation and identification of Frailty Syndrome in older adults.

A descriptive synthesis of the results of the studies was written in a structured way, describing the content of the scoping review.

DATA AVAILABILITY

The entire dataset supporting the results of this study is available upon request to the corresponding author, Juliana Fernandes de Souza Barbosa.

RESULTS

The initial search identified a total of 158 articles, and an additional 2 were identified from the manual search in the references of eligible studies (Figure 1).

After excluding duplicates, 154 articles remained. The articles were analyzed by reading the titles and abstracts, with another 144 being excluded after this process. After reading the full papers, 6 articles were excluded for not meeting the eligibility criteria.

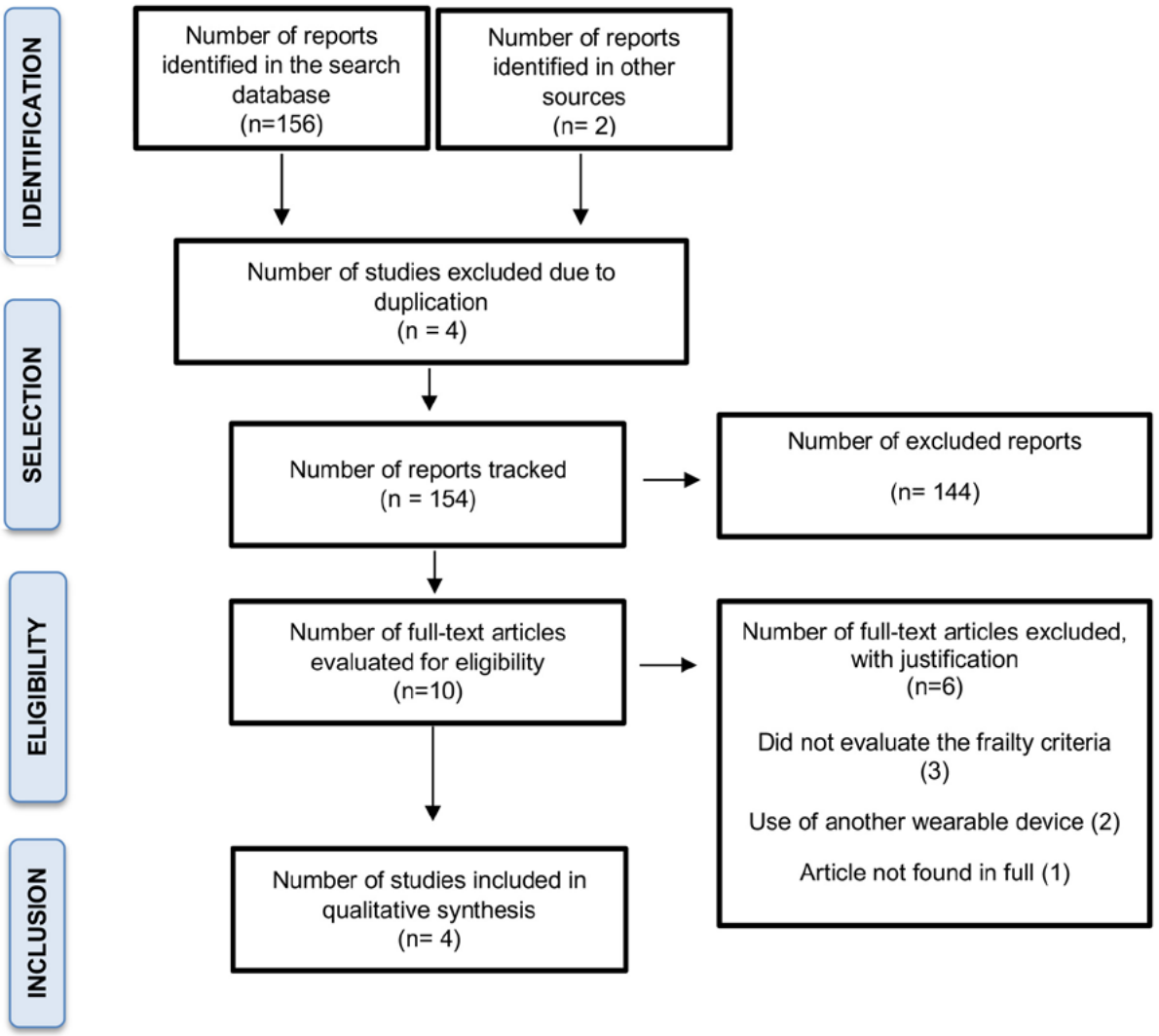

Figure 1. Flowchart of the selection process of articles included in the scoping review according to PRISMA-ScR (Preferred Reporting Items for Systematic Review and Meta-Analyses extension for Scoping Reviews)[14].

Source: The authors.

Chart 2 contains the main characteristics of the articles included, such as the study design and location, sample characterization, type of smartwatch used in the study and the main measures derived from the smartwatch, which were used to assess the frailty criteria. The articles are organized in chronological order.

All studies included in this review are prospective observational and used smartwatch or smartband monitoring bracelets to assess frailty criteria, with or without association with other health conditions. The studies were carried out in the following areas: home (2), long-stay institution (1) and hospital and/or outpatient setting (1).

The number of participants ranged from 12 to 88, the average age was 76.76 years and most were female.

A study by Kim and Lee[15] demonstrated that participants classified as frail were significantly older ($p < 0.01$). Data from these participants reported significantly lower daily step counts than non-frail (mean steps per day: 367.11 vs. 1,023.95, respectively; $p = 0.04$). The five sleep measures evaluated (total sleep time, deep sleep time, light sleep time, sleep quality and awake time) were moderately correlated with frailty. In this study, no relationship was found between HR measurements and the state of frailty. Regarding the prediction of frailty, the logistic regression model that used the variables derived only from the wearable device data (step count, deep sleep time, light sleep time, HR standard deviation) demonstrated that the time of deep sleep was a predictor of frailty ($p < 0.01$), and increased sleep time was significantly associated with increased odds of frailty (adjusted odds ratio [OR] 1.02, 95%CI 1.01-1.05, $p < 0.01$).

A study developed by Mach et al.[16] used a non-randomized open-concept test, which evaluated the pre-procedure activity of transcatheter aortic valve implantation, in which the prevalence of frailty was also evaluated through the Fitness-tracker assisted Frailty-Assessment Score (FIFA) and compared to the assessment data using the Edmonton Frail Scale (EFS-C) and the 6-minute walk test (6MWT). The production of daily data through the measures provided by the smartwatch were used to calculate the weekly average values, excluding the incomplete activity data available from the first and last day of monitoring. From this data compilation, threshold levels in three predefined categories (HR, pre-procedure stress and walking) were calculated. Patients were assigned one point per category in the FIFA when exceeding (in categories with positive correlation) or falling back (in categories with negative correlation) threshold levels, and then grouped into four categories (0, no frailty; 1, mild frailty; 2, moderate frailty; 3, severe frailty). The study demonstrated a strong predictive performance of a smartwatch-based frailty assessment in which the FIFA score correctly identified frail patients, as demonstrated from the strong correlation with baseline serum albumin levels ($p=0.005$) – a well-established biomarker for frailty.

In another study by Kim et al.[17], three of the 12 study participants used smartwatches for at least five days during the post-hospital discharge monitoring period. The patients wore the smartwatches for an average of 26.33 days. Frail patients had significantly lower daily step counts than non-frail patients (1,336.40 vs 3,781.04 steps; $p = 0.02$; d = 1.81). They performed less daily physical activity than non-frail participants (2.02 vs 16.34 minutes per day; $p = 0.04$; d = 0.94). There was no difference in sleep and HR measures between frail and non-frail groups. However, there was a strong correlation between mean HR and the Clinical Frailty Scale (CFS) and ($r = -0.72$; $p= 0.046$) with the CFS score at hospital discharge.

In a study by Schmidle et al.[18], the older adults used the smartwatch for an average of 17.5(± 5.1) days, for a period of at least eight hours a day. The parameters derived from the smartwatch used to assess frailty were the measure of physical activity intensity based on changes in acceleration intensity, taking into account the median of all values (MAD median); and the daily step count, based on the cadence percentile parameter in steps per minute (STEP95). Correlations between clock measurements were made with two frailty scores, the classic 0 to 5 scale including all five physical frailty criteria (weight loss, exhaustion, muscle strength, physical activity, and weakness) and a shortened version omitting the two parameters (muscle strength and weight loss) which could not be assessed by a wrist-worn sensor.

Moderate negative correlations were found between the 'STEP95' gait parameter and both frailty scores (R^2 = 0.25 and 0.26). Furthermore, weak to moderate negative correlations were also found between the 'MADmedian' activity parameter and both scores (R^2 = 0.07 & 0.14). There were three different types of cluster behavior based on the behavioral data: (1) participants with high activity and low extent of ambulation; (2) participants with high activity and high extent of ambulation; and (3) participants with low activity and low extent of ambulation. The cluster analyzes showed statistically significant differences for the variables of: activity, gait, age, gender, number of chronic diseases, current health status, and use of walking aids; the chance of being female and frail increased significantly for cluster 1. A significant difference for gait-related parameters was found for almost all frailty criteria, suggesting that mobility may be the driving parameter related to frailty[18].

Chart 2. Description of studies included in the Scoping Review, September 2023.

Author	Title	Design and study location	Purpose of the study	Sample	Smartwatch used	Parameters derived from the smartwatch that were used to assess frailty criteria
Kim, B. et al., 2020[15]	Consumer-Grade Wearable Device for Predicting Frailty in Canadian Home Care Service Clients: Prospective Observational Proof-of-Concept Study	Prospective Study Conducted in Canada, participants wore a monitoring device for a minimum of 8 days.	To prove that the use of a wearable device to assess frailty in older adults home care clients may be possible.	N = 37 participants Mean age= 82.23 (±10.84) female sex = 76%	Xiaomi Mi Band Pulse 1S	Daily step count, sleep measures (deep sleep time, light sleep time, total sleep time, sleep quality), heart rate measures.
Mach, M. et al., 2020[16]	Fitness-Tracker Assisted Frailty-Assessment Before Transcatheter Aortic Valve Implantation: Proof-of-Concept Study	Prospective Study Conducted in Austria in 2017-2018, each patient used a monitoring device for 1 week before the surgical procedure.	To develop a simple, efficient and cost-effective method for assessing pre-procedure frailty of transcatheter aortic valve implantation, based on parameters measured by a wearable health monitoring device	N = 50 patients Mean age= 77.5 (±5.1) years female sex = 44%	Garmin Vivosmart 3	Daily step count, distance covered (in kilometers), calories burned, time spent at different stress levels, hours and depth of sleep, minimum and maximum heart rate, and number of flights of stairs climbed.
Kim, B.; Kim, A., 2021[17]	Using Consumer-Grade Physical Activity Trackers to Measure Frailty Transitions in Older Critical Care Survivors: Exploratory Observational Study	Prospective Study Performed in Canada, patients were followed up for 4 weeks after hospital discharge	Examine data generated from wearable devices for their association with frailty progression after hospital discharge.	N = 12 Mean age= 66.75 (±6.80) years. female sex = 58.3%	Fitbit Charge HR	Daily step count, active and sedentary time, sleep efficiency (obtained from the percentage of sleep time over total sleep time) and heart rate.

to be continued

Continuation of Chart 2

Author	Title	Design and study location	Purpose of the study	Sample	Smartwatch used	Parameters derived from the smartwatch that were used to assess frailty criteria
Schmidle, S. et al., 2023[18]	The relationship between self-reported physical frailty and sensor-based physical activity measures in older adults – a multicentric cross-sectional study	Multicenter cross-sectional study Conducted in Germany and France between May and November 2019, the average time of use of the smartwatch was 17.5 (± 5.1) days with ≥8 hours per day	Assess whether and to what extent a self-reported assessment of frailty is associated with daily physical activity patterns.	N = 88 Mean age= 80.6 (±9.1) female = 55%	Huawei 2 (4G)	Measure the intensity of acceleration changes, i.e. the intensity of physical activity, for every five seconds of data and daily step count.

Source: The authors.

DISCUSSION

This scoping review aimed to describe and map the measures provided by smartwatches as a tool to identify Frailty Syndrome in older adults. The use of wearable sensors, such as the smartwatch, can be useful in combating the challenges in measuring frailty, as it is a viable, practical, accessible, reproducible and reliable instrument, without jeopardizing daily activity in the various areas in which the older adult is inserted[19]. The four studies included[15–18] used daily step count measures, and three of the four also used sleep and HR data to assess frailty in older adults[15–17].

The studies carried out by Kim and Lee[15] and Kim et al.[17] reported that daily step counts were significantly lower in frail than non-frail individuals. In a study by Lefferts et al.[20], older adult individuals with a greater number of daily steps had lower BMI, greater grip strength, greater walking speed, greater energy expenditure, less exhaustion, less frailty and fewer comorbidities ($p < 0.05$). In addition, daily step count is strongly correlated with moderate to vigorous daily physical activity, as this type of activity is positively associated with health-related quality of life components[21].

Participants classified as frail also performed less daily physical activity than non-frail participants[15,17]. This corroborates what was found by Razjouyan et al.[22], as their results suggest that the total number of steps, amount of sedentary behavior and moderate to vigorous physical activity were associated with the progression of the frailty stages. The more physically active a person is, the better their physical capacity, which may contribute to the transience between the different frailty stages, as they can go from pre-frail to robust, and from frail to robust, although to a lesser extent[1,23].

With regard to sleep parameters, the results obtained by Kim and Lee[15] suggest that increased deep sleep time was significantly associated with increased odds of frailty. Studies indicate that poor sleep is a significant risk factor for increasing the likelihood of frailty[24,25]. Among the findings in a study carried out by Ensrud et al.[26], it was found that sleep disturbances, such as poor sleep quality, excessive daytime sleepiness and prolonged sleep latency, are associated with greater evidence of frailty status, as sleep disturbances can be considered an indicator of health problems, comorbidities, depressive symptoms, cognitive dysfunction and functional impairments, which not only affect sleep quality, but also increase the likelihood of a

greater state of frailty. The study by Razjouyan et al.[22] demonstrated that although the non-frail group had significantly less sleep disturbances, there was no significant difference between pre-frail and frail.

HR correlated with the presence of frailty in participants during the hospital discharge period in the study by Kim and Lee[15], but no associations were found between this parameter and frailty in the other studies included in this review. This may be due to the fact that the participants in the aforementioned study had recently experienced a critical illness. Literature data[27] show that changes in HR patterns may be caused by the inability to evoke dynamic physiological processes to restore balance.

The results obtained from this review generally indicate that the parameters derived from the smartwatch have been used to identify the frailty stages in different areas, with most of the studies associated with other clinical conditions (cardiovascular risk, pre-procedure of transcatheter aortic valve implantation and post-hospital discharge periods of critically ill patients)[15–18].

Despite the efforts to carry out a complete search in the databases most frequently used for reviews in general, it is possible that some references were missed. Studies that correlate the use of smartwatches and the assessment of frailty are still scarce. Some studies had small numbers of participants and some frail and pre-frail cohorts were combined for statistical analysis. It was also observed that most studies were not restricted to the isolated assessment of Frailty Syndrome, but this factor did not invalidate the findings. It is worth mentioning that this is the first scoping review that we are aware of which addresses the use of smartwatches as having technological potential to be used to help in screening Frailty Syndrome criteria in older adults.

CONCLUSION

Smartwatches make an excellent frailty tracking tool through daily step count measurements, sleep data and heart rate. It consists of an accessible and practical evaluation method which can be used in different areas (home, outpatient and hospital). The results obtained from the use of these devices may suggest a broader assessment of older adults when faced with an increased risk for developing Frailty Syndrome. In view of the wide variety of smartwatch models available on the market and the results offered by each device, the discussion of this topic is an open field for further research aimed at establishing parameters in order to define how to more accurately track people at greater risk of frailty.

AUTHORSHIP

- Amanda Caroline de Andrade Ferreira - Substantial contributions to the conception and design of the study; acquisition, analysis and interpretation of work data; preparation of preliminary versions of the article; article writing; approval of the version to be published; agreement to be responsible for all aspects of the work.
- Betuel Gomes da Silva - Substantial contributions to the conception and design of the study; acquisition, analysis and interpretation of work data; preparation of preliminary versions of the article; article writing; approval of the version to be published; agreement to be responsible for all aspects of the work.
- Cristiano dos Santos Gomes - Substantial contributions to the study design; critical review; final approval of the manuscript; agreement to be responsible for all aspects of the work.
- Armele de Fátima Dornelas de Andrade - Substantial contributions to the study design; critical review; final approval of the manuscript; agreement to be responsible for all aspects of the work.
- Etiene Oliveira da Silva Fittipaldi - Substantial contributions to the study design; critical review; final approval of the manuscript; agreement to be responsible for all aspects of the work.
- Juliana Fernandes de Souza Barbosa - Substantial contributions to the conception and design of the study; critical review of important intellectual content; final approval of the version to be published; agreement to be responsible for all aspects of the work.

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