Use of different reference values for handgrip strength in individuals with COPD: analysis of agreement, discriminative capacity, and main clinical implications

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METHODS OF THE LITERATURE SEARCH

Studies reporting reference values and/or prediction equations for handgrip strength were retrieved by searching the MEDLINE (PubMed) database on September 13, 2021. The search strategy consisted of a combination of the following terms: "reference values"; "reference ranges"; "normative data"; "normative values"; "normal ranges"; "prediction equation"; "reference equation"; "hand strength"; "handgrip strength"; "handgrip force"; "grip"; "grasp" and similar terms. The term "cut-off values" was not included in the search because in general it does not take age into consideration. A manual search of the reference lists of the selected studies was also conducted.

The selection process was performed by one reviewer, initially by looking for the terms reference values and prediction equation(s) for handgrip strength in the title, and, subsequently, by checking this information in the abstract of the studies selected by title. After the reading of the full text of the studies selected by title and abstract, they were included if they reported normative data or prediction equations for handgrip strength based on healthy adult men and women.

As a final step of the selection process we identified studies to be included in the statistical analysis. Given that the present sample was in the 47- to 89-year age bracket and in order to avoid bias (overestimation or underestimation), we considered for inclusion in the analysis sets of reference values that had the following characteristics: 1) values derived from samples consisting of individuals = 45 years of age or older (70 years of age at least); and 2) values from studies employing methods of assessment of handgrip strength similar to those used in the present study, which were those recommended by the American Society of Hand Therapists[1] and Nyberg et al.[2] (i.e., with the patient in a seated position, with arms along the body, elbows flexed to 90°, and wrists in a neutral position, three trials being performed for each hand). Regarding prediction equations, we included studies presenting equations with easy-to-measure predictive variables (i.e., variables that do not require extensive training and/or complex equipment and are commonly assessed in any setting, such as anthropometric variables).

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Table S1. Characteristics of the 36 studies that met the inclusion criteria but were not included in the analysis, including the reasons for exclusion.

Study	Sample Age range	Country	Reference values	Method of handgrip strength evaluation	Reasons for exclusion
Angst et al.[3]	n = 798 18-96	Switzerland	Reference values stratified by sex and age (5-year age groups) plus an equation (R^2 = 0.76)	Handgrip strength was evaluated in accordance with the ASHT recommendations,[a] with a Jamar dynamometer (Patterson Medical/Sammons Preston, Bolingbrook, IL, USA) set in the second handle position; values were expressed in kg; the mean of three trials for each hand was used.	The study sample was the same as that investigated by Werle et al.[31] The equations take into consideration the occupation of the individual.
Balogun et al.[4]	n = 960 7-84	Nigeria	Reference values stratified by sex and age (10-year age groups)	Measurements were performed with the patient in a standing position, with the elbow fully extended, the shoulder joint adducted and neutrally rotated, and the forearm and wrist joint in a neutral position; the position of the handle was adjusted so that the uppermost part of the dynamometer comfortably rested on the thenar eminence; both hands were assessed twice each, the highest values (expressed in kg) being used; the assessments were performed with 5-s contractions and 2-5 min of rest; verbal encouragement was given.	The instrument had not been validated (i.e., showed differences in comparison with the Jamar dynamometer).
Bohannon et al.[5]	n = 3,594 6-80	USA	Reference values	First sample: Measurements were performed with the patient in a standing position (unless the participant was physically limited), with the use of a digital handgrip dynamometer (Takei Scientific Instruments Co., Ltd., Niigata, Japan); a practice trial was performed; the grip size of the dynamometer was adjusted so that the second joint of the participant's index finger was at a 90° angle on the handle; each hand was tested three times; best values (expressed in kg) and mean values were determined for each hand. Second sample: Measurements were performed with the patient in a seated position, with arms by the sides, elbows flexed at 90°, and forearms in a neutral position, with the handle in the second position; a digital Jamar dynamometer (Patterson Medical/Sammons Preston) was used; a single submaximal practice trial was performed for each hand and, after at least 30 s, was followed by a single maximal trial of 3 to 4 s for each hand; verbal encouragement was given; values were recorded in pounds and converted to kg.	Different methods of evaluation of handgrip strength were used in order to analyze two samples together. The assessment method differs from the method proposed in the present study.
Budziareck et al.[6]	n = 300 18-90	Brazil	Reference values stratified by sex and age	Measurements were performed with the patient in a seated position, with elbows flexed at 90° and supported at the time of measurement; three 3-s measurements were performed for each hand; the mean value was used; information about the instrument used is not available.	The age groups were too broad (i.e., 18-30 years, 31-59 years, and > 60 years).

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Study	Sample Age range	Country	Reference values	Method of handgrip strength evaluation	Reasons for exclusion
Dodds et al.[7]	n = 49,964 4-102	UK	Reference values stratified by sex and age (5-year age groups)	12 studies were analyzed: five different devices were used across studies; 3 to 6 trials were performed; almost all studies assessed both hands; the test position varied between a seated position and a standing position; maximum values were used.	The evaluation method differs from that recommended by the ASHT.
Eika et al.[8]	n = 354 20-80[b]	Denmark	Reference values stratified by sex and age (10-year age groups)	Measurements were performed with the patient in a seated position, with the back straight and shoulders in their anatomical position; the Wii Balance Board (Nintendo Co., Ltd., Kyoto, Japan) was held vertically, resting on the thighs, about 20 cm away from the torso; while squeezing the corner of the Wii Balance Board; participants viewed a force-time curve in real time on a computer screen; 2-3 submaximal recordings were made for familiarization; maximal isometric handgrip strength was assessed twice for each hand in an alternating fashion; participants were encouraged to squeeze as long and hard as possible until a plateau on the force-time curve was reached; If such a plateau was not reached, the participant was instructed to stop when he or she was unable to further increase the force on the force-time curve; the average of the two trials was used.	The evaluation position differs from that recommended by the ASHT.
Fraser et al.[9]	n = 120 20-79	UK	Reference values stratified by sex and age (10-year age groups)	Measurements were performed with participants seated in a chair without arms, with the shoulders in a neutral position, elbows flexed at 90°, and wrists in a neutral position; a Martin vigorimeter (Karl Leibinger Medizintechnik GmbH & Co. KG, Mühlheim, Germany) was used in order to measure handgrip strength in pounds per square inch; two trials were performed for each hand, one trial with a large bulb and one with a medium-sized bulb.	A Martin vigorimeter was used in order to evaluate handgrip strength (pressure measurement). The number of individuals per group was small (10 individuals).
Gilbertson et al.[10]	n = 260 15-92	UK	Reference values stratified by sex and age (5-year age groups, the eldest individuals being > 75 years of age)	Measurements were performed in accordance with the ASHT recommendations,[a] with the use of a Jamar dynamometer (Patterson Medical/Sammons Preston) set in the second handle position; values were expressed in kg; the mean of three trials for each hand was used; no encouragement was given.	The number of individuals per group was small (10 individuals).
Graciano et al.[11]	n = 470 18-60*	Brazil	Reference values stratified by sex and age (10-year age groups)	Measurements were performed with the patient in a seated position in front of a support table, with the arm at a 90° angle; three trials were performed alternately for each hand, with a 5-s interval between trials; a hydraulic dynamometer (Kratos Equipamentos Industriais, São Paulo, Brazil) was used; the highest value was used.	The maximum age of individuals included in the sample is not clear.

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Study	Sample Age range	Country	Reference values	Method of handgrip strength evaluation	Reasons for exclusion
Günther et al.[12]	n = 769 20-95	Germany	Reference values stratified by sex and age (10-year age groups) plus equations (R^2 = 0.76 for the right hand and 0.75 for the left hand)	Measurements were performed with the arm, forearm, and wrist in a neutral position; three consecutive attempts were made, with 1-min intervals between attempts; a Baseline digital hydraulic dynamometer (Fabrication Enterprises Inc., White Plains, NY, USA) was used; values were expressed in kg; the average of three trials was used.	The evaluation position differs from that recommended by the ASHT.
Kim et al.[13]	n = 7,969 10-80[b]	South Korea	Reference values stratified by sex and age (5-year age groups)	Measurements were performed with the patient in a standing position and looking forward, with feet hip-width apart and the elbow fully extended; a digital handgrip strength dynamometer (TKK 5401 GRIP D; Takei Scientific Instruments Co., Ltd.) was held in a neutral, comfortable position with 90° flexion at the index finger; three trials were performed for each hand alternately; a 60-s interval was given between trials; the average of three trials for each hand was used.	The evaluation method differs from that recommended by the ASHT.
Kim et al.[14]	n = 11,073 18-80[b]	South Korea	Reference values stratified by sex and age (5-year age groups)	Measurements were performed with the patient in an upright position, with shoulders in a neutral position, arms at the side, and elbows fully extended. The handles were adjusted to accommodate hand size, with the index finger of each hand at 90° flexion between the proximal and middle interphalangeal joints; three 3-s maximum efforts were made for each hand alternately, with 60-s rests between measurements for the same hand; verbal encouragement was given; the greatest value for each hand was used; values were expressed in kg.	The evaluation position differs from that recommended by the ASHT.
Landi et al.[15]	n = 11,331 18-98	Italy	Reference values stratified by sex and age (5-year age groups)	Measurements were performed with the patient in a seated position, with shoulders in a neutral position, elbows near the trunk and flexed at 90°, and wrists in a neutral position (thumbs up); a hydraulic hand dynamometer (North Coast Medical, Inc., Morgan Hill, CA, USA) was used; a familiarization trial was made before the test; both hands were assessed, and the highest value was used in the analysis; values were expressed in kg.	Only one trial was performed for each hand.
Lee et al.[16]	n = 23,716 10-80[b]	Korea	Reference values stratified by sex and age (5-year age groups) plus cutoff values	Measurements were performed with the patient in a standing position and looking forward, with feet hip-width apart and elbows fully extended; a digital hand dynamometer (Takei Scientific Instruments Co., Ltd.) was held in a neutral, comfortable position with 90° of flexion at the index finger; three trials of at least 3 s for each hand were performed alternately, with a resting interval of at least 30 s between trials; values were expressed in kg; the maximum value obtained in the six trials was used.	The evaluation method differs from that recommended by the ASHT.

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Study	Sample Age range	Country	Reference values	Method of handgrip strength evaluation	Reasons for exclusion
Lim et al.[17]	n = 6,577 10-70[b]	Korea	Reference values stratified by sex and age (10-year age groups) plus reference equations (R = 0.85)	Measurements were performed with the patient in a standing position, with shoulders straight and both arms falling naturally to either side; feet were positioned under the hips, with toes pointing forward; three trials were performed for each hand alternately; a digital handgrip strength dynamometer (TKK5401; Takei Scientific Instruments Co., Ltd.) was used; values were expressed in kg; the mean of the three measurements was used.	The evaluation method differs from that recommended by the ASHT. The equations take into consideration waist circumference and occupation.
Luna-Heredia et al.[18]	n = 517 17-97	Spain	Reference values stratified by sex and age (10-year age groups)	Three consecutive measurements were performed for each upper limb, with a between-measurement interval of 5 s; values were expressed in kg; two different validated dynamometers (Baseline; Fabrication Enterprises Inc., and GRIP-D; Takei Scientific Instruments Co., Ltd.) were used; there was no information on participant position during the test.	The method of evaluation of handgrip strength is not clear.
Malina et al.[19]	n = 229 20-80	Mexico	Graphs of handgrip strength across ages	Measurements were performed for both hands; an adjustable Smedley dynamometer (TTM, Tokyo, Japan) was used; the better of two trials for each hand was used; values were expressed in kg; there was no information on participant position during the test.	The method of evaluation of handgrip strength is not clear. The sample consisted exclusively of individuals living in a rural community.
McKay et al.[20]	n = 1,000 3-101	Australia	Reference values stratified by sex and age (10-year age groups until the age of 60 years, with one group of individuals > 60 years of age)	A portable hand-held dynamometer (CITEC CT 3001; C.I.T. Technics, Groningen, the Netherlands) was used. There was no information on participant position during the trials or the number of trials performed.	There was only one group of individuals over 60 years of age.
Massy-Westropp et al.[21]	n = 419 18-97	Australia	Reference values stratified by sex and age (10-year age groups)	Measurements were performed in accordance with the ASHT recommendations[a]; the second handle setting was used for all participants; a Jamar dynamometer (Patterson Medical/Sammons Preston) and a Grippit dynamometer (Catell AB, Stockholm, Sweden) were used; values were expressed in kg for the Jamar dynamometer, and peak, average, and final handgrip strengths were recorded in N for the Grippit dynamometer.	In the middle of the data collection process, the protocol was changed from three trials for each hand to one trial for each hand.
Mohammadian et al.[22]	n = 1,008 20-75[b]	Iran	Reference values stratified by sex and age (5-year age groups)	Measurements were performed in accordance with the ASHT recommendations[a]; a Jamar hydraulic dynamometer (Patterson Medical/Sammons Preston) was used; the handle of the dynamometer was adjusted to the second position for all of the participants; the mean of three successive trials was used.	The outcome was reported in kgf (a unit of measurement that differs from the one used in the present study).

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Table S1. Characteristics of the 36 studies that met the inclusion criteria but were not included in the analysis, including the reasons for exclusion. (Continued...)

Study	Sample Age range	Country	Reference values	Method of handgrip strength evaluation	Reasons for exclusion
Nilsen et al.[23]	n = 566 20-94	Norway	Reference values stratified by sex and age (10-year age groups)	A Grippit dynamometer (Catell AB) was used; all testing was performed in accordance with basic testing procedures for a Grippit dynamometer; both hands were assessed, with one trial being performed for each hand; force recordings in N were displayed on the electronic unit every 0.5 s over a period of 10 s; peak and values were expressed in N.	The evaluation instrument showed discrepant values in comparison with the gold standard.
Pratt et al.[24]	n = 9,431 18-92	Ireland	Reference values stratified by sex and age (10-year age groups)	Measurements were performed with the patient in a standing position, with the arm positioned straight by the side; two maximal attempts of ≥ 3 s were performed; a Jamar dynamometer (Patterson Medical/Sammons Preston) was used; the dynamometer was adjusted so that the middle phalanx was at ~90° to the handle; values were expressed in kg; the average of the highest score for each hand was used in the analysis.	The evaluation position differs from that recommended by the ASHT.
Puh[25]	n = 199 20-79	Slovenia	Reference values stratified by sex and age (14-year age groups)	Measurements were performed in accordance with the ASHT recommendations[a]; a baseline hydraulic hand dynamometer (Fabrication Enterprises Inc.) set at the second position for all participants was used; verbal encouragement was given; the mean of the three measurements was used.	The age groups were too broad (14-year age groups).
Schlüssel et al.[26]	n = 3,050 20-70[b]	Brazil	Reference values stratified by sex and age (10-year age groups)	Measurements were performed with the patient in a standing position, with both arms pending sideways and with the dynamometer facing outward from the body; a warm-up was performed; three trials were performed on each side alternately, with a rest period of at least 1 min between trials for the same hand; a Jamar mechanical dynamometer (Patterson Medical/Sammons Preston) was used; the handle position was set so that individuals could fit the instrument comfortably into their hands; the highest value for each side was used.	The evaluation position differs from that recommended by the ASHT.
Steiber[27]	n = 11,790 17-90	Germany	Reference values stratified by sex, height (5-cm height groups), and age (5-year age groups)	A Smedley dynamometer (TMM) was used; two measurements were performed for each hand; the maximum value achieved with either hand was used; there was no information on participant position during the tests or the use of verbal encouragement.	The evaluation position differs from that recommended by the ASHT.
Stoll et al.[28]	n = 543 20-82	Switzerland	References values stratified by sex	A Martin vigorimeter (in bars; 1 bar = 100 N/m^2) was used; both hands were assessed; values were expressed in bars; there was no information on patient position during the trials, the number of trials performed, or the use of verbal encouragement.	The method of evaluation of handgrip strength is unclear.

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Study	Sample Age range	Country	Reference values	Method of handgrip strength evaluation	Reasons for exclusion
Tveter et al.[29]	n = 370 18-90	Norway	Reference values stratified by sex and age (10-year age groups)	Measurements were performed with the patient in a seated position, with the upper arm alongside the trunk and the elbow at 90° of flexion; a hydraulic hand dynamometer with 5 handle positions was used; both hands were tested; the mean of two trials for each hand was used; values were expressed in kg; there was no information on the use of verbal encouragement or on the dynamometer brand used.	The sample is not representative (e.g., individuals who were unable to climb stairs were excluded).
Vianna et al.[30]	n = 2,648 18-90	Brazil	Reference values stratified by sex and age (5-year age groups, the eldest individuals being > 76 years of age) plus reference equations (R = 0.65 for males and 0.61 for females)	Measurements were performed with the patient in a standing position and holding the dynamometer close to the body, with the arm fully extended; a digital dynamometer (Takei Kiki Kogyo Co., Ltd., Niigata, Japan) was used; the size of the grip was adjusted so that the patient felt comfortable; two attempts were performed for each hand; values were expressed in kg; the best value obtained during the four attempts was used; there was no information on verbal encouragement.	The evaluation position differs from that recommended by the ASHT. The sample is not representative (i.e., almost all of the participants were White and had a high socioeconomic status).
Wang et al.[31]	n = 1,232 18-85	USA	Reference values stratified by sex and age (5-year age groups)	Measurements were performed with participants in a seated position and in an upright posture, with arms by their sides, elbows flexed at 90°, and forearms in a neutral position; a Jamar dynamometer (Patterson Medical/ Sammons Preston) was used with its handle in the second position; a practice trial was allowed; both hands were assessed; the highest value for both hands was used.	Only one trial was performed for each hand.
Wang et al.[32]	n = 13,676 6-80	USA	Reference values stratified by sex and age (5-year age groups)	Measurements were performed with the patient in a standing position, with feet hip-width apart and even, toes pointing forward, knees comfortable but not bent, shoulders back, chest up, eyes straight ahead, shoulders abducted ~10°, arms straight down side, elbows fully extended, and wrists in a neutral position; a digital dynamometer (Takei Scientific Instruments Co., Ltd.) was used; grip size was adjusted so that the second joint of the index finger was at a 90° angle on the handle; a practice trial was performed; both hands were assessed three times each, with 60-s breaks between trials; values were expressed in kg; the best value for each hand was used; verbal encouragement was given.	The evaluation position differs from that recommended by the ASHT.
Wong[33]	n = 11,108 6-79	Canada	Reference values stratified by sex and age (5-year age groups) plus equations (R^2 values not reported)	Measurements were performed with the patient in a standing position, with feet slightly apart and a Smedley III handgrip dynamometer (Takei Scientific Instruments Co., Ltd.) held in line with the forearm away from the body at the level of the thigh; both hands were assessed twice each alternately; values were expressed in kg; the highest handgrip strength value on either hand was used.	The evaluation position differs from that recommended by the ASHT.

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Table S1. Characteristics of the 36 studies that met the inclusion criteria but were not included in the analysis, including the reasons for exclusion. (Continued...)

Study	Sample Age range	Country	Reference values	Method of handgrip strength evaluation	Reasons for exclusion
Wu et al.[34]	n = 37,707 18-93	China	Reference values stratified by sex and age (5-year age groups)	Measurements were performed with the patient in a standing position and holding a dynamometer (EH101; CAMRY, Guangdong, China) beside but not against the body; the width was adjusted for optimal fit for each participant according to the manufacturer instructions; both hands were assessed twice each; values were expressed in kg; the maximum value achieved with either hand was used; verbal encouragement were given.	The evaluation position differs from that recommended by the ASHT.
Xiao et al.[35]	n = 193 unclear	China	Reference values stratified by sex and occupation	Measurements were performed with the patient in a seated position, in front of a support table, and holding a grip dynamometer with the palm facing up; the span of the grip dynamometer was set at 2.5 cm; both hands were assessed; right and left handgrip strengths were collected; there was no information on the number of trials or the use of verbal encouragement.	The information about the instrument used is not clear. The reference values were stratified by occupation categories.
Yoo et al.[36]	n = 4,553 18-80	Korea	Reference values stratified by sex and age (5-year age groups)	Measurements were performed with the patient in a standing position, with the forearm away from the body at the level of the thigh; both hands were assessed three times each, with at least 30 s of rest; a digital hand dynamometer (Takei Scientific Instruments Co., Ltd.), and the maximum value for the dominant hand was used.	The evaluation position differs from that recommended by the ASHT.
Yoshimura et al.[37]	n = 2,468 40-97	Japan	Reference values stratified by sex and age (10-year age groups until the age of 80 years, with one group of individuals > 80 years of age)	A handgrip dynamometer (Toei Light Co., Ltd., Saitama, Japan) was used; both hands were assessed; the better value was used; there was no information on patient position during the trials or the number of trials performed.	The method of evaluation of handgrip strength is not clear.
Yu et al.[38]	n = 4,728 18-80[b]	China	Reference values stratified by sex and age (10-year age groups)	Measurements were performed with the patient in a standing position, facing forward, and holding a digital dynamometer (TKK 5401 Grip-D; Takei Scientific Instruments Co., Ltd.) with the grip meter indicator facing outward, away from any part of the body, with feet shoulder-width apart and elbows fully extended; one practice trial for each hand was allowed; both hands were assessed, with two trials for each hand alternately; the interval between trials was approximately 30 s.	The evaluation position differs from that recommended by the ASHT.

[a]Second handle position of the dynamometer. Three successive handgrip strength determinations should be recorded in either kilograms or pounds. The patient should be seated, with the shoulder adducted and neutrally rotated, the elbow flexed at 90°, and the forearm and wrist in a neutral position. [b]The eldest individuals were at least that age. Although it clearly goes beyond that age, the upper limit is not clear.

Table S2. Kappa values for the level of agreement among sets of reference values for handgrip strength when classifying COPD patients in Brazil as having low handgrip strength.

Study	Fredericksen et al.[40]	Massy-Westropp et al.[41]	Mathiowetz et al.[42]	Peters et al.[43]	Shim et al.[44]	Spruit et al.[45]	Werle et al.[46]
Bohannon et al.[39]	0.02	0.06	0.09	0.51	0.02	0.03	0.27
Fredericksen et al.[40]		0.62	0.55	0.10	0.55	0.58	0.69
Massy-Westropp et al.[41]			0.90	0.16	0.81	0.52	0.36
Mathiowetz et al.[42]				0.24	0.73	0.46	0.42
Peters et al.[43]					0.16	0.22	0.37
Shim et al.[44]						0.66	0.37
Spruit et al.[45]							0.36

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