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Relation of Anthropometric Measures and Indices to Isokinetic Trunk Strength – a Retrospective Analysis

Der Zusammenhang von anthropometrischen Messgrößen mit isokinetischer Rumpfkraft – eine retrospektive Analyse

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Summary

- **Problem:** Relations between anthropometric measures and isokinetic trunk strength are known for age, sex, weight and height in a healthy population as well for body mass index (BMI) in an obese population. Limited data exists regarding the interaction with waist circumference, waist-to-height ratio (WHtR) and BMI. Previously, different testing positions and methods were performed. Hence, this study aims to examine the relationship between anthropometric measurements and isokinetic trunk strength measured in the sitting position and in an athletic population.
- **Methods:** Age, sex, weight, height, waist circumference, BMI and WHtR obtained from 1480 participants were analyzed regarding their relationship to parameters of isokinetic trunk strength (torque, power and work). Statistics were performed by Pearson-correlation and mixed linear models.
- **Results:** Greater weight, height, waist circumference, BMI, WHtR and male sex were related with greater isokinetic trunk strength. Increasing age was associated with lower isokinetic trunk strength. There is no relevant relation between anthropometric variables and flexion-/extension-ratios. Factors related to isokinetic trunk strength can be ordered in the following ranking: BMI>age>WHtR.
- **Discussion:** Relations of anthropometric factors with isokinetic trunk extension and flexion strength measured in the sitting position are comparable to trunk strength measured with other measurement techniques. Modern anthropometric measurements and indices like waist circumference and WHtR are related with trunk strength as well.
- **Conclusions:** Professionals using isokinetic measurements should be aware of the association with anthropometric factors.

KEY WORDS:
Core Strength, Age, Waist Circumference, Body-Mass-Index (BMI), Waist-to-Height-Ratio (WtHR)

Zusammenfassung

- **Problemstellung:** Zusammenhänge zwischen anthropometrischen Größen und isokinetischer Rumpfkraft sind für Alter, Geschlecht, Gewicht und Größe in einer gesunden Bevölkerung sowie für den Body-Mass-Index (BMI) in einer fettleibigen Bevölkerung bekannt. Für den Taillenumfang, die Waist-to-Height-Ratio (WHtR) und den BMI liegen kaum Daten vor. Da in früheren Studien unterschiedliche Testpositionen und -methoden verwendet wurden, zielt diese Studie darauf ab, den Zusammenhang zwischen anthropometrischen Größen und im Sitzen gemessener isokinetischer Rumpfkraft in einer sportlich ambitionierten Population zu untersuchen.
- **Methoden:** Alter, Geschlecht, Gewicht, Größe, Taillenumfang, BMI und WHtR von 1480 Probanden wurden auf ihren Zusammenhang mit Parametern der isokinetischen Rumpfkraft (Drehmoment, Leistung und Arbeit) untersucht. Die Statistik wurde mittels Pearson-Korrelation und gemischter linearer Modelle durchgeführt.
- **Ergebnisse:** Ein höheres Gewicht, eine höhere Körpergröße, ein höherer Taillenumfang, ein höherer BMI, eine höhere WHtR und das männliche Geschlecht waren mit einer höheren isokinetischen Rumpfkraft verknüpft. Zunehmendes Alter hing mit einer geringeren isokinetischen Rumpfkraft zusammen. Es gibt keinen relevanten Zusammenhang zwischen anthropometrischen Variablen und Flexions-/Extensionsverhältnissen. Hinsichtlich der Stärke des Zusammenhanges mit der isokinetischen Rumpfkraft konnte eine Rangfolge ermittelt werden: BMI>Alter>WHtR.
- **Diskussion:** Die Wechselwirkungen anthropometrischer Faktoren mit der im Sitzen gemessenen isokinetischen Rumpfstreck- und -beugekraft sind vergleichbar mit der mit anderen Messverfahren gemessenen Rumpfkraft. Moderne anthropometrische Maße wie der Taillenumfang hängen in vergleichbarer Weise mit der Rumpfkraft zusammen.
- **Schlussfolgerungen:** Sportmediziner, die isokinetische Messungen durchführen, sollten sich der Wechselwirkungen mit anthropometrischen Faktoren bewusst sein.

SCHLÜSSELWÖRTER:
Rumpfkraft, Alter, Taillenumfang, Body-Mass-Index (BMI), Taille-zu-Größe-Verhältnis (WtHR)

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Introduction

The measurement of isokinetic trunk strength is a safe and accepted method for quantifying trunk strength not only in sports medicine, but also in the treatment and rehabilitation of back pain (14, 15, 17, 19, 24, 34, 41, 43). Advice on trunk strength training is a key element of professional intervention, particularly in sports and rehabilitation medicine. High trunk strength can lead to advantages in performance, in example as a predictor of pedalling power in elite racing cyclists (30), or in the prevention of injuries, in example in reducing non-contact lower extremity sprain and or strain in soccer players (1). In patients with extremity impairment, it is not possible to measure trunk strength in the standing position or using field tests, like the double-leg-lowering test or Biering-Sorensen-test (13, 40). Therefore, iso-

Table 1

Results of anthropometric measurements. BMI=body-mass-index, WHtR=Waist to Height-Ratio.

PARAMETER	MALE AND FEMALE SUBJECTS (N= 3172-3754)	FEMALE SUBJECTS (N= 95-160)	MALE SUBJECTS (N=3073-3594)
Age (years)	37.9±10.2	32.5±13.9	38.0±10.0
Height (cm)	180.6±7.0	167.6±6.1	181.1±6.6
Weight (kg)	85.6±2.6	66.3±12.2	86.2±12.1
BMI (kg/m²)	26.1±3.1	23.5±3.9	26.2±3.1
Waist circumference (cm)	89.3±9.9	77.17±10.5	89.8±9.7
WHtR	0.49±0.06	0.46±0.06	0.50±0.05

Table 2

Results of isokinetic trunk strength measurements. EPP=Extension peak power, EPT=extension peak torque, EPW=Extension peak work, ETW=Extension total work, FPP=Flexion peak power, FPT=flexion peak torque, FPW=Flexion peak work, FTW=Flexion total work, F/E-Ratio=Ratio of flexion and extension, PP=peak power, PT=peak torque, PW=peak work, SD=standard deviation, SEM=standard error of the mean.

PARAMETER	MALE AND FEMALE SUBJECTS (N=3754)		FEMALE SUBJECTS (N= 160)		MALE SUBJECTS (N=3594)	
	MEAN (±SD)	SEM	MEAN (±SD)	SEM	MEAN (±SD)	SEM
FPT (Nm)	228.2 (± 54.3)	0.89	140.47 (±34.03)	2.69	232.10 (± 51.67)	0.86
EPT (Nm)	399.3 (± 108.2)	1.77	228.08 (±71.22)	5.63	406.87 (±103.15)	1.72
FPW (Joule)	101.3 (± 25.9)	0.42	56.39 (±14.66)	1.16	103.30 (±24.48)	0.41
EPW (Joule)	193.5 (± 56.1)	0.92	103.84 (±37.95)	3.00	197.50 (±53.38)	0.89
FPP (Watt)	143.4 (± 38.9)	0.64	77.67 (±22.48)	1.78	146.30 (±36.84)	0.61
EPP (Watt)	267.2 (± 82.1)	1.34	137.24 (±52.34)	4.14	273.00 (±78.34)	1.31
FTW (Joule)	941.6 (± 246.0)	4.01	523.45 (±141.90)	11.22	960.17 (±232.74)	3.88
ETW (Joule)	1778.1 (± 532.6)	8.69	956.39 (±365.51)	28.90	1814.68 (±508.91)	8.49
average of FPT (Nm)	180.8 (± 47.0)	0.77	110.27 (±27.22)	2.15	183.89 (±45.21)	0.75
average of EPT (Nm)	351.6 (± 98.8)	1.61	199.82 (±66.93)	5.29	358.37 (±94.52)	1.58
average of FPW (Joule)	94.2 (± 24.4)	0.40	52.60 (±14.35)	1.13	96.01 (±23.02)	0.38
average of EPW (Joule)	177.8 (± 53.2)	0.87	95.73 (±36.33)	2.87	181.50 (±50.88)	0.85
average of FPP (Watt)	128.2 (± 35.4)	0.58	68.36 (±20.61)	1.63	130.92 (±33.57)	0.56
average of EPP (Watt)	240.5 (± 76.3)	1.25	122.49 (±49.26)	3.89	245.79 (±73.06)	1.22
F/E-Ratio peak torques	0.60 (± 0.16)	0.003	0.65 (±0.18)	0.014	0.59 (±0.16)	0.003
F/E-Ratio peak work	0.55 (± 0.17)	0.003	0.59 (±0.19)	0.015	0.55 (±0.17)	0.003
F/E-Ratio peak power	0.57 (± 0.18)	0.003	0.62 (±0.20)	0.016	0.57 (±0.18)	0.003
F/E-Ratio average of PT	0.54 (± 0.17)	0.003	0.60 (±0.21)	0.017	0.54 (±0.17)	0.003
F/E-Ratio average of PW	0.56 (± 0.19)	0.003	0.60 (0.21)	0.017	0.56 (±0.19)	0.003
F/E-Ratio average of PP	0.57 (± 0.20)	0.003	0.62 (0.23)	0.018	0.57 (±0.20)	0.003
F/E-Ratio total work	0.56 (± 0.19)	0.003	0.60 (±0.22)	0.017	0.56 (±0.19)	0.003

kinetic measurement in the sitting position is a reliable method for assessing trunk strength (19,33). Furthermore, anthropometric measurements during the intervention and observation of athletes or patients in training and rehabilitation are necessary to provide professional advice based on changes in the body composition. Finally, relations between trunk strength and anthropometric changes during the intervention are feasible.

Extensive data exist on the relationship between anthropometric factors and isokinetic trunk strength measured in the standing position. Associations were found between age (8, 17, 20, 35, 39), sex (2, 10, 18, 27), height (11, 17), and weight (2,8,10). In obesity research, body mass index (BMI) and waist-to-height ratio (WHtR) have been identified as influencing factors (3, 16, 21, 29). A higher waist circumference, which indicates abdominal obesity, was estimated to lead to a higher flexion peak torque in equation models for trunk strength (31). Since most of the previous studies are more than 20 years old, it is unknown whether those previous results can be still applied to modern isokinetic devices.

Isokinetic trunk strength measurements in the standing and sitting positions can differ for several reasons. Possible influencing factors include different testing setups, gravity com-

Table 3

Pearson-product-moment-correlation between parameters of isokinetic trunk strength and age, sex, height, weight and waist circumference. EPP=Extension peak power, EPT=extension peak torque, EPW=Extension peak work, ETW=Extension total work, FPP=Flexion peak power, FPT=flexion peak torque, FPW=Flexion peak work, FTW=Flexion total work, p-value=level of significance (2-tailed), r=Pearson-correlation-coefficient.

PARAMETER	SEX (N=3754)		AGE (N=3750)		HEIGHT (N=3319)		WEIGHT (N=3205)		WAIST CIRCUMFERENCE (N= 3172)	
	R	P-VALUE	R	P-VALUE	R	P-VALUE	R	P-VALUE	R	P-VALUE
FPT	-0.341	<0.001	-0.158	<0.001	0.416	<0.001	0.480	<0.001	0.235	<0.001
EPT	-0.334	<0.001	-0.275	<0.001	0.382	<0.001	0.463	<0.001	0.189	<0.001
FPW	-0.365	<0.001	-0.208	<0.001	0.434	<0.001	0.483	<0.001	0.195	<0.001
EPW	-0.337	<0.001	-0.238	<0.001	0.483	<0.001	0.447	<0.001	0.177	<0.001
FPP	-0.356	<0.001	-0.228	<0.001	0.428	<0.001	0.496	<0.001	0.207	<0.001
EPP	-0.334	<0.001	-0.248	<0.001	0.363	<0.001	0.447	<0.001	0.178	<0.001
FTW	-0.359	<0.001	-0.206	<0.001	0.426	<0.001	0.473	<0.001	0.190	<0.001
ETW	-0.326	<0.001	-0.252	<0.001	0.364	<0.001	0.414	<0.001	0.139	<0.001
average of FPT	-0.316	<0.001	-0.160	<0.001	0.419	<0.001	0.493	<0.001	0.240	<0.001
average of EPT	-0.324	<0.001	-0.262	<0.001	0.374	<0.001	0.452	<0.001	0.184	<0.001
average of FPW	-0.360	<0.001	-0.205	<0.001	0.426	<0.001	0.472	<0.001	0.190	<0.001
average of EPW	-0.326	<0.001	-0.252	<0.001	0.364	<0.001	0.414	<0.001	0.139	<0.001
average of FPP	-0.357	<0.001	-0.225	<0.001	0.429	<0.001	0.494	<0.001	0.205	<0.001
average of EPP	-0.326	<0.001	-0.260	<0.001	0.358	<0.001	0.420	<0.001	0.144	<0.001

pensation, pre-tension of the muscles, participation of the hip flexors and extensors in trunk extension and flexion, starting position in the hip joint and the specified range of motion (7, 13, 38, 43). Therefore, the data acquired in the standing position must be confirmed.

Previously, only three studies have measured isokinetic trunk strength in a sitting position (9, 21, 25). Although the relationships between age, sex, height, BMI, and the isokinetic trunk strength in the sitting position are known (9, 21, 26), no relationship has yet been reported between waist circumference and the WHtR. These anthropometric factors are a central tool not only for the prediction of abdominal obesity and cardiovascular health but also in sports and rehabilitation medicine because professionals provide diet or training advices depending on pathological or non-pathological values (23).

Furthermore, most isokinetic studies focussed on trunk extension. Trunk flexion matters when throwing overhead or when canoeing is the main discipline, and hence it should be considered (42, 43).

There is a well known relationship between anthropometric measurements and trunk strength in the standing position. Modern tests are performed in a sitting position and measures can differ due to the changed range of movement (ROM) in the hip during measurement (13). Therefore, it is necessary to evaluate different measures and associations in athletic populations in the sitting position. It is necessary to demonstrate this in an athletic population, as isokinetic measurements are frequently performed on athletes. To date, torque, work, and power parameters have been considered separately. A complete dataset should be provided here.

Materials and Methods

Experimental Approach to the Problem

This study was a retrospective analysis of participants tested between 2008 and 2018. Anthropometric measurements of the following metric variables were performed (as the independent variables): age, sex, height, body weight, and waist circumference. BMI and WHtR were also calculated. Before starting the isokinetic assessment, the participants had a personal appointment with an orthopedic surgeon for the collection of medical history and examination. The exclusion criteria for isokinetic measurement were acute illness, acute pain, or structural damage to the spine (acute disc herniation, spinal implants, tumours, and fractures) which would lead to incorrect data. For the best reliability of isokinetic measurements, instructions from previous studies were considered (2, 17, 18, 25, 32, 35). The following metric isokinetic measurement parameters were the dependent variables representing flexion and extension trunk strength: absolute and average parameters of torque, work, power, and total work as well as the flexion-to-extension ratios of all parameters. Data were collected retrospectively from the archive and digitally from the isokinetic device in MS Excel format and transformed into SPSS®-Data.

Subjects

A total of 1,480 participants (1,372 male and 108 female soldiers) who underwent routine checkups were included in this study. Isokinetic and anthropometric measurements were performed once or several times between 2008 and 2018. Out of the 1480 participants, 732 were assessed only once, 231 twice, 134 three times, 83 four times, 108 five times, 103 six times, 62 seven times, 20 eight times, two nine times, two ten times, one eleven times, one 12 times and one 13 times. Depending on the analyzed parameters, 3,172-3,754 samples were obtained. All anthropometric measurements (age, height and weight, and waist circumference) were recorded by medical assistance personnel on the day of the isokinetic measurements. Waist circumference measurements were made in a horizontal line halfway between the crista iliaca and the inferior costal arch, according to WHO recommendations (44). BMI was calculated as: weight (kg) / (height (m))^2. WtHR was calculated as waist circumference (m) / height (m) The results of the anthropometric measurements are shown in table 1.

Table 4

Pearson-product-moment-correlation between flexion-/extension-ratios of isokinetic trunk strength and sex, age, weight and Body-Mass-Index (BMI). BMI=body-mass-index, F/E-Ratio=Ratio of flexion and extension, PP=peak power, PT=peak torque, PW=peak work, p-value=level of significance (2-tailed), r=Pearson-correlation-coefficient.

PARAMETER	SEX (N=3754)		AGE (N=3319)		WEIGHT (N=3205)		BMI (N=3203)	
	R	P-VALUE	R	P-VALUE	R	P-VALUE	R	P-VALUE
F/E-Ratio peak torques	0.074	<0.001	0.179	<0.001	-0.077	<0.001	-0.083	<0.001
F/E-Ratio peak work	0.047	0.004	0.088	<0.001	-0.057	0.001	-0.071	<0.001
F/E-Ratio peak power	0.056	0.001	0.087	<0.001	-0.045	0.01	-0.062	<0.001
F/E-Ratio average of PT	0.073	<0.001	0.13	<0.001	-0.047	0.007	-0.056	0.001
F/E-Ratio average of PW	0.043	0.009	0.11	<0.001	-0.051	0.004	-0.059	0.001
F/E-Ratio average of PP	0.049	0.003	0.111	<0.001	-0.035	0.046	-0.046	0.009
F/E-Ratio total work	0.042	0.01	0.108	<0.001	-0.046	0.009	-0.055	0.002

All of the participants provided written consent to the use of their data for research before measurement. The local and institutional ethics boards approved this study (file number: A2019-0123), which was conducted following the Declaration of Helsinki.

Procedures

The isokinetic device IsoMed2000 (D.&R. Ferstl, Hemau, Germany) was used to assess trunk strength. This device includes gravitational compensation (2, 17, 25, 35). As recommended in earlier studies, the participants were seated on an isokinetic device after a ten-minute warm-up on a bicycle-ergometer, and the measurements were acquired under the supervision of an experienced examiner who encouraged the participant to exert maximum effort (18, 25, 32). The procedure consisted of 10 repetitions at an angular velocity of 90 degrees per second (17, 35). The range of motion was -24 to +22°, starting from 90° flexion of the hip joint. All the parameters were measured separately for trunk extension and flexion. The following measured values were referred to as absolute parameters: peak torque (Newtonmeter, Nm), peak work (Joule, J), peak power (Watt, W) and total work (Joule, J). The peak parameters were the best out of 10 repetitions, and the total work was summed up from 10 repetitions. The average parameters denoted the average values from 10 repetitions of the peak torque, peak work, and peak power. The flexion-to-extension ratios of the absolute and average parameters were calculated. Isokinetic measurements were performed at least one month apart to avoid intra-individual learning effects. There was no control group or condition, however, 24 subjects were examined twice in within 0-2 days. Coefficients of variation and intraclass correlations-(ICCs) were calculated from that data. ICCs were calculated one-way random and thus corresponded to Type (1,k) according to Shrout & Fleiss (36) or Type K as per McGraw & Wong (22).

Statistical Analysis

The export function of the IsoMed 2000 device was used to output data as comma separated values (CSV) files. These files were digitally transformed using Excel-based-software and checked for plausibility. SPSS Version 23 (IBM, Armonk, NY, USA) was used for the statistical analysis. Data were first transformed into a long-range format in order to consider repeated measurements. Normal distribution was analyzed visually owing to the known limitation of Kolmogorov-Smirnov and Shapiro-Wilk tests in large sample sizes (12). A normal distribution was demonstrated for the measured variables of height, weight, BMI, and WHtR. No normal distribution was demonstrated for age and sex as the population of soldiers mainly consisted of young and male participants (age range 18-81 years, percentage of male participants 95,74%). Subsequent statistical procedures were performed under the assumption of the central limit theorem. Using further descriptive statistics, the metric variables were analyzed using Pearson's product-moment correlation to calculate the Pearson correlation coefficient (r). Cohen´s rules were used to interpret the strength of correlation (6). Regression analyses were performed separately for each isokinetic parameter to quantify the correlation between the anthropometric variables and dependent isokinetic parameters. Mixed linear regression models were used to consider the intraindividual effects of up to 13 measurements per participant over the observation period. Subsequently, the residuals, and thus the error terms, were visually checked for normal distribution using a histogram and Q-Q-plot. Due to multicollinearity, not all anthropometric influencing variables were included in the regression analyses. Only age, BMI and WHtR were included in the analyses to produce comparable models. Sex as a dichotomic variable was not included in regression analyses, because the predominantly male study population was not applicable to investigate differences between the sexes. Owing to the large numerical differences in the regression coefficients (RCs), the T-statistic was used. In regression analyses, the T-statistic allowed for more comparable results. The T-statistic was calculated by dividing the RC by the standard error. With zero variance, one result was confirmed by a generalized linear model, which was checked for heteroscedasticity using the Breusch-Pagan test and the residuals were visually checked for normal distribution. No differences were observed in the RCs of the mixed linear model. Significance was reached when $p \leq 0.05$. All isokinetic parameters provided good reliability (coefficients of variation<0.19, and ICC>0.82, except for the average torque of trunk flexion=0.656).

Results

Isokinetic Measurements

Table 2 shows the results of the isokinetic measurements.

Relation to Sex and Age

Female sex and increasing age correlated with decreasing absolute and average parameters of torque, work, power, and total work (table 3). While a moderate to strong correlation was observed for sex, a weak correlation was observed for age (table 3). In the regression analyses, older age was negatively associated with absolute and average parameters of torque, work, power, and for the total work (table 6). A greater quantitative decrease in extension than in flexion can be determined per year of life. For example, peak torque extension decreased by 2.9 Nm per year of life, and peak torque flexion by 1.1 Nm per year of life. The highest age-related absolute decrease was observed in total work at extension. The strongest decrease, corrected for the standard error, was observed in the peak torque for trunk extension. Flexion-to-extension ratios correlated very weakly with age and sex (table 4). The correlations between age and flexion-to-extension ratios could not be quantified using mixed linear models due to missing normal distribution of the residuals.

Relation to Height and Weight

Higher height and weight were correlated with increased isokinetic trunk strength in the absolute and average parameters of torque, work, power and total work (table 3). Body weight showed a strong correlation, while height showed a moderate to strong correlation (table 3). Higher weight was weakly correlated with lower flexion-to-extension ratios (table 4), and no significant correlation was observed for height (data not shown). However, the effects of height and weight could not be quantified using the mixed linear models. The correlations between height respectively weight and flexion-to-extension ratios could not be quantified using mixed linear models due to missing normal distribution of the residuals.

Relation to Waist Circumference

A larger waist circumference was weakly correlated with higher absolute and average values of torque, work, power and total work (table 3), whereas no significant association with the flexion-to-extension ratios could be detected (data not shown). It was not possible to quantitatively analyze the correlations of the waist circumference in the mixed linear models. The correlations between waist circumference and flexion-to-extension ratios could not be quantified using mixed linear models due to missing normal distribution of the residuals.

Relation to BMI and WHtR

Higher BMI was moderately correlated with increasing absolute and average values of torque, power, work, and total work (table 5). In the regression analyses, this was confirmed by a high level of significance for all absolute and average parameters of torque, power, work, and total work (table 6). A higher BMI correlated very weakly with lower flexion/extension ratios. (table 4). The association between BMI and the flexion/extension ratios could not be quantified using mixed linear models due to missing normal distribution of the residuals.

A higher WHtR was weakly correlated with higher absolute and average values of isokinetic trunk strength (table 5). In the regression models, strong negative and positive RCs were detected in some cases (table 6). The correlations between WHtR and flexion-to-extension ratios could not be quantified using mixed linear models due to missing normal distribution of the residuals.

Ranking of the Influencing Factors

One of the goals was to use regression analyses to rank the relationship between anthropometric variables and trunk strength. Owing to the lack of normal distribution of the residuals in the regression analyses for the flexion-to-extension ratios and multicollinearity in the models, including independent variables such as sex, height, weight and waist circumference, only three factors could be listed in this ranking. According to the RCs alone, the strength of the correlation of the three anthropometric variables with the absolute and average parameters of isokinetic trunk strength can be ordered as follows: WHtR (average RC=-3540,273-158,086 [the strongest factor in 14/14 models])>BMI (average RC=4,841-102,179)>age (average RC=-20,860 to-11,736). According to the T-statistics and level of significance (p-value), the ranking of the three anthropometric variables changed in the following manner: BMI (average T-statistics=27,963-22,979 [the strongest factor in 13/14 models]; average p-value=1,1917*e^{-90}-3,6674 *e^{-31} [the strongest factor in 14/14 models])>age (T-statistics=-20,860 to -11,736 ; average p-value=5,6714*e^{-154}-3,3411*e^{-108})>WHtR (T-statistics=-15,844-10,279 ;average p-value=1,8146^{*e-54}-2,1455^{*e-24}). Notably, the t-statistics were more comparable. Accordingly, we preferred the following ranking: BMI>Age>WtHR

Table 5

Pearson-product-moment-correlation between parameters of isokinetic trunk strength and Body-Mass-Index / Waist-to-Height-Ratio. EPP=Extension peak power, EPT=extension peak torque, EPW=Extension peak work, ETW=Extension total work, FPP=Flexion peak power, FPT=flexion peak torque, FPW=Flexion peak work, FTW=Flexion total work, p-value=level of significance (2-tailed), r=Pearson-correlation-coefficient.

PARAMETER	BMI (N=3203)		WHTR (N=3176)	
	R	P-VALUE	R	P-VALUE
FPT	0.332	<0.001	0.094	<0.001
EPT	0.338	<0.001	0.054	0.003
FPW	0.326	<0.001	0.049	0.006
EPW	0.326	<0.001	0.052	0.003
FPP	0.345	<0.001	0.061	0.001
EPP	0.332	<0.001	0.053	0.003
FTW	0.319	<0.001	0.048	0.007
ETW	0.291	<0.001	0.017	0.348
average of FPT	0.345	<0.001	0.096	<0.001
average of EPT	0.329	<0.001	0.051	0.004
average of FPW	0.318	<0.001	0.048	0.007
average of EPW	0.291	<0.001	0.017	0.343
average of FPP	0.342	<0.001	0.058	0.001
average of EPP	0.300	<0.001	0.020	0.248

Discussion

Concordant with previous research, significant positive relationships of height, weight, and male sex, as well as negative relationships of female sex and age, on the isokinetic trunk strength could also be shown for isokinetic trunk strength measured in the sitting position (2, 8, 9, 10, 11, 17, 20, 27, 32, 35). Despite the different test conditions, evidence from research with different testing positions and different measurement approaches showed comparable results (2, 8, 10, 17, 27, 32, 39). Garcia-Vacquero et al. postulated the need for further investigations into the association between anthropometric parameters and trunk strength (14). The results of the present study describe the relationship of all common anthropometric factors concerning trunk strength.

BMI and WHtR had a positive relationship with isokinetic trunk strength. With an increase in anthropometric parameters (BMI, WHtR, weight, and waist circumference) in- ›

Table 6

Mixed linear regression models for variables of isokinetic trunk strength to age, Body-Mass-Index (BMI) and Waist-to-Height-Ratio (WHtR) (n=3172). EPP=Extension peak power, EPT=extension peak torque, EPW=Extension peak work, ETW=Extension total work, FPP=Flexion peak power, FPT=flexion peak torque, FPW=Flexion peak work, FTW=Flexion total work, p-value=level of significance (2-tailed), RC=regression coefficient, T=t-statistics.

PARAMETER	AGE			BMI			WHTR		
	RC	T	P-VALUE	RC	T	P-VALUE	RC	T	P-VALUE
FPT	-1.024	-11.736	<0.001	9.972	22.979	<0.001	-312.534	-12.269	<0.001
EPT	-3.341	-20.860	<0.001	21.991	27.622	<0.001	-684.302	-14.630	<0.001
FPW	-0.588	-14.765	<0.001	5.284	26.690	<0.001	-181.885	-15.637	<0.001
EPW	-1.510	-17.770	<0.001	11.095	26.267	<0.001	355.593	-14.329	<0.001
FPP	-0.974	-16.583	<0.001	8.165	27.963	<0.001	-268.633	-15.661	<0.001
EPP	-2.297	-18.523	<0.001	16.632	26.982	<0.001	-534.513	-14.760	<0.001
FTW	-5.542	-14.535	<0.001	48.983	25.846	<0.001	-1.679.975	-15.089	<0.001
ETW	-14.564	-17.827	<0.001	102.179	25.162	<0.001	-3.540.273	-14.838	<0.001
average of FPT	-1.136	-13.489	<0.001		*BMI excluded*		158.086	10.279	<0.001
average of EPT	-2.939	-19.748	<0.001	19.655	26.566	<0.001	-616.475	-14.183	<0.001
average of FPW	-0.546	-14.474	<0.001	4.841	25.798	<0.001	-166.098	-15.068	<0.001
average of EPW	-1.456	-17.833	<0.001	10.217	25.172	<0.001	-353.778	-14.835	<0.001
average of FPP	-0.875	-16.288	<0.001	7.446	27.898	<0.001	-248.420	-15.844	<0.001
average of EPP	-2.162	-18.571	<0.001	15.031	25.971	<0.001	-517.661	-15.224	<0.001

dicating low cardiovascular fitness and high cardiovascular risk, trunk strength also increased. Previous studies have also described this paradox. Most of these studies have described a positive correlation among body weight, BMI, and absolute trunk strength (3, 5, 16, 28, 31, 37).

The results of this study suggest, that waist circumference is a relevant influencing factor in the seated measuring position, too (28). Higher waist circumference values correlated with a higher extent of trunk strength, and the correlation coefficients were slightly higher for the trunk flexion parameters. In this athletic population, a higher waist circumference probably indicated greater muscle mass in the flexors and extensors. Whether the relationship with the trunk extensors is more important than that with the flexors in an obese population is unknown. However, it is plausible, as with increasing waist circumference, indicating abdominal obesity, that the center of mass is shifting to the anterior inferior and hence more leverage of mainly the trunk extensors is needed to maintain an upright body position (31).

The relation between anthropometric measurements and the flexion-to extension ratios was either very weak or missing and was probably not relevant.

While absolute parameters represent the best out of 10 repetitions and show maximal trunk strength, average parameters, especially the total work, express trunk strength endurance. Anthropometric parameters are also related to isokinetic trunk strength parameters.

As trunk flexion parameters are also related to anthropometric variables, not only the known linear increase in the muscle mass and thickness of the erector spinae but also an increase in ventral trunk muscle mass and total muscle mass results in higher isokinetic strength and endurance (7, 18, 35). Finally, this assumption is plausible as the trunk muscles need more leverage to maintain trunk position with increasing weight and height, which results in higher isokinetic trunk strength (31, 37).

The analyzed population consisted predominantly of young soldiers. Female and older participants were also underrepresented. However, the absolute number of female participants was comparable to that in previous studies (3, 9, 16, 18, 26). Despite the low percentage of female participants, there was a significant relationship between sex and trunk strength in the regression models.

Only Timm et al. reported a comparable number of participants of both sexes (39). In that study, trunk strength testing was performed in the standing position without gravity compensation (exclusively for trunk extension). They demonstrated the relationship between trunk extension, sex, and age.

Other studies reported comparable relationships between anthropometric factors and trunk strength. In most of these studies, trunk strength measurements differed and icluded maximum bearable weight lifting (37), isometric measurements of trunk strength (28), and isokinetic trunk strength in a standing position (2, 3, 11, 16, 20, 35, 39).

In the holistic approach of this study, the relationships of several anthropometric variables with all relevant parameters of isokinetic trunk strength, expressed in the physical quantities of torque, work, and power, which were measured in the sitting position, could be analyzed. Previously, only three studies were performed using comparable measurement techniques in a sitting position, but with smaller study populations (9, 21, 26).

Isokinetic trunk strength measurements in standing and sitting positions can lead to different results (7, 13, 38, 43). It is worth mentioning, that we showed the quantitative effects of anthropometric changes on all isokinetic parameters of trunk strength. For example, with a one-year age increase, the peak torque decreased by 1,024 Nm in trunk flexion and 3,341 Nm in trunk extension (Table 6). An increase of one BMI point resulted in an increase of 9,972 Nm in trunk flexion and 21,991 Nm in trunk extension. An increase of 0,01 in WHtR resulted in a 3,125 Nm increase in trunk flexion and 6,843 Nm in trunk extension. With these benchmarks, professionals can better understand and interpret the trunk strength changes in athletes due to anthropometric alterations.

Although Pajoutan et al. showed a difference in relative isometric trunk strength in a small population of participants with obesity, further research is necessary for obese and non-obese populations regarding the association of pathological values of BMI and WHtR with isokinetic trunk strength (4, 28).

There are many limitations to the statistical analysis. Only age, BMI, and WHtR were included in mixed linear models. No alternative mixed linear or generalized linear model that met the quality criteria and included more anthropometric variables were created. Although a low numerical variation in WHtR (0.49±0.06) and a larger numerical variation in BMI (26.1±3.1) and age (37.9±10.2 years) were associated with similar changes in trunk strength, the RCs were not comparable. For this reason, the level of significance (p-value) and T-statistics were used to better distinguish the strength of the relationship. The study population mainly consisted of male athletic soldiers. Consequently, no conclusions could be drawn regarding different populations. Other results are feasible in obese populations. Furthermore, using correlation and regression analyses, it was not possible to conclude the cause and effect. Mixed linear regression was used to reduce intra-individual effects with up to 13 repeated measurements, however, intra-individual effects were still feasible.

This is necessary because with the trunk, in contrast to the measurement of the strength at the extremities, there is no opposite side for the intra-individual comparison. At first glance, the younger (37,9±10,2 years, age range 18-81) and more athletic population may be a limitation, but on the other hand it is an advantage, as it creates a dataset for this specific population of male and active subjects that can help to guide training advice for almost all age groups of patients in sports and rehabilitation medicine.

To the authors knowledge, this was the first study to establish a ranking of the relationship between anthropometric parameters and isokinetic trunk strength after considering the entire spectrum of isokinetic parameters.

Conclusion

Trunk strength is a key element in the success of interventions, particularly in rehabilitation and sports medicine. In patients with pain or injuries to the extremities, trunk strength should not be measured in the standing position or during field tests. The results of this study suggest that there seems to be no difference in the relationship of isokinetic trunk strength with anthropometric parameters when compared with the standing position in an athletic population. For current anthropometric parameters such as waist circumference, BMI, and WHtR, a relationship with trunk strength was observed. Concerning the absolute and average parameters of torque, work, power, and total work, a ranking of importance was created to describe the amount of influence for three of them: BMI>Age>WHtR.

Overlapping with obesity research, there is a positive relationship between trunk extension and flexion strength and body weight, height, waist circumference, BMI, and WHtR in an athletic population.

During observation of athletes and patients in rehabilitation medicine, several anthropometric and trunk strength measurements are performed. Professionals should be aware of the interactions between anthropometric factors and trunk strength and should improve their advices for patients during training and rehabilitation.

Conflict of Interest

The authors have no conflict of interest.

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