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ORIGINAL ARTICLE

Low physical performance determined by chair rising test muscle mechanography is associated with prevalent fragility fractures

Tobias Rupp[1] · Sebastian Butscheidt[1] · Katharina Jähn[1] · Maciej JK Simon[1,2] · Haider Mussawy[1,2] · Ralf Oheim[1] · Florian Barvencik[1] · Michael Amling[1] · Tim Rolvien[1,2]

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Abstract

Summary This study examined associations between physical performance assessed by chair rising test muscle mechanography and DXA T-score as well as body composition in a large patient cohort. Next to various significant interrelationships between these muscle and bone parameters, lower physical performance was associated with prevalent fragility fractures.

Purpose Although the interaction between muscle and bone has been demonstrated in various aspects, the clinical focus in the diagnosis of musculoskeletal disorders mainly lies on the skeletal assessments. Accordingly, the association between muscle function, bone mineral density (BMD), and fragility fractures remains to be further elucidated with a feasible muscle assessment in a clinical setting.

Methods Patient data (2076 patients, 1538 women, 538 men) were evaluated retrospectively from a large dual energy X-ray absorptiometry (DXA) database as well as from chair rising test (CRT) that was performed on a muscle mechanograph. To determine potential predictors of the CRT time and maximum force, a multivariate regression analysis was performed including age, DXA T-score, and body composition indices. Furthermore, CRT results were compared between non-fracture and fracture cases.

Results We determined independent predictors for CRT time such as age, femoral DXA T-score, and total fat mass, whereas CRT force was only influenced by total lean mass. Both women and men with previous fragility fractures displayed a longer CRT time (women $p = 0.009$, men $p = 0.001$) and lower CRT force (women $p < 0.001$, men $p < 0.001$) than those with no fractures, while no clear differences in CRT results could be detected between normal BMD, osteopenia, and osteoporosis based on DXA T-scores.

Conclusions Our study demonstrates that in addition to the associations between chair rising time and femoral T-score assessed by DXA, low muscle strength is associated with previous fragility fractures.

Keywords DXA · Muscle force · Osteoporosis · Bone-muscle crosstalk

Introduction

Bone and skeletal muscle are the two largest tissues in the body and demonstrate a strong functional connection, both mechanically and biochemically. On a molecular level, the muscle-bone crosstalk is regarded to be of major relevance [1, 2]. Namely, bone cells secrete circulating factors that can affect muscle function, i.e., osteocalcin, which is secreted predominantly by late osteoblasts and affects the energy metabolism and most likely also muscle activity [3]. Muscle contractile function can be stimulated by osteocyte-secreted factors through the activation of the Wnt/beta-Catenin pathway in muscle cells [4]. Reversely, muscle-secreted factors, so-called myokines, can have effects on bone tissue [2]. Given the regional effect of muscular strength on bone mineral density (BMD) in patients [5, 6], muscle tests have been suggested as appropriate method to select patients that could benefit from a bone densitometry and subsequent treatment decision [7]. In fact, quadriceps strength was found to be strongly associated with femoral neck BMD [8]. Furthermore, low grip

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✉ Tim Rolvien
t.rolvien@uke.uni-hamburg.de

[1] Department of Osteology and Biomechanics, University Medical Center Hamburg-Eppendorf, Lottestr. 59, 22529 Hamburg, Germany

[2] Department of Orthopedics, University Medical Center Hamburg-Eppendorf, Hamburg, Germany

strength was associated with bone mineral density and vertebral fracture risk in women [9].

While BMD measurements are usually performed by dual energy X-ray absorptiometry (DXA) at the hip and spine, muscle mechanography represents a method that can quantitatively assess muscle function using a ground force reaction plate (GRFP) [10]. Mechanography has many advantages including the high reproducibility and sensitivity as opposed to other non- or semi-quantitative tests [11]. Although it is known that peak forces in the vertical jump and one-legged hopping test (other common mechanography tests) are double those observed in the chair rising test [12], these tests are not practicable in a clinical setting in, i.e., elderly and osteoporotic patients. Furthermore, a high correlation between jumping mechanography and chair rising test results was previously noted ($r = 0.86$, [13]). The chair rising test combined with muscle mechanography represents a muscle performance test that is feasible in a clinical setting and that can be applied in nearly all patients.

We have evaluated DXA measurements from the spine and both hips and body composition indices as well as chair rising test (CRT) results (i.e., time and maximum force) derived from a GRFP and the presence of previous fragility fractures in a large patient collective to test for the various and site-specific interrelationships between BMD and muscle strength. Accordingly, the aim of the present study was to determine the associations between the chair rising test and bone mass parameters as well as fracture data. As it is furthermore not clear if patients with discrepancies in BMD between both legs (right vs. left) have equal differences in muscle strength, we have tested for the associations between DXA and CRT ratios from both legs. In this article, we point out that fragility fractures are associated with longer CRT time and lower maximum force in both women and men. Longer CRT time was furthermore predicted by lower femoral T-score, while spinal T-score was not associated with the CRT results when adjusted for body mass index.

Methods

Dual energy X-ray absorptiometry

Data from 2076 patients (1538 women, 538 men) measured with dual energy X-ray absorptiometry (DXA, Lunar iDXA, GE Healthcare; Madison, WI, USA) were evaluated retrospectively from 2013 to 2017. Namely, the areal bone mineral density (aBMD, absolute values) as well as DXA T-scores and Z-scores were determined and evaluated from both hips and the lumbar spine. From the 2076 patients, 1182 (873 women, 309 men) were additionally measured by whole body DXA including measures of total lean mass and total fat mass. This subgroup with available whole body DXA was equal in sex distribution (complete study group: 74.1% women; subgroup = 73.9% women) as well as in age (complete study group: women = 64.7, men = 61.8; subgroup: women = 64.3, men = 62.5 years) and BMI (complete study group: women = 23.9, men = 26.0; subgroup: women = 23.7, men = 25.9 kg/m^2). DXA quality assurance was achieved following the institutional standard operating procedures (SOPs) and by daily calibration scans with a special phantom according to the manufacturer's recommendations. Furthermore, precision tests including least significant change calculations were performed regularly according to the recommendations of the International Society for Clinical Densitometry (ISCD).

Chair rising test on a ground force reaction plate

Physical performance was tested using a Leonardo Mechanograph® Ground Force Reaction Plate (Leonardo GFRP, Novotec Medical GmbH, Pforzheim, Germany) in all patients. For this purpose, a specific bench was installed on the force plate at height of 45 cm. After sitting on the bench with both feet on the ground, patients were instructed to stand up straight and sit down again as fast as possible for five cycles [10]. Both CRT time per cycle and maximum force in kN in both legs were documented for chair rising tests performed on the mechanograph. Reference values for this test have been previously published [14].

Fragility fracture history

The medical records of the patients were evaluated regarding the presence of any previous fragility fracture as well as previous vertebral fracture, non-vertebral fracture, or no fracture. A total of 35.7% of men and 36.6% of women had a previous fragility fracture. Vertebral fractures were diagnosed by conventional radiography, or if not available, confirmed with vertebral fracture assessment (VFA) by DXA. The included non-vertebral fractures were classical fragility fractures including the distal forearm and proximal humerus as well as the femoral neck, while traumatic causes for fractures served as exclusion criteria.

Study design and statistical analysis

We have included the patients with a DXA T-score between −6 and +2.5, thereby excluding strong outliers with very low or high bone mass with possible monogenetic causes. As the diagnostic tests were conducted in a large outpatient clinic for skeletal disorders, patients with osteoporosis and other typical skeletal diseases underwent these tests and were subsequently included in the database. Regarding the chair rising time, values 1.5 times the interquartile range above the 75th seconds quartile (> 4.4761 s per cycle) were interpreted as statistical

outliners (potential measurement errors, e.g., patients did not follow the instructions to get up from the bench as quickly as possible). As a result, values above 4.4761 s may represent potential measurement errors, which is why they were excluded from the analysis. Body mass index (height and weight) was assessed from all patients prior to the DXA and CRT measurement. The included patients ranged from underweight to obesity with a BMI of 14 to 50 kg/m^2 (mean 24.9 ± 4.9 kg/m^2). This study was approved by the local ethics committee (*PV3874*).

An overview of the study design can be found in Fig. 1a while the basic characteristics of the study population are demonstrated in Table 1. SPSS 25 software (version 25.0, IBM, Armonk, NY, USA) was used for statistical analyses. The quantitative characteristics are presented as mean ± SD. Normal distribution of the data was tested with the Kolmogorov–Smirnov test. To test the differences between the study groups, we used the unpaired two-sided *t* test on the normally distributed data.

Subsequently, male and female subjects were evaluated separately. To test for correlations between the variables such as femoral T-score or lean mass and CRT time or force, Pearson's correlation analysis was performed, while *r* represents the linear correlation coefficient. In order to determine potential predictors of CRT time and force, we performed a multivariate regression model including age, BMI, and DXA T-score at the lumbar spine and the hip, as well as lean mass and fat mass including all predictors at a single step. The association between CRT time and DXA T-score in the spine and hip was adjusted for BMI in a separate partial correlation model.

CRT time and force were compared between three groups: "normal" (T-score between − 1 and + 1), "osteopenia" (T-score between − 2.5 and − 1), and "osteoporosis" (T-score lower than − 2.5) based on DXA T-scores. Lastly, we compared the CRT time and force of women and men with no fractures, any fragility fracture as well as vertebral and non-vertebral fractures alone. The CRT-fracture associations were furthermore tested for interactions with sex, age, and BMD by analysis of covariance (ANCOVA). p values of < 0.05 were considered statistically significant.

Results

Overview of DXA and CRT results

The results from the DXA scans were normally distributed with a mean T-score within the osteopenia range for the spine and the hip in both women and men mirroring the selective patient collective in a setting of a specialized outpatient clinic for osteoporosis and other metabolic bone diseases. However, the overall mean DXA Z-scores were essentially only very moderately decreased (Fig. 1a, Table 1). The differences in age, weight, BMI, DXA, and mechanography results between women and men are demonstrated in Table 1. Specifically, women demonstrated with a lower BMI, a lower spinal T-score, a proportional higher fat mass to lean mass ratio (59.1 vs. 42.3%), and a lower CRT strength compared to men. While we could not detect differences in CRT time, the CRT maximum force/weight (N/kg) was slightly higher in women.

Initial correlation analyses

In the first part of the analysis, we tested for correlations between bone mineral density (DXA T-score) and muscle performance. There was no significant correlation for the lowest femoral T-score and the CRT time in women (Fig. 1b). However in men, the femoral T-score correlated significantly with the CRT time indicating a shorter CRT time with better DXA T-score (Fig. 1c). In women, there was a significant correlation between total lean mass and CRT maximum force (Fig. 1d), while in men, we found an even higher significant correlation between total lean mass and CRT force (Fig. 1e).

Predictors for muscle performance using a multivariate regression analysis

We used a multivariate regression model to search for independent predictors for CRT time and force in both women and men. Age, BMI, DXA T-score, lean mass, and fat mass were included as variables (Table 2). Age was identified as an independent predictor for CRT time and force, while BMI did not serve as a predictor for these muscle measures.

In this model, no associations between DXA values and CRT maximum force were found. However, lower femoral T-score was associated with longer CRT time in women and men. Although, in this model, low spinal T-score predicted shorter CRT time, there was no effect between spinal T-score and CRT time when adjusting for BMI in a partial correlation ($r = 0.057$; $p = 0.083$). The negative correlation between CRT time and femoral T-score remained significant after adjustment for BMI ($r = -0.1$; $p = 0.002$). Total lean mass was significantly associated with muscle force, while total fat mass was associated with CRT time in both sexes (Table 2).

Fragility fractures and muscle performance

When comparing three groups based on DXA T-scores "normal" (T-score between − 1 and + 1), "osteopenia" (T-score between − 2.5 and − 1), and "osteoporosis" (T-score lower than − 2.5), no significant differences in CRT

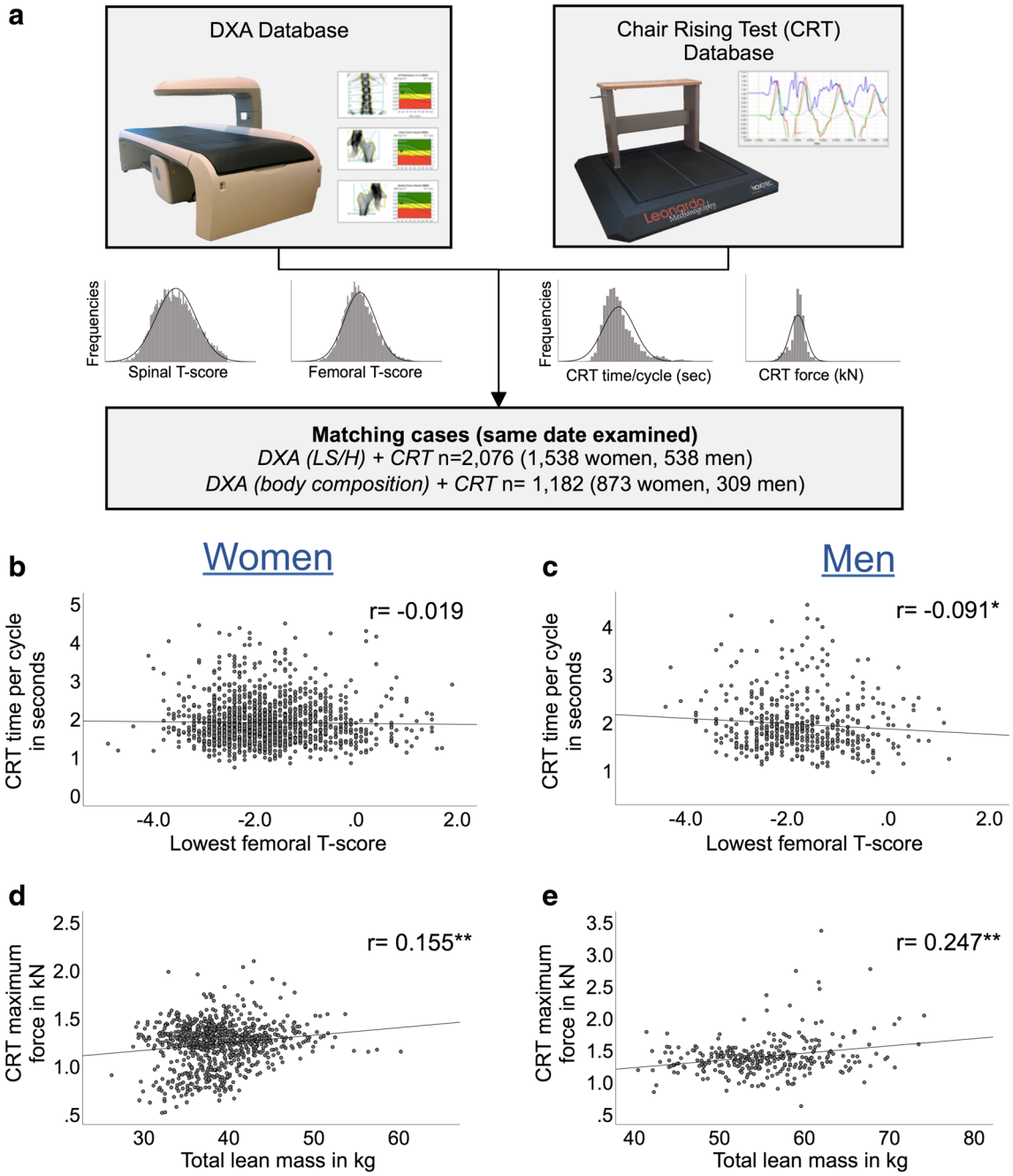

Fig. 1 Analysis of potential associations between DXA and CRT results. **a** Data from 2076 patients (1538 women, 538 men) were evaluated. All values were normally distributed. **b** For femoral T-score and CRT time, no significant correlations were detected in women. **c** A significant negative correlation for femoral T-score and CRT time was found in men indicating a shorter CRT time with higher DXA T-score. **d** and **e** Analysis of whole body DXA and CRT yielded no correlations for total lean mass and CRT force in women, but a significant correlation in men. $*p < 0.05$, $**p < 0.001$

time or force were seen in women (Fig. 2a, b). In men, we detected a significantly longer CRT time in osteoporosis cases compared to those subjects with a normal T-score, while a lower CRT force was found in the osteopenia compared to the normal group (Fig. 2c, d).

We then compared the CRT time and force in patients with no fractures compared to patients with any fragility fracture as well as to those with vertebral and non-vertebral fractures. The characteristics of these study groups are shown in Supplemental Table 1. The fragility fracture group was significantly older; however, age did not additionally influence the association between fracture and CRT results (CRT time women $p = 0.99$, men $p = 0.43$; CRT force women $p = 0.75$, men $p = 0.12$).

Table 1 Basic characteristics of the study population

	Women Mean (±SD)	Men Mean (±SD)	*p*
Demographic characteristics			
Age (years)	64.69 (± 11.48)	61.84 (± 14.73)	< 0.001
Weight (kg)	64.67 (± 12.35)	81.88 (± 13.97)	< 0.001
BMI (kg/m^2)	23.91 (± 4.28)	25.97 (± 4.01)	< 0.001
DXA			
Total lean mass (kg)	38.78 (± 4.51)	55.25 (± 6.44)	< 0.001
Total fat mass (kg)	22.93 (± 8.91)	23.38 (± 8.90)	0.457
Spinal T-score (L1-L4)	− 1.5 (± 1.5)	− 0.8 (± 1.5)	< 0.001
Spinal Z-score (L1-L4)	− 0.9 (± 1.4)	− 0.5 (± 1.5)	< 0.001
Femoral T-score	− 1.8 (± 1.0)	− 1.7 (± 1.0)	0.363
Femoral Z-score	− 0.5 (± 1.0)	− 0.8 (± 1.0)	< 0.001
Mechanography			
CRT time per cycle (s)	1.89 (± 0.57)	1.94 (± 0.58)	0.139
CRT maximum force (kN)	1.24 (± 0.21)	1.37 (± 0.26)	< 0.001
CRT maximum force/weight (N/kg)	19.75 (± 4.75)	17.12 (± 3.92)	< 0.001
CRT maximum force/lean mass (N/kg)	32.05 (± 6.68)	25.44 (± 5.29)	< 0.001

Furthermore, ANCOVA analysis of CRT time and the presence of fractures revealed no sex-specific influence ($p = 0.22$). In contrast, the association of CRT force and fracture was highly sex-specific ($p = 0.005$). As a result, both sexes were evaluated separately. Both sexes demonstrated a significantly longer CRT time as well as a lower CRT force when having any fragility fracture or vertebral fractures (Fig. 3). Additionally, women but not men with non-vertebral fracture displayed significantly longer CRT time and lower force compared to the no fracture group. When additionally adjusting for BMD in ANCOVA analysis, the association between fractures and CRT values were not additionally influenced by BMD measurements ($p = 0.18$ for CRT force $p = 0.888$ for CRT time).

Site-specificity right vs. left limb

To test whether patients with local differences in BMD between the right and left hip have equal discrepancies in CRT force between the right and left leg, the ratios of DXA BMD and CRT force right to left leg were correlated. Both the DXA BMD ratio and the CRT force ratio were normally distributed with a mean of 0.994–1.03 indicating that an equal amount of patients had a higher right or left BMD and CRT result. When comparing the ratios of DXA BMD and CRT force, there was a weak significant correlation indicating a possible local effect of muscle and bone interaction (Fig. 4a, b). When comparing only the trochanter BMD with CRT force, there was a higher correlation between these ratios (Fig. 4c, d). In general, men

Table 2 Predictors for CRT time and force using a multivariate regression analysis. Italic indicates significant predictors ($p < 0.05$)

	Women						Men					
	CRT time (s)			CRT force (kN)			CRT time (s)			CRT force (kN)		
	ß	*T*	*p*	*ß*	*T*	*p*	*ß*	*T*	*p*	*ß*	*T*	*p*
Age (years)	0.257	6.499	*< 0.001*	− 0.034	− 0.806	0.421	0.211	3.029	*0.003*	− 0.122	− 1.677	0.095
BMI (kg/m^2)	− 0.142	− 1.366	0.173	− 0.057	− 0.519	0.604	− 0.242	− 1.688	0.093	0.203	1.358	0.176
Spinal T-score	0.134	2.911	*0.040*	− 0.028	− 0.582	0.561	0.138	1.569	0.118	− 0.057	− 0.621	0.536
Femoral T-score	− 0.139	− 2.794	*0.005*	0.012	0.223	0.823	− 0.206	− 2.379	*0.018*	0.056	0.624	0.533
Total lean mass (kg)	0.019	0.450	0.653	0.145	3.166	*0.002*	0.030	0.387	0.699	0.180	2.254	*0.025*
Total fat mass (kg)	0.343	3.476	*0.001*	0.076	0.724	0.469	0.428	3.217	*0.002*	− 0.124	− 0.891	0.74
R^2 adjusted		0.120			0.017			0.141			0.067	

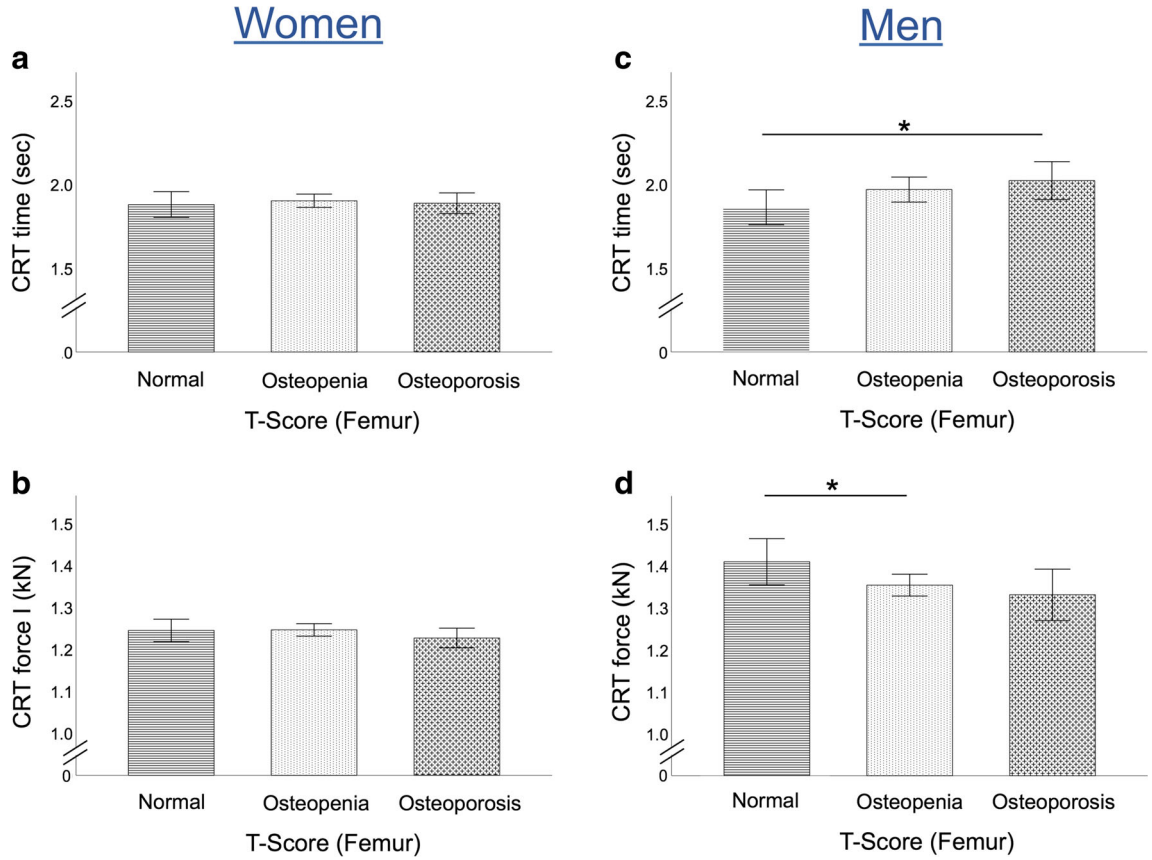

Fig. 2 Differences in CRT results between normal BMD, osteopenia, and osteoporosis. **a**, **b** No differences in CRT time or forces between the three groups in women. **c** Significantly longer CRT time in men with osteoporosis compared to those with BMD within the reference range (normal). **d** A lower CRT force was detected in men with osteopenia compared to normal BMD. *$p < 0.05$

presented with higher correlation coefficients than women regarding the site-specificity.

Discussion

In this study, we have demonstrated the significant predictive value of femoral BMD expressed by T-score on muscle performance expressed by chair rising time. The analysis of prevalent fragility fractures additionally revealed a significantly reduced muscle performance in patients with previous fragility fracture compared to those with no fractures. While no associations between maximum force and DXA values could be detected, higher spinal T-score surprisingly predicted a longer CRT time. However, given the confounding positive influence of BMI on BMD [15], a separate partial correlation analysis revealed no association between spinal T-score and CRT time when adjusted for BMI.

While other studies have found positive correlations between muscle force and BMD [5, 8], another study on 862 women could also not confirm a significant association after adjusting for lean mass [16]. The results derived from CRT are not only important regarding their association with BMD but may also help clinicians to predict fall risk with subsequent risk of fracture [17]. It is well known that DXA has a number of limitations, which is why many patients suffer from fragility fractures although having T-scores within the normal or osteopenic range [18, 19]. A major effect of muscle strength on fall and fracture risk independent from BMD is known [17, 20] and was supported by our findings, which revealed that fragility fractures correlated with CRT values with no additional interaction with BMD. In fact, objective measures of lower-extremity function were previously found to be highly predictive of subsequent disability [21]. Additionally, it was shown previously that both men and women with poor physical performance (i.e., inability to rise from a chair) have a higher risk for hip fractures [22, 23]. The prevalence of vertebral fracture increased significantly as jump power decreased [24]. In general, it is of major relevance to identify the patients with increased fall risk and subsequent risk of fracture by physical performance tests, i.e., chair rising test.

DXA remains the gold standard for the detection of muscle mass and body composition [25]. A positive association was detected between total lean mass and CRT maximum force indicating better physical performance with higher lean mass.

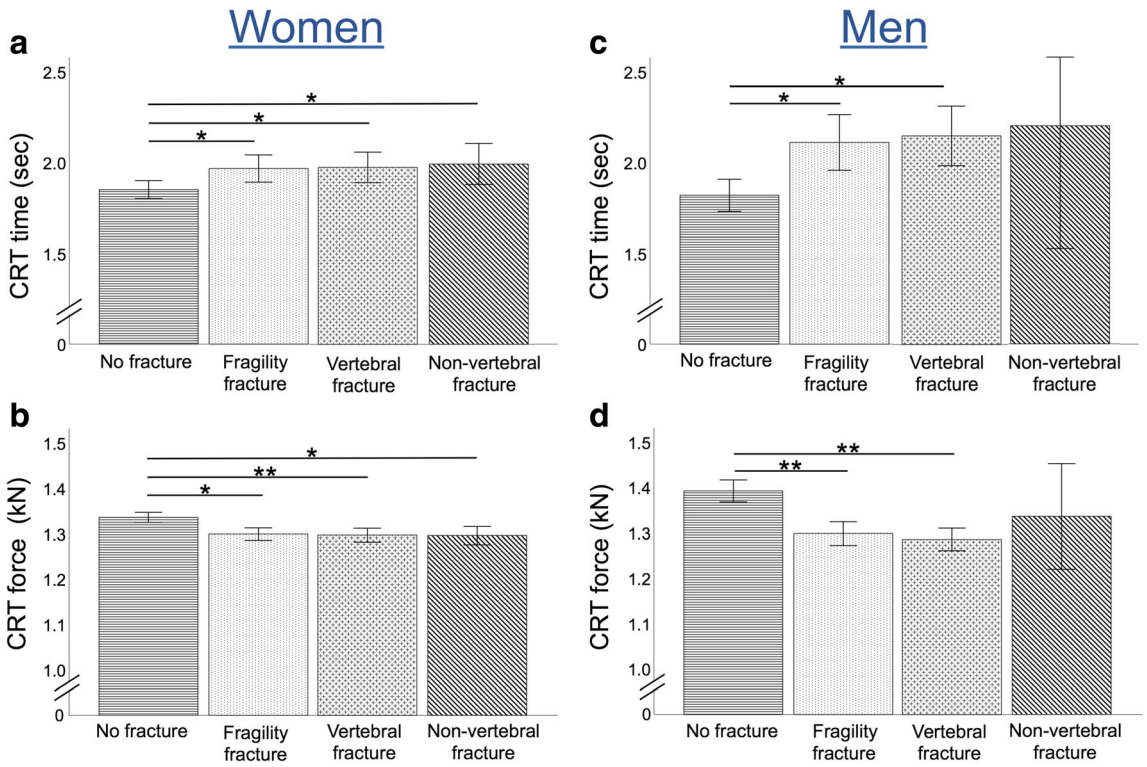

Fig. 3 Muscle performance and previous fragility fractures including subgroups vertebral vs. non-vertebral fracture. **a** CRT time in women. **b** CRT maximum force in women **c**. CRT time in men. **d** CRT maximum force in men. *$p < 0.05$, **$p < 0.001$

An increased maximum force assessed by mechanography has been previously detected in obese male adolescents [26]. A significant correlation between lean mass and functional tests like grip strength and two-leg jump test was previously found in

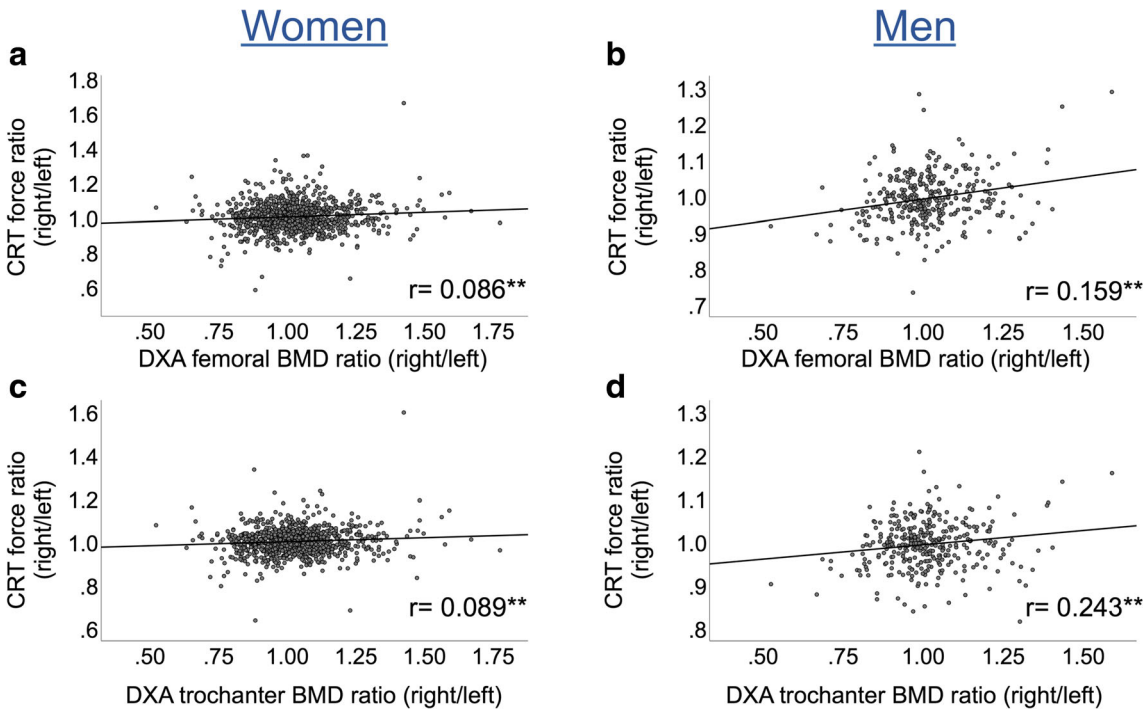

Fig. 4 Local associations between DXA and CRT results of the right vs. left limb. **a**, **b** A correlation analysis between the ratios of the DXA results from both hips and CRT force from both legs revealed significant correlations for both sexes with a higher *r* for men. **c**, **d** When comparing only the trochanter BMD with CRT force, there was a higher correlation between these ratios right/left. *$p < 0.05$, **$p < 0.001$

community-dwelling adults (men and women) [27]. We could also detect an increasing CRT time with increasing fat mass indicating possible limitations to get up from the bench.

Lastly, we tested whether patients with local discrepancies in BMD between the right and left hip have equal discrepancies in CRT force between the right and left leg. Men exhibited a higher correlation between the DXA BMD ratio and the CRT force ratio of the right to the left limb. These results point to possible differences in local muscle and bone interactions between the sexes. The fact that trochanter BMD and CRT force yielded higher *r* values than total femoral BMD could speak for a possible local muscle-bone interaction as well as muscle insertion at the greater trochanter (i.e., gluteus medius muscle) leading to osteoanabolic stimuli.

The limitations of this study include the retrospective study design and the inability to assess further clinical data from the patients. Therefore, a number of secondary diagnoses with possible effects on BMD and muscle strength could not be excluded. Both sexes were evaluated separately and the correlations between BMI, lean mass, BMD, and CRT parameters were tested. All of the analyses were based on a selective patient collective derived from a specialized outpatient clinic for musculoskeletal diseases.

In conclusion, our work offers insights into the significant negative association between femoral DXA T-scores and CRT time. While this suggests better physical performance with higher bone mass at the femur, no clear association was found between spinal DXA values and CRT time as well as DXA values at any skeletal site and the maximum force on the muscle mechanograph. Importantly, women and men with previous fragility fractures displayed lower CRT values compared to non-fracture patients. To our knowledge, this is the largest study that includes measures of BMD, physical performance determined by CRT muscle mechanography, and their association with fracture data. Next to DXA measurements that have been found to correlate only poorly with fracture risk, physical performance tests such as CRT potentially represent an additional measure for frailty, sarcopenia, and subsequent fracture risk.

Authors' roles Study design: MA and T Rolvien. Study conduct: T Rupp, SB, MJKS, HM, RO, FB, MA, and T Rolvien. Data analysis: T Rupp, SB, KJ, MJKS, HM, RO, FB, MA, and T Rolvien. Drafting manuscript: T Rupp and T Rolvien. Revising manuscript: T Rupp, SB, KJ, MJKS, HM, RO, FB, MA, and T Rolvien. T Rupp and T Rolvien take responsibility for the integrity of the data analysis.

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Compliance with ethical standards

This study was approved by the local ethics committee (PV3874).

Conflicts of interest None.

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