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Hand grip endurance moderating the effect of grip force on functional ability and disease activity in rheumatoid arthritis patients: a cross-sectional study

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Abstract
To examine the effect of endurance on the relationship between grip force and measures of functional capacity and disease activity, we performed a cross-sectional study at the University Department of Rheumatology, Physical medicine and Rehabilitation from January 2017 to August 2018. Functional capacity of the hand was measured by ABILHAND-RA questionnaire and disease activity was assessed by the Disease Activity Score (DAS-28-CRP). All participants underwent dynamometric measurements of maximal grip force and hand grip endurance during repeated gripping. We analyzed the data from 34 RA patients at the median (IQR) age of 57 (51–61), 31 (91%) of them women, and 44 healthy participants at the age of 55 (50–59), 39 (89%) of them women. The moderating effect of endurance on the correlation between maximum grip force and the ABILHAND-RA score was not significant in healthy participants ($b = 0.000$, 95% CI − 0.005–0.004, $p = 0.862$), but it was in RA patients ($b = 0.003$, 95% CI 0.000–0.005, $p = 0.027$). In RA patients, the effect of maximum grip force on the ABILHAND-RA score increased with the increase in hand grip endurance. In RA patients, the interaction between endurance and grip force significantly explained the 15% more variance of the disease activity than main effects of these two measures, age, gender and body mass index alone. Hand grip endurance during repeated gripping affects the correlation between maximum grip force and the ABILHAND-RA score in a pattern that differs in RA patients and in the healthy population. In RA patients, hand grip endurance significantly moderates the correlation between maximum grip force and the DAS-28-CRP.

Keywords Rheumatoid arthritis · Functional performance · Hand strength · Endurance

Introduction

Rheumatoid arthritis (RA) is a chronic inflammatory rheumatic disease, with polyarthritis of the hand as its hallmark. Beside the joint disease, cachexia is also common in RA. Inflammatory factors and the lack of physical activity are the main causes of deterioration of cells, which is in

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RA mainly related to those in skeletal muscle (rheumatoid sarcopenia) [1]. As a result, muscular strength and consequently grip strength are reduced in patients with RA [2]; hence, the grip strength measuring is a common method of clinical evaluation of these patients [3]. Standard hand dynamometry registration of one-grip force or recording a series of multiple grips are commonly used to evaluate hand function [4, 5]. In this way, one can get a rough measure of handgrip strength, but a more detailed insight is lacking [2]. Among the hand-held dynamometers, the Jamar® dynamometer is commonly used as the gold standard for measuring grip strength. Although it demonstrates a proven validity and reliability [6] and excellent reproducibility [7], it also has some shortcomings such as variation in the average and maximum force strength during the multiple successive attempts [2]. The accuracy of the hand grip force measurement of the muscle strength can be affected by the hand size and differences in the measurement protocol such as the time of measurement, hand and fist position, number of repetitions, motivation and previous training, and encouragement of participants [8]. All these differences jeopardize the replicability and may result in inconsistencies in results from different studies [2, 9]. A more analytical approach to grip force would be useful to tailor rehabilitation of the hand in patients with RA, as well as patients with other non-rheumatic hand-involved conditions.

Hand grip endurance is the ability to sustain grip until fatigue (static protocol) or perform multiple grips over a time period (dynamic protocol). Gerodimos et al. compared reliability of both protocols and concluded that a static protocol and a 12-repetition dynamic protocol are both reliable for assessment of hand grip endurance. Dynamic protocols with a lower number of repetitions (eight and ten) demonstrated lower reliability [10]. The grip strength beyond single measurement of the maximal grip force was examined before in various clinical studies. The dynamic measurement of grip force was performed by Karatrantou et al. on the population showing chronic obstructive pulmonary disease. They used pinch and grip analyzer for three repetitions of squeezing and a software for visualization of amplitude distribution during the test. Patients were instructed to maintain targeted force within a defined range as long as possible using audio–visual control. Endurance was explained as time in which the load was within the targeted range [11]. A group of authors from Greece used a hydraulic dynamometer (Jamar®) and investigated the test–retest reliability of hand grip endurance in older women, based on 12 repetitions. In this study, endurance referred to the percentage of the change in maximal grip force during repetitions [12]. Myers and Triscari used the Baltimore Therapeutic Equipment (BTE) endurance protocol, widely used in rehabilitation of occupational upper arm dysfunction, in comparison with the Jamar® dynamometer [13].

The aim of this study was to propose endurance in repeated gripping as a valuable independent outcome measure which contributes to assessment of the functional state in RA patients. The objective was to determine the relationship between hand grip endurance during repeated gripping and maximal grip force, first through functional ability measured by the ABILHAND-RA questionnaire, and second through disease activity measured by DAS-28.

Methods

Study design

We performed a cross-sectional study at the Department of Rheumatology, Physical Medicine and Rehabilitation of the Sestre milosrdnice University Hospital Centre, Zagreb, Croatia, from January 2017 to August 2018. The study protocol was approved by the Ethics Committee of the Sestre milosrdnice University Hospital Centre (protocol number EP–13030/11–8). We obtained the Informed consent from all participants. Their anonymity was preserved by keeping the Informed consents separately from the questionnaires and assigning the numeric codes to all participants' data. The study was conducted in accordance with the World Medical Association Declaration of Helsinki 2013 [14].

Participants

The target population was patients of both genders, aged 30–65 years, diagnosed with RA by a rheumatologist (according to ACR/EULAR 2010 criteria) [15], and showing disease involvement of the hand. The patients were undergoing a stable therapy with disease-modifying antirheumatic drugs during the last 3 months. They were allowed to take non-steroidal antirheumatics as necessary, except for 2 days prior to the enrollment, as well as systemically administered glucocorticoids at doses up to 10 mg/day of prednisolone or equivalent, and the dose should have been stable over the last 3 months. Patients with other conditions that can affect the hand were excluded: compression neuropathies of the arm, cervicobrachial syndrome, thoracic outlet syndrome, previous surgery or trauma, vasculopathies of the arm. Also, we did not include subjects with metabolic diseases that can affect muscle strength (hypothyroidism, hyperthyroidism, insulin-dependent type of diabetes or insulin-independent type of diabetes if the disease lasts longer than 10 years and if patients have symptoms of polyneuropathy, adrenal dysfunction), as well as patients taking medications proven to cause myopathy. We selected the consecutive sample of participants in the order of their arrival. The control population was ambulatory patients of the Physical and Rehabilitation Medicine Outpatient Department of the Sestre milosrdnice University Hospital Centre aged 30–65 years, neither diagnosed with RA nor diagnosed and treated for the conditions that may result in decreased hand strength or function. Other inclusion and non-inclusion criteria were the same for the control group as for the RA patients. We selected the consecutive sample of patients from the control population in the order of their arrival for the exam.

Needed sample size

We performed the needed sample size calculation before data collection. We set the targeted power at 0.80, and the two-tailed statistical significance at $p < 0.05$. For the large effect size of $f^2 = 0.35$ and two predictors (hand grip endurance and grip force), we needed the sample of $n = 31$ for the multiple regression analysis. The power analysis was performed using PASS 14 Power Analysis and Sample Size Software (2015) (NCSS, LLC, Kaysville, Utah, USA).

Primary outcome

The primary outcome was physical function capacity of the hand measured by the ABILHAND-RA total score in patients diagnosed with RA and in rheumatologically healthy participants [16, 17]. A higher ABILHAND-RA score indicates better hand functional ability. The original generic ABILHAND was derived from the ICF classification by Rasch analysis [17]. It was designed at the Department of Physical and Rehabilitative Medicine of the Université Catholique de Louvain. It consists of 27 questions that describe the performance of certain actions that require the use of hands, on which the patient responds by a 3º scale: 0 = impossible, 1 = difficult, 3 = easy. Particular activities that a patient did not perform during the previous 3 months are excluded. Validation of the ABILHAND in patients with RA proved a high correlation with the measures of disease activity, structural damage, duration of disease and hand grip strength measured by the Jamar® dynamometer [16]. It has a proven and good sensitivity in detecting minor changes in the condition during treatment and its application is justified in many clinical trials [18]. We calculated the total ABILHAND-RA score as the mean result of all answered questions.

Secondary outcome

The secondary outcome was disease activity in patients diagnosed with RA as assessed by the standard Disease Activity Score (DAS-28) [19]. A higher DAS-28 score indicates a higher disease activity. DAS is a composite score derived from four variables: tender joint count, swollen joint count, both evaluated by the rheumatologist during physical examination, a global pain and overall status assessed by the patient on the visual analog scale, and blood markers of inflammation: erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP). The overall DAS can range from 0 to 10. In this study, we used the 28-joint version (DAS-28) and the CRP as an acute-phase laboratory marker. DAS-28 > 5.1 implies active disease, ≤ 3.2 low disease activity, and < 2.6 indicates remission [20].

Independent variables

Independent variables were hand grip endurance during repeated gripping and strength defined as the maximum grip force. Endurance or the occurrence of fatigue was defined as the ordinal number of the grip at which grip force starts to decrease. Previously, our group presented a new custom-designed electronic dynamic sensor that can measure grip endurance along with various other and standard parameters of handgrip evaluation [21]. This system was developed at the Center for Informatics and Computer Science and the Department of Electronics of the "Ruđer Bošković" Institute. The system consists of a rubber ergonomic measuring probe with four incorporated tensiometric sensors, also provided with sound signals. Data acquisition and data processing are performed via a system that is controlled through a specially developed computer software and connected to a PC via USB port. Grip strength was measured on the dominant hand by a standardized technique used to evaluate hand function [22]. The measurement technique was in accordance with the instructions of the American Association of Hand Therapy. During examination patients were in a sitting position, with the arm in adduction, the elbow flexed to 90 degrees, and the forearm and wrist in neutral position (between supination and pronation) [23]. The dominant hand was tested in a room at a stable and comfort temperature (20–23.5 °C), from 1 to 3 PM to avoid the influence of morning stiffness typical of patients with RA. The measurement protocol was previously explained in detail [21]. It comprises the synchronous consecutive probe squeezing, holding and releasing with a certain frequency, predicted number of cycles and time holding. The cycle duration was 3 s, "maximum" force was defined as a non-disturbing grip force to the examinee during regular (synchronous) squeezing and releasing cycle performance, an optimal squeezing and releasing phase tempo was 0.8 s (between two sound signals), and a total of 50 determined squeezing, handling and releasing cycles were performed. The evaluation of the patient´s hand functional deficit was performed by registering and extracting previously defined parameters in time and spectral domain over the processed time grip series of the dominant hand. To minimize the slope fluctuation and amplitude effects, the Fourier analysis was conducted for each cycle. The most irregular cycles, such as those containing irregular maximums, uneven grip phase, delay at the beginning and at the end of each grip, were removed.

Possible confounding factors

We controlled the possible confounding effects of age, gender and body mass index. We did not control the effects of circumference and length of the forearm or hand because they did not differ between RA patients and the healthy group and, therefore, had no confounding potential. We described the sample of RA patients by the duration of the illness in years, global functional stage [24], the Steinbrocker radiographic stage [25], the Health Assessment Questionnaire Disability Index (HAQ-DI) [26], the Disease Activity Score (DAS-28) [19], morning stiffness, number of painful joints, pain in the hand during the previous week, overall health condition assessed by the patient and by the rheumatologist using the visual analog scale [27], and the therapy. Data on the possible confounding and descriptive factors were obtained by the physical examination of anthropometric forearm and hand parameters, and a detailed history taken by the rheumatologist.

Statistical analysis

We performed the primary analysis in per-protocol population of RA patients with complete data. We analyzed the moderating effect of endurance on the correlation between maximum grip force and the ABILHAND-RA score in healthy participants and in RA patients using the ordinary least square linear regression and the Johnson–Neyman technique as it was implemented in the macro-program "Process" written by Andrew F. Hayes. In the analysis of the primary outcome (ABILHAND), we used the Hayes's Model 3. In the analysis of the secondary outcome (DAS-28), we used the Hayes's Model 1 (Fig. 1). In both analyses, we adjusted all coefficients according to age, gender and body mass index. We checked the assumption of linearity by residual scatter-plots and by checking whether the means of residuals are zero, the assumption of nonmulticollinearity by variance inflation factors and correlations, and the assumption of normality of residuals by inspecting the Q–Q plots. We presented the unstandardized regression coefficients with their 95% confidence intervals, indicating the expected change in the ABILHAND-RA and the DAS-28 at unit differences in the maximum grip strength at different percentiles of hand grip endurance during repeated gripping. We corrected statistical significances for multiple testing using the sequential Holm–Bonferroni method. For statistical data analysis, we used the R Core Team (2018). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org.

Results

Participants

We enrolled 45 patients diagnosed with RA and 45 healthy participants. One healthy participant and 11 (24%) RA patients had missing values on dynamometry parameters and we excluded them from the primary analysis. Compared to the RA patients with complete data, these patients were more often men, with lower body mass index, longer duration of RA, more often in global functional stage II and more often with more severe radiological damage according to the Steinbrocker Radiographic Classification, with somewhat less active disease, longer duration of morning

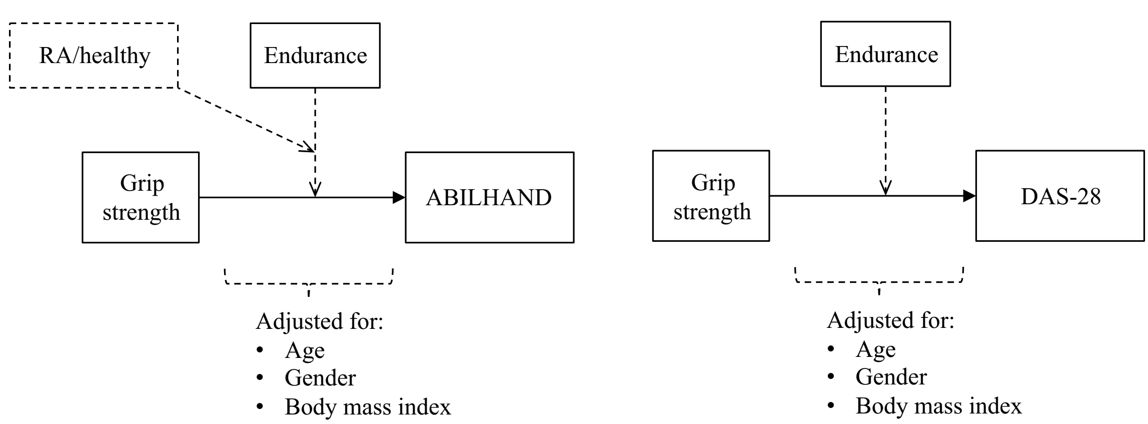

Fig. 1 Analysis conceptual diagrams [Hayes Process Model 3 (ABILHAND), and Model 1 (DAS-28)] representing the conditional effect of the grip strength and endurance interaction in RA and healthy participants to ABILHAND-RA score and in RA patients to Disease Activity Score (DAS-28); solid line represents direct effects; dotted lines represent moderation (interaction effects); estimates are based on setting covariates to their sample means

Table 1 Participants' characteristics

	RA patients (*n* = 34)	Healthy group (*n* = 44)
Age (years)	57 (51–61)	55 (50–59)
Gender, *n* (%)		
Men	3 (9)	5 (11)
Women	31 (91)	39 (89)
Body mass index (kg/m^2), median (IQR)	28 (23–31)	26 (23–29)
Body mass index (kg/m^2), n (%)		
Normal (< 25.0)	12 (36)	16 (38)
Overweight (25.0–29.9)	11 (33)	19 (45)
Obese (≥ 30.0)	10 (30)	7 (17)
Body height (cm)	165 (162–170)	165 (161–171)
Anthropometric measurements		
Circumference of the dominant hand forearm (cm)	25 (22–26)	25 (23–28)
Length of the dominant hand forearm (cm)	27 (25–27)	25 (24–26)
Dominant hand circumference (cm)	20 (19–22)	20 (19–21)
Dominant hand length (cm)	19 (18–21)	20 (19–20)
Clinical characteristics		
Duration of RA (years)	7 (4–10)	
Global functional stage, *n* (%)		
I	21 (62)	
II	13 (38)	
Steinbrocker radiographic classification (dominant hand), *n* (%)		
Stage I	11 (33)	
Stage II	8 (24)	
Stage III	6 (18)	
Stage IV	8 (24)	
HAQ-DI	1.06 (0.63–1.75)	
Disease Activity Score (DAS-28)	4.7 (3.3–5.7)	
Disease Activity Score (DAS-28), *n* (%)		
Inactive (≤ 3.2)	3 (9)	
Moderate (> 3.2 but ≤ 5.1)	18 (56)	
Very active (> 5.1)	11 (34)	
Morning stiffness, *n* (%)	25 (74)	
Morning stiffness (min)	30 (0–60)	
Number of painful joints	7 (3–15)	
Number of swollen joints	5 (3–8)	
Pain in the hand during the previous week (VAS)	48 (30–69)	
Overall health condition (VAS)		
Patients' assessment	44 (30–53)	
Physician's assessment	36 (17–49)	
Therapy, *n* (%)		
DMARDs	30 (88)	
Biologics	2 (6)	
Glucocorticoids	8 (24)	
Diabetes mellitus type II	2 (6)	

Data are presented as median (interquartile range) if not stated otherwise

DMARDs disease-modifying antirheumatic drugs, *NSAID* non-steroidal anti-inflammatory drugs, *VAS* visual analog scale, *HAQ-DI* The Health Assessment Questionnaire Disability Index

Data were missing for body mass index in 2 healthy participants and 1 patient diagnosed with RA, for the DAS-28 for 2 patients, and for the Steinbrocker Functional Classification for 1 patient stiffness but better overall health condition and were more often treated with glucocorticoids (Supplementary Table 1). Participants with complete data and excluded patients were comparable with regard to other sociodemographic, anthropometric and clinical characteristics. The median (IQR) age of RA patients and healthy control cases that we included in the primary analysis was 57 (51–61) and 55 (50–59) respectively, with 31 (91%) and 39 (89%) being women (Table 1). Samples from the RA and healthy population were comparable with regard to forearm and hand anthropometric parameters, but RA patients were somewhat more often obese.

Primary outcome (ABILHAND-RA)

After the adjustment according to age, gender and body mass index, the moderation effect of hand grip endurance during the repeated gripping on the correlation between maximum grip force and the ABILHAND-RA score was not significant in healthy participants ($b = 0.000$, 95% CI – 0.005–0.004, $p = 0.862$), but it was in RA patients ($b = 0.003$, 95% CI 0.000–0.005, $p = 0.027$). In RA patients, the effect of maximum grip force on the ABILHAND-RA score was increasing with the increase in hand grip endurance during repeated gripping, indicating the increase in hand functional ability (Table 2; Fig. 2). Using the Johnson–Neyman technique, we detected the region of significance of the endurance moderating effect in RA patients. Maximum grip force showed to be significantly associated with the ABILHAND-RA score when endurance was higher than ≈ 23 grips.

Secondary outcome (DAS-28)

The overall regression model containing hand grip endurance during repeated gripping, maximum grip force, age, gender and body mass index, explained 42% of the DAS-28 score variance [$R^2 = 0.42$ ($F(6,25) = 3.06$, $p = 0.022$)]. After the adjustment according to age, gender and body mass index, the moderation effect of hand grip endurance during repeated gripping on the correlation between maximum grip force and the DAS-28 score was significant ($b = -0.02$, 95% CI – 0.03 to – 0.00, $p = 0.017$). The variance of DAS-28 score independently explained by the interaction of hand grip endurance during repeated gripping and maximum grip force significantly increased by 15% [$R^2 = 0.15$ ($F(1,25) = 6.55$, $p = 0.017$)] compared to the variance explained by endurance and grip force main effects, age, gender and body mass index alone. The correlation between maximum grip force and the DAS-28 score was increasing with the increase in hand grip endurance during repeated gripping (Table 3; Fig. 3). The correlation had a negative sign meaning that the increase in maximum grip force indicates a lower DAS-28 score and a lower disease activity. Using the Johnson–Neyman technique, we detected the region of significance of the endurance moderating effect in RA patients. This effect was significant when endurance was higher than ≈ 24.5 grips. About 69% of patients showed such value of endurance.

Table 2 Adjusted changes of ABILHAND-RA score at unit difference in maximum grip strength in different percentiles of hand grip endurance during repeated gripping in healthy participants ($n = 44$) and RA patients ($n = 34$)

	Expected change in ABILHAND at unit change of grip strength (95% CI)	p	p_{corr}
Healthy participants ($n = 44$)			
Endurance percentile			
10th (24.0 grips)	0.003 (– 0.015–0.021)	0.765	> 0.999
25th (24.3 grips)	0.003 (– 0.015–0.020)	0.764	> 0.999
Median (25.0 grips)	0.002 (– 0.013–0.018)	0.766	> 0.999
75th (26.5 grips)	0.002 (– 0.012–0.016)	0.807	> 0.999
90th (27.7 grips)	0.001 (– 0.014–0.016)	0.870	0.870
RA patients ($n = 34$)			
Endurance percentile			
10th (24.0 grips)	0.009 (0.004–0.013)	< 0.001	0.010
25th (24.3 grips)	0.010 (0.005–0.014)	< 0.001	0.009
Median (25.0 grips)	0.011 (0.006–0.016)	< 0.001	0.008
75th (26.5 grips)	0.015 (0.008–0.022)	< 0.001	0.007
90th (27.7 grips)	0.018 (0.009–0.028)	< 0.001	0.006

CI confidence interval, p statistical significance, p_{corr} statistical significance corrected for multiple testing using the sequential Holm–Bonferroni method

[a]Coefficients were adjusted for age, gender and body mass index

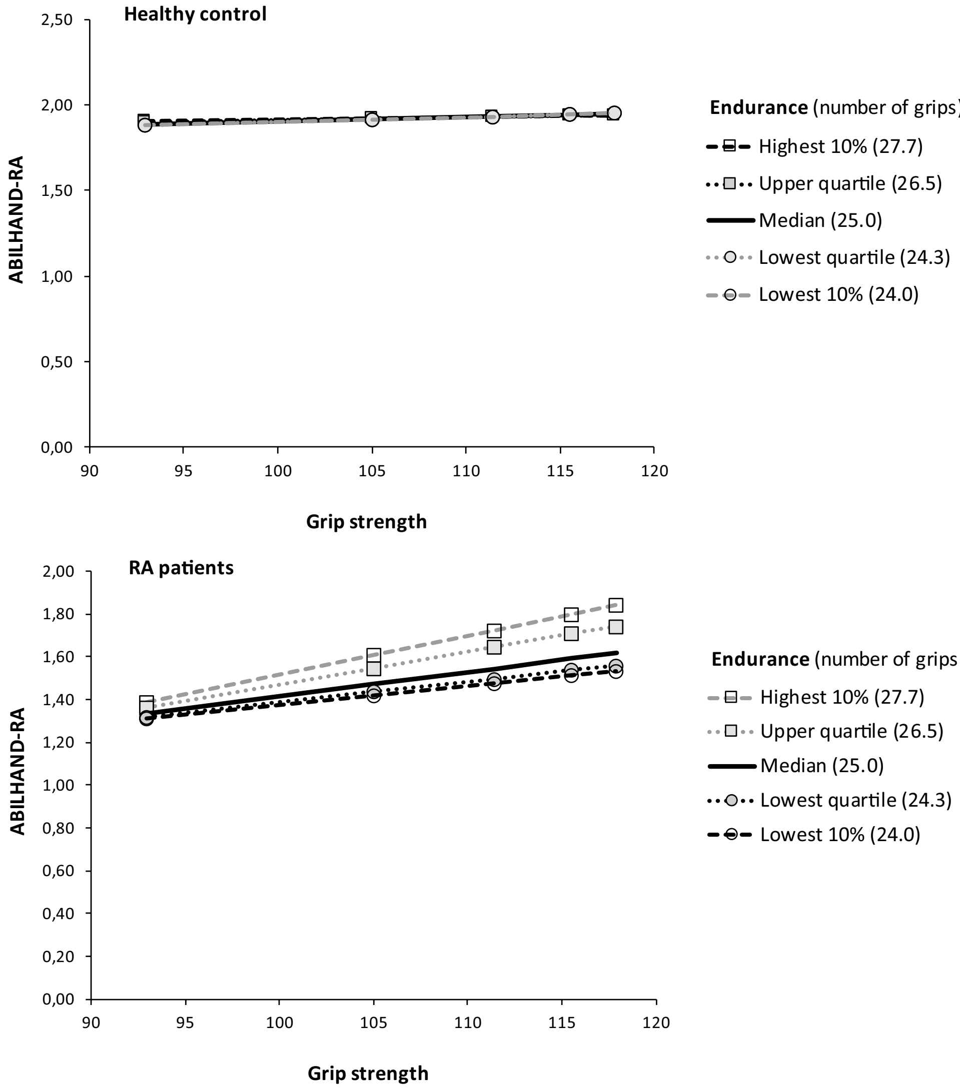

Fig. 2 Association of grip strength with ABILHAND-RA score at five different levels of endurance in healthy control group ($n = 44$) and in RA patients ($n = 34$)

Table 3 Adjusted changes of Disease Activity Score (DAS-28) at unit difference in maximum grip strength in different percentiles of hand grip endurance during repeated gripping in RA patients ($n = 34$)

	Expected change in DAS-28 at unit change of grip strength (95% CI)	*p*	p_{corr}
Endurance percentile			
10th (24.0 grips)	– 0.01 (– 0.04 to – 0.01)	0.253	0.253
25th (24.3 grips)	– 0.02 (– 0.05 to – 0.00)	0.084	0.168
Median (25.0 grips)	– 0.04 (– 0.07 to – 0.01)	0.017	0.051
75th (26.5 grips)	– 0.06 (– 0.10 to – 0.02)	0.007	0.035
90th (27.7 grips)	– 0.07 (– 0.13 to – 0.02)	0.007	0.028

Coefficients were adjusted for age, gender and body mass index

CI confidence interval, *p* statistical significance, p_{corr} statistical significance corrected for multiple testing using the sequential Holm–Bonferroni method

Discussion

In our study, we investigated the effect of hand grip endurance during repeated gripping on the correlation between maximum grip force and the ABILHAND-RA score in RA patients and in the healthy population. RA patients with later occurrence of fatigue and greater endurance in repeated gripping showed a significant influence of maximal grip force on functional ability measured by the ABILHAND-RA. That moderation effect of endurance in repeated gripping was not shown in healthy population. Considering disease activity, patients with RA and better endurance showed a stronger relationship between higher maximal grip force and lower DAS-28 score.

In the preliminary study of Matschke et al., the authors concluded that the physiological performance of muscles did not differ in patients with stable rheumatoid arthritis, compared to

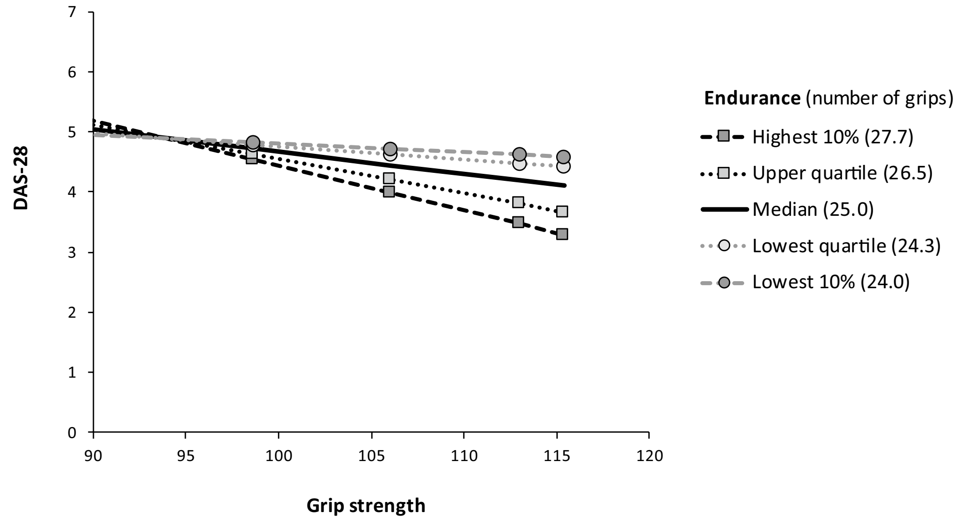

Fig. 3 Association of grip strength with Disease Activity Score (DAS-28) score at five different levels of endurance in RA patients (*n* = 34)

the healthy population, despite the proven reduction in physical function [28]. An intervention review by Williams et al. 2018 presented an insight into the usefulness of hand exercises for patients with rheumatoid arthritis. They concluded that the short-term benefit of hand exercises to increase the grip force and the pinch force is questionable, while high-quality evidence suggests no long-term benefits [29]. They highlighted the need for further research aimed at the function as a major outcome, with exercises defined by TIDieR guidelines [30].

In a recent study, a group of authors from Finland emphasized the importance of studying other muscle performance except grip strength. In the same study, the authors demonstrated a linear decrease in muscle performance with an increase in disease activity [31]. In our study, the population of patients with RA greater maximal grip force contributes to improved function, particularly in those with greater endurance. It is highly significant that measured force values depend considerably on the device calibration method; hence, they should be taken as approximate and qualitative. Despite the lack of accurate absolute values, we observe that endurance in repeated gripping is a measure that independently contributes to improvement of the physical function, together with maximum grip force. Based on this statement, it can be concluded that targeted rehabilitation or exercise, focused on improving endurance, can improve the recovery of function in patients with rheumatoid arthritis. Using the results of a multicenter, investigator-blind, randomized, controlled trial, Lamb et al. showed that a tailored exercise hand program (including mobility, strength and endurance) provides an additional benefit to various drug regimens in patients with rheumatoid arthritis and should be an important treatment aim [32]. Meticulous evaluation of the hand function offers possibilities to plan the appropriate rehabilitation protocol, therapeutic exercise in the first place, to obtain the best possible result.

Demmelmaier et al. emphasized the complex interplay of fatigue, physical function and disease activity. In their study on patients with moderate RA and low/moderate disease activity, physical function measured by grip strength is only marginally associated with severe fatigue. The authors concluded that further research with multi-dimensional assessment of fatigue was needed, as well as a more detailed assessment of physical function to determine their relationship more accurately [33].

According to prior studies, the disease activity is the most consistent factor associated with impaired hand function, but there is the problem of evaluating hand function in patients in DAS-28 remission, that of course cannot be counted in the group whose function is within the normal range [34]. The contribution of endurance measuring in those patients would be an additional parameter in objectifying functional capacity. One of the limitations of the study is that the Croatian version of ABILHAND-RA was not formally validated. Before the questionnaire was used both the translation and back translation by a native speaker were performed.

Particular activities included in the ABILHAND-RA that had not been attempted during the previous 3 months are conventionally excluded from the analysis. While it is possible that some participants just did not have the opportunity to screw a nut on, or handle a four-color ballpoint pen with one hand, it is unlikely that someone did not have the single opportunity to turn a key in a keyhole, turn off a tap, take the cap off a bottle, or cut off the nails. It is more likely that at least some RA patients who answered that they had not attempted any of particular activities did not do it just because they were aware of their hand functional disability. Otherwise, the number of skipped activities should be similar between RA patients and healthy participants. However, in our sample 42 (93%) of healthy participants rated all ABILHAND-RA items, and only 15 (33%) of RA patients did so (Supplementary Table 2). In such cases, by excluding these answers and activities from the total ABILHAND-RA score, we are inducing the bias promoting a null hypothesis and thus overestimate the functional ability and increase the risks of false negatives (error type II or β).

Conclusion

Our study showed different effects of hand grip endurance during repeated gripping on the correlation between maximum grip force and the ABILHAND-RA score in RA patients and in the rheumatologically healthy population. Our study showed an even larger moderating effect of endurance on the correlation between maximum grip force and the disease activity measured by the DAS-28.

Author contributions All authors were involved in the study design. Ines Doko and Simeon Grazio were local investigators. Žarko Bajić undertook the statistical analyses and the interpretation of the results and contributed significantly in writing the manuscript. Amir Dubravić is an author of the measuring algorithm and he wrote a significant part of the Method section of the manuscript. Merita Qorolli contributed in writing of the Introduction and Discussion parts of the manuscript. Simeon Grazio masterminded and contributed significantly in writing the manuscript and merited for critical revision of the manuscript. All authors participated in the preparation of the final version of the manuscript, read and approved the version to be submitted.

Compliance with ethical standards

Conflict of interest Ines Doko, Žarko Bajić, Amir Dubravić and Merita Qorolli declare that they have no conflict of interest. Simeon Grazio is a member of the Editorial Board of Rheumatology Int.

Ethical approval All procedures performed were in accordance with ethical standards of the institutional research committee (protocol number EP–13030/11–8), and with the 1964 Helsinki Declaration and its later amendments.

Informed consent Informed consent was obtained from all individual participants included in the study.

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