IJMCR
International Journal of Medical and Clinical Research
ISSN: 0976-5530 & E-ISSN: 0976-5549, Volume 2, Issue 2, 2011, pp-41-48
Available online at http://www.bioinfo.in/contents.php?id=39

# GRIP FORCE AND ULTRASOUND EXAMINATION OF MUSCLE ARCHITECTURE IN RHEUMATOID ARTHRITIS PATIENTS-A PILOT STUDY

**BRORSSON S.[1*], HILLIGES M.[1], SOLLERMAN C.[2,3], AURELL Y.[4] AND NILSDOTTER A.[5]**
[1]Exercise Physiology, Biomechanics and Health at School of Business and Engineering, Halmstad University, Sweden
[2]R & D centre Spenshult Hospital for Rheumatic Diseases, Halmstad, Sweden
[3]Department of Hand Surgery, Sahlgrenska Academy, Göteborg, Sweden
[4]Department of Diagnostic Radiology, Sahlgrenska Academy, Göteborg, Sweden
[5]Department of Research and Education, Halmstad Central Hospital, Halmstad, Sweden
*Corresponding author: Email: sofia.brorsson@hh.se

Received: July 05, 2011; Accepted: August 01, 2011

**Abstract-** The aims of this study were to measure grip force (flexion and extension force) in patients with Rheumatoid Arthritis (RA) and compare them with healthy subjects. We also wanted to explore the possible causes of impaired finger extension force with the help of ultrasound muscle analyses. The study group comprised of 20 patients with RA and 20 healthy age-matched controls. The grip force was measured and the extensor digitorum communis muscle was examined with ultrasound. The results showed significant differences in force capacity as well as differences in structural parameters and the intra muscle movements were more pronounced in the healthy subjects than in RA patients. The results show differences in structural parameters as well as functional tests, i.e. contraction time and extension muscle force capacity, between normal and RA muscles. Ultrasound and grip force measurements are useful tools for evaluation of muscle architectures and grip force after rehabilitation.
**Key words** - muscle architechture, grip force, extensor muscles, finger extensor force, hand/finger, forearm, rheumatoid arthritis

## Introduction

The hand is used in many ways and in many different situations in our daily lives. Injuries, diseases or deformities of the hand may affect the hand function and patients' quality of life [33, 11]. The complicated biomechanical architecture of the hand poses challenges in the study and understanding of the control strategies that underlie good coordination of finger movement and force capacity [36]. Grip function is based on the force of the muscles that are involved in finger and wrist motion. The force that can be generated is dependent on the muscle architecture, including aspects such as muscle fibre length, muscle pennation angle, the contraction pattern, the muscle thickness and the muscle volume [23, 27]. These architectural parameters and the muscle function can be studied non-invasively with ultrasonography. There is a need for better understanding of the dynamic motion of skeletal muscle and the relation between muscle function and muscle force [35, 14, 25].

Although patients with rheumatoid arthritis (RA) frequently experience muscle weakness, limited information exists on disease specific muscle changes. RA commonly affects the metacarpophalangeal (MCP) joints of the hand and the classic MCP joint deformities are flexion and ulnar deviation with dislocation or subluxation. In rheumatoid arthritis, loss of finger extension is common, and is an important predominates for the development of ulnar deviation of the fingers [31]. The mechanism of muscle force impairment in RA is not fully elucidated. Whether the reported loss of strength is dependent on inactivity or disease specific changes in the muscular structure, is unclear. Measurements of finger extension force might be useful in the rehabilitation after hand injuries and after reconstructive surgery such as tendon transfers or arthroplasty of the MCP-joints in rheumatoid arthritis. We also think that extensor force measurements are important before reconstruction of finger extensors and might be helpful in patient selection for such procedures.

In this study, we have used high-resolution ultrasound in combination with a finger extension force measuring device for non-invasive measurements of muscle architecture and force. We have developed an extension force measurement device (EX-it), and have investigated the measurement accuracy, usability and test-retest reliability [9]. We have also shown that high-resolution ultrasound (US) technology is a highly valuable tool for studying muscle architecture and muscle function in healthy men and women [8].

This study was conducted to investigate the relation between force production and architectural parameters of the forearm *in vivo*, based on measurements of the m. extensor digitorum communis (EDC).

## Material and Methods

*(a)Subjects*

Measurements of finger extension force together with ultrasound analyses were performed in two groups, one RA group and one healthy control group. The RA group consisted of 20 patients with RA, (RA diagnosis based on 1987 ACR criteria [3]), mean disease duration 20 (range 2-40) years, mean age 57 (33-70) years. The inclusion criterion for the RA patients was disease duration time of at least one year. The patients should be able to fully extend their fingers. Patients with RA who visited the outpatient clinic at Spenshult Hospital for Rheumatic Diseases, during one month were asked to participate in the study. A control group matched by age and gender were recruited from the staff of Halmstad University. The control group consisted of 20 healthy women, with a median age of 59 (range 36-73) years [8]. The exclusion criteria for the healthy subjects were inflammatory or muscle diseases or previous hand or arm injuries. The investigation was approved by the Region Ethics Committee of the Faculty of Medicine at Lund University. All procedures complied with the Declaration of Helsinki.

*(b) Grip force measurements*
All finger extension force measurements were performed using a newly developed finger force measurement device based on the biomechanics of the hand [9]. The device isolates and measures the forces developed around the metacarpophalangeal (MCP) joint (Fig. 1). Considerable effort was made to ensure standardized conditions during the tests. All measurements were performed with the same value of α at the MCP joint and special care was taken when placing the hand in the device.

The electronic device Grippit (Detektor AB, Göteborg, Sweden) was used for measuring finger flexion force [30]. The procedure for the measurements was standardized in terms of sitting position, instructions and encouragement [21, 4]. The sitting position we used was recommended by the American Society of Hand Therapists (ASHT) [12], and the force measurements were performed according to previously described methods [8]. The subjects were seated in an upright position in a chair in front of the instrument. Data (extension and flexion force in Newton (N)) were collected and saved for further analysis in a computer. The results from the measurements were showing the mean, maximal forces and continuous force over the measured time. The examiner first demonstrated the extension- and flexion grip procedure, and the subjects were allowed to familiarise themselves with the device and practice sub-maximally. The subjects were then instructed to extend/flex their fingers as much as possible against the resistance of the bar for a period of three seconds. The participant performed one measurement on each measuring device. Before and after the measurement, the subject was asked to report the level of pain in the fingers/wrist, based a visual analogue scale, ranging from 0 to 10 [5] (0 = no pain, 10 = highest pain tolerance limit).

*(c) Ultrasound examination*
Ultrasound examination of the m. extensor digitorum communis (EDC) was performed (Fig. 2) with a Siemens Acuson, Aspen system using a 7.5 MHz linear transducer (38 mm width). The measurements were performed according to a previous published protocol [8] and produced data on muscle cross-sectional area (CSA), muscle circumference, muscle thickness, pennation angle, contraction pattern (inter muscle movement pattern). The muscle volume was calculated [1] and the fascicle length was estimated from the muscle thickness and the pennation angle [19]. Images were analysed in both transverse and longitudinal views. Ultrasound recordings were obtained during a change from a neutral relaxed position to maximal static contraction of the extensor muscles, and were performed simultaneous with finger extension force measurements, maintaining a neutrally positioned wrist. All images were interpreted blindly on saved ultrasound images by two independent investigators (SB & YA) to establish the inter-observer reliability. In order to estimate intra-observer reliability all the images were interpreted twice by one of the investigators (SB).

*(d) Statistics*
For group comparisons of independent samples the One-way ANOVA was used. Descriptive data included mean values ± Std. deviation (SD) and 95% confidence interval (CI). To assess the correlations between the measured variables, Pearson's rank (r) correlation test was applied. A p-value of less than 0.05 (two-tailed test) was considered to be significant. Repeatability and agreement of the continuous variables from the ultrasound images were assessed using the graphic technique described by Bland and Altman [6]. SPSS version 18.0 for Windows XP and MedCalc 5.0 were used in the statistical analysis.

**Results**
*(a) Force capacity in RA patients and healthy women*
Both the finger extension and finger flexion force was significant impaired in the RA group compared to the control group ($p < 0.001$). The mean finger extension force in the RA group was 14.7 ± 10.0 (CI 10.0-19.4) N and 39.6 ± 10.8 (CI 34.6- 44.6) N in the control group. The mean flexion force measured with the Grippit was 81.4 ± 47.2 (CI 59.2-103.5) N in the RA group compared to 174.0 ± 43.0 (CI 153.9-194.1) N in the control group. The individual values of finger extension and flexion force are given in Table 1. The RA group prove to have 37 % of the extension force and 47 % of the flexion force compared to the control group. The finger extension force in the RA group was 18.5 % of their finger flexion force. The corresponding value in the control group was 22.9 %, this difference was not significant. The RA group reported a mean pain level of 1.9 ± 0.4 (CI 1.0 – 2.7) after the force measurements and the control group had a mean pain level of 0.05 ± 0.5 (range 0.0 – 0.4).

*(b) Muscle architecture parameters*
Significant differences were found between the groups regarding muscle thickness, CSA, fascicle length, muscle volume and the muscle thickness. The overall shape

changes of the muscle architecture during contraction were more pronounced in the control group than in the RA group ($p < 0.01$). However, no significant difference was found between the two groups concerning the muscle pennation angle. The mean values of the parameters describing the muscle architecture are given in Table 2.

*(c) Extensor muscle force in relation to muscle architecture parameters*

In the RA group the extension force showed a significant correlation to muscle thickness ($r = 0.51$, $p = 0.03$) and muscle shape change during contraction ($r = 0.57$, $p = 0.02$). No correlations were found between extension force and muscle volume, extension force and CSA, extension force and pennation angle. In the control group, no correlations were found between extension force and muscle thickness, extension force and muscle shape change during contraction, extension force and muscle volume, extension force and CSA, extension force and pennation angle.

*(d) Inter- and intra-observer reliability of the ultrasound method*

A total of 40x2 images were assessed regarding muscle CSA, muscle pennation angle and muscle thickness. The distributions of the differences and limits of agreement for 95% of the cases for the inter-observer assessment of three parameters are presented in Figure 3. The result from the intra-observer agreement was in the same range as the result from the inter-observer agreement (data not shown).

## Discussion

A sometimes neglected but, important ability for obtaining good hand function is the wrist and finger extension motion. Finger extension control is a difficult function to regain after hand injuries and loss of this capability is regarded as a primary disabler for hand function [10]. In rheumatoid arthritis, impaired finger extension is a common entity. The present study shows differences in extension and flexion muscle force capacity as well as in muscle architectural parameters, between normal and RA muscles. To our knowledge, no other *in vivo* imaging study has been presented describing the EDC muscle architecture and its relation to finger extension force in healthy and RA women.

*(a) Effects on the rheumatic muscle*

In the present study with measurements of finger extension force with the EX-it device, a pronounced decrease in finger extension force was found in the RA group; the control group showing 40 % greater force capacity than the RA patients. Earlier studies have reported that RA patients also have weaker grip -, pinch - and tripod strength than healthy controls, and it has been suggested that force assessment could be used as an accurate indicator of upper limb ability and that grip strength (i.e. flexion strength and pinch strength) should be included in the evaluation and follow-up of the patients with RA in hand rehabilitation units [13, 7, 2, 17]. The decrease in force capacity could be explained by a direct effect of the disease on muscle function, disuse or impaired neuromuscular transmission, different medications, but it could also be due to the fact that the RA patients experienced more pain than the healthy subjects, which could influence their maximal muscle exertion. Loss of hand grip strength has been shown to result from pain, or fear of pain, or mechanical malfunction [13]. However, data obtained in the present study did not show a significant correlation between finger extension force and pain level, although the RA group had significantly more pain than the control group. Furthermore, the present study with ultrasound measurements on EDC, significant differences in muscle architecture between the two groups were found; all muscle parameters, except pennation angle, being significantly decreased in the RA group.

*(b) Muscle architecture and force*

Ultrasound technology has been shown to be a valuable tool for studying muscle architecture and muscle function and has opened new opportunities for non-invasive studies of the physiological mechanisms inside the living body [28]. Real-time ultrasonography has been shown to be a highly valuable tool for studying muscle function and relationships between muscle force and muscle size [16, 26]. The finger extension muscle architecture and its relation to force development capacity was studied with two non-invasive methods, extension force measurements and ultrasound analyses of the muscle structure. The present study showed a correlation between finger extension force and muscle thickness (contracted muscle) and are in line with previous studies on other muscle systems. A correlation has been established between quadriceps muscle thickness and knee extension force and muscle thickness in the masseter and temporals and bite force [15, 32]. Furthermore, the present study showed correlation between finger extension force and muscle CSA.

This results supports from previous studies on both lower and upper extension muscles analysed on healthy men [20, 26]. Furthermore the present study showed correlation between finger extension force and muscle volume. Trapper, Holzbaur and colleagues used non-invasive methods (magnet resonance imaging) to study the relationship between muscle volume and force. They found correlations between muscle volume and muscle force in both the upper and lower extremities. However, their study groups were small ($n = 18$ and $n = 10$) and contained both men and women [18, 37].

Experimental measurements of the muscle pennation angle have been made in a previous study, using small wire markers on the muscle surface which were filmed during contraction. The results of that study showed that the pennation angle varied considerably [38]. The finding that the pennation angle appears to be free to rotate during contraction has a number of implications that make the equation proposed by Powell et al [34]:

$$PCSA(mm^2) = \frac{musclemass(g) x \cos ine(\alpha)}{\delta(g/mm^3) x fiberlength(mm)},$$

unreliable in predicting force in certain muscles. Fibre rotation during muscle shortening allows muscle fibres to maintain a higher level of force generation than when the fibres are constrained to maintain a constant pennation angle [22]. This is one potential explanation for the results in the present study where we found a correlation between the change in shape of the muscle and the extension force, but no correlation between pennation angle and finger extension force.

*(c) Muscle architecture and force in the RA group and the control group separately*

In the present study, when analysing the results from the two groups separately, one muscle parameter, muscle thickness was significant correlated to finger extension force in the RA and the control group. Furthermore, the RA group showed a correlation between the shape change of the muscle and finger extension force. The shape change of the RA muscle was significant decreased compared to health muscle as well as the contraction time. The present study could not support some expected correlations such as correlation between finger extension force and muscle CSA. Helliwell and Jackson reported a correlation between CSA and grip strength both for RA patients and healthy controls. However, they had measured and correlated the flexion force with an estimated CSA (using an equation based on forearm circumference, area from radius and ulna (antropometric data) and skin thickness) [17].

One possible explanation of the result in the present study when analysing the data from the two groups' separately, is that the separate groups are too homogeneous to achieve statistical significance. This is supported by fact that earlier studies have been designed with an internal variance using mixed groups (men/women or mixed ages). One of these studies also failed to show any correlation when the groups were analysed separately [29]. It is also possible that a muscle designed for precision tasks and grip control rather than force exertion is constructed differently from the large force-generating muscles in the lower limbs. It may also be due to methodological problems, although we have in this and previous studies shown good validity and reproducibility of our methods. Another explanation could be that the study population was too small to detect correlations. However, this is not very likely since there is not even a statistical tendency towards significance. Yet another possibility could be that there is a breakpoint, in other words, the muscle has to have a specific size before the correlation is seen. The fact that the men in our previous study showed a correlation between force and volume could support this theory [8].

Patients with rheumatoid arthritis suffer from a variety of functional deficiencies, of which impaired muscle function is a serious one. There is a recent trend towards the use of non-invasive methods in studying disease-specific changes, such as magnetic resonance imaging and ultrasound. Increased knowledge concerning muscle morphology and function in RA will allow better diagnosis and evaluation of interventions, such as surgical procedures, physiotherapy and/or pharmacological treatment. In a longer perspective it may be possible to establish a more efficient rehabilitation programme for RA patients. If combined with functional and clinical measures of disability, information on muscle architecture could then be used as an objective tool in the assessment of hand function after physical therapy and hand surgery.

**Conclusion**

The two non-invasive methods that we have combined provide new and detailed information concerning the EDC architecture. Our results indicate that rheumatoid arthritis may affect the geometry of skeletal muscle. The results show differences in structural parameters as well as functional tests, i.e. contraction time and extension muscle force development, between normal and RA muscles. Whether these differences depend on a disease-specific effect on the muscles in RA, or are secondary to inactivity due to hand deformities, remains to be elucidated. The present study demonstrated a strong correlation between finger extension force and muscle thickness (in both the RA group and the healthy control group), and this may provide a clinically useful measure for evaluating the outcome of hand surgery and hand rehabilitation. Muscle architecture is a primary determinant of muscle function. The understanding of structure-function relationship is of great clinical importance. Not only to elucidate the physiological basis of force production and movement, but also to provide a scientific rationale for surgical treatment that may involve arthroplasties and tendon-transfer procedures [24].

**Acknowledgments**

We wish to thank the patients at Spenshult Hospital and the healthy controls who participated in the study. This study was supported by The Crafoord Foundation, Camp Scandinavia AB, Siemens AB and Halmstad University.

**References**

[1] Aagaard P., Andersen J. L., Dyhre-Poulsen P., Leffers A. M., Wagner A, Magnusson S. P., Halkjaer-Kristensen J. and Simonsen E. B. (2001) *J Physiol,* 534, 613-23.

[2] Adams J., Burridge J., Mullee M., Hammond A. and Cooper C. (2004) *Clin Rehabil,* 18, 405-13.

[3] Arnett F. C., Edworthy S. M., Bloch D. A., McShane D. J., Fries J. F., Cooper N. S., Healey L. A., Kaplan S. R., Liang M. H., Luthra H. S. and et al. (1988) *Arthritis Rheum*, 31, 315-24.

[4] Ashford R. F., Nagelburg S and Adkins R. (1996) *J Hand Surg [Am]*, 21, 402-5.

[5] Berntson L and Svensson E. (2001) *Acta Paediatr*, 90, 1131-6.

[6] Bland J. M. and Altman D. G. (1986) *Lancet*, 1, 307-10.

[7] Bodur H., Yilmaz O. and Keskin D. (2006) *Rheumatol Int,* 26, 541-4.
[8] Brorsson S., Nilsdotter A., Hilliges M., Sollerman C. and Aurell Y. (2008) B*MC Med Imaging*, 8, 6.
[9] Brorsson S., Nilsdotter A., Sollerman C., Baerveldt A. J. and Hilliges M. (2008) *Technol Health Care*, 16, 283-92.
[10] Cauraugh J., Light K., Kim S., Thigpen M. and Behrman A. (2000) *Stroke*, 31, 1360-4.
[11] Dahlin L., Friden J., Hagberg L. and Lundborg G. (2000) *Ugeskr Laeger,* 162, 1725-30.
[12] Fess E. (1992) *Cited in: American Society of Hand Therapists. Clinical Assment Recommendations vol 2nd*.
[13] Fraser A., Vallow J., Preston A. and Cooper R. G. (1999) *Rheumatology (Oxford),* 38, 521-8.
[14] Fukunaga T., Ichinose Y., Ito M., Kawakami Y. and Fukashiro S. (1997) *J Appl Physiol*, 82, 354-8.
[15] Fukunaga T., Miyatani M., Tachi M., Kouzaki M., Kawakami Y. and Kanehisa H. (2001) *Acta Physiol Scand*, 172, 249-55.
[16] Hakkinen K. and Keskinen K. L. (1989) E*ur J Appl Physiol Occup Physiol,* 59, 215-20.
[17] Helliwell P. S. and Jackson S. (1994) *Ann Rheum Dis*, 53, 726-8.
[18] Holzbaur K. R., Murray W. M., Gold G. E. and Delp S. L. (2007) *J Biomech*, 40, 742-9.
[19] Ichinose Y., Kawakami Y., Ito M., Kanehisa H. and Fukunaga T. (2000) *J Appl Physiol,* 88, 851-6.
[20] Ikai M. and Fukunaga T. (1968) *Int Z Angew Physiol,* 26, 26-32.
[21] Innes E. (1999) *Austral Occup Ther J*, 120–40.
[22] Kawakami Y., Akima H., Kubo K., Muraoka Y., Hasegawa H., Kouzaki M., Imai M., Suzuki Y., Gunji A., Kanehisa H. and Fukunaga T. (2001) *Eur J Appl Physiol,* 84, 7-12.
[23] Langenderfer J. E., Patthanacharoenphon C., Carpenter J. E. and Hughes R. E. (2006) *Clin Biomech (Bristol, Avon)*, 21, 701-9.
[24] Lieber R. L. and Friden J. (2000) *Muscle Nerve,* 23, 1647-66.
[25] Maganaris C. N., Baltzopoulos V. and Sargeant A. J. (1998) *J Physiol,* 512, ( Pt 2) 603-14.
[26] Maughan R. J., Watson J. S. and Weir J. (1984) *Br J Sports Med*, 18, 149-57.
[27] Morse C. I., Thom J. M., Birch K. M. and Narici M. V. (2005) *Acta Physiol Scand*, 183, 291-8.
[28] Morse C. I., Thom J. M., Reeves N. D., Birch K. M. and Narici M. V. (2005) *J Appl Physiol*, 99, 1050-5.
[29] Narici M. V., Maganaris C. N., Reeves N. D. and Capodaglio P. (2003) *J Appl Physiol,* 95, 2229-34.
[30] Nordenskiold U. M. and Grimby G. (1993) *Scand J Rheumatol,* 22, 14-9.
[31] Pearl R. M. and Hentz V. R. (1993) *Plast Reconstr Surg*, 92, 507-10.
[32] Pereira L. J., Gaviao M. B., Bonjardim L. R., Castelo P. M. and van der Bilt A. (2007) E*ur J Orthod,* 29, 72-8.
[33] Pollard L, Choy E. H. and Scott D. L. (2005) *Clin Exp Rheumatol,* 23, S43-52.
[34] Powell P. L., Roy R. R., Kanim P, Bello M. A. and Edgerton V. R. (1984) *J Appl Physiol,* 57, 1715-21.
[35] Rutherford O. M. and Jones D. A. (1992) *Eur J Appl Physiol Occup Physiol,* 65, 433-7.
[36] Schieber M. H. and Santello M. (2004) *J Appl Physiol,* 96, 2293-300.
[37] Trappe S. W., Trappe T. A., Lee G. A. and Costill D. L. (2001) *Int J Sports Med*, 22, 186-91.
[38] Zuurbier C. J. and Huijing P. A. (1993) *J Morphol,* 218, 167-80.

*Table - 1 - Force capacity in RA patients and healthy women*

| RA group (n=20) | | | | | Control group (n=20) | | | |
|---|---|---|---|---|---|---|---|---|
| Subject | Age | Diesese duration (years) | Ef (N) | Ff (N) | Subject | Age | Ef (N) | Ff (N) |
| RA 1 | 39 | 38 | 34 | 57 | HC 1 | 60 | 30 | 201 |
| RA 2 | 36 | 23 | 21 | 45 | HC 2 | 57 | 51 | 188 |
| RA 3 | 42 | 10 | 20 | 57 | HC 3 | 58 | 34 | 145 |
| RA 4 | 49 | 11 | 27 | 108 | HC 4 | 59 | 45 | 195 |
| RA 5 | 57 | 10 | 25 | 132 | HC 5 | 33 | 54 | 159 |
| RA 6 | 51 | 2 | 4 | 88 | HC 6 | 46 | 43 | 167 |
| RA 7 | 60 | 6 | 2 | 124 | HC 7 | 69 | 47 | 101 |
| RA 8 | 56 | 8 | 10 | 88 | HC 8 | 60 | 24 | 191 |
| RA 9 | 60 | 28 | 9 | 36 | HC 9 | 70 | 46 | 177 |
| RA 10 | 49 | 13 | 2 | 72 | HC 10 | 66 | 51 | 219 |
| RA 11 | 62 | 32 | 28 | 240 | HC 11 | 37 | 57 | 245 |
| RA 12 | 53 | 30 | 30 | 98 | HC 12 | 54 | 50 | 198 |
| RA 13 | 65 | 18 | 2 | 40 | HC 13 | 69 | 46 | 200 |
| RA 14 | 64 | 13 | 12 | 70 | HC 14 | 62 | 33 | 138 |
| RA 15 | 65 | 24 | 16 | 61 | HC 15 | 68 | 32 | 90 |
| RA 16 | 65 | 19 | 7 | 100 | HC 16 | 54 | 36 | 218 |
| RA 17 | 73 | 35 | 12 | 39 | HC 17 | 50 | 33 | 238 |
| RA 18 | 72 | 19 | 7 | 44 | HC 18 | 58 | 35 | 127 |
| RA 19 | 67 | 20 | 10 | 45 | HC 19 | 60 | 20 | 144 |
| RA 20 | 68 | 40 | 15 | 83 | HC 20 | 60 | 25 | 139 |

*Finger extension force (Ef), Flexion force (Ff), RA subject (RA#), Healthy controll (HC#)*

*Table- 2 - Muscle architectures of EDC*

| Muscle parameter | **RA group (n=20)** | **Control group (n=20)** |
|---|---|---|
| Thickness (cm) | 0.8±0.2 (0.8-0.9) | 1.0±0.1 (0.9-1.0)* |
| CSA (cm²) | 1.6±0.5 (1.4-1.9) | 1.9±0.4 (1.7-2.1)* |
| Fascicle length (cm) | 4.3±0.9 (3.9-4.8) | 5.0±0.9 (4.6-5.4)* |
| Pennation angle (degree) | 5.6±0.8 (5.2-5.9) | 5.7±1.4 (5.0-6.3) |
| Volume (cm³) | 12.4±4.6 (10.1-14.7) | 16.8±4.6 (14.7-19.0)** |
| Contraction time (s) | 1.6±0.2 (1.4-1.7) | 1.0±0.3 (0.8-1.1)** |

*Muscle parameters are presented as mean ± SD (95 % Confidence intervals).*
** p < 0.05, ** p < 0.01 (sig. differences between control group - RA group).*

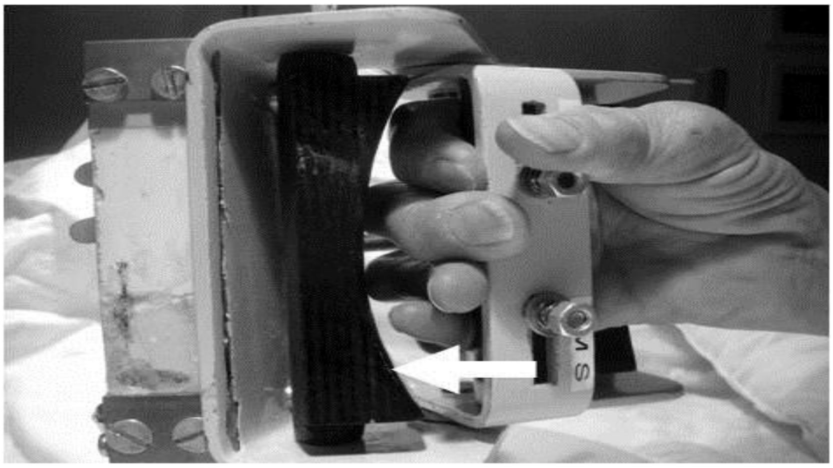

*Fig. 1-Finger extension force measurements were performed using a newly developed device (EX-it). The measurements start when the test subjects press their fingers against the hand pad (with arrow).*

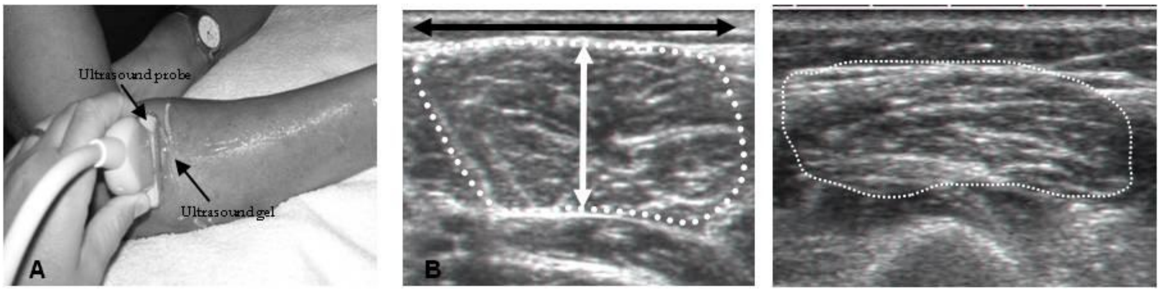


*Fig. 2-(A) The ultrasonic transducer was placed on the skin over the muscle EDC at a distance 15% distally from the muscle origin. (B) Transverse US image of EDC. The CSA is the area within the dotted line; the muscle thickness is indicated by the double headed white arrow and the muscle length indicated by the black double-headed arrow. (C) Transverse US image from one RA patient, taken when the fingers are fully extended.*

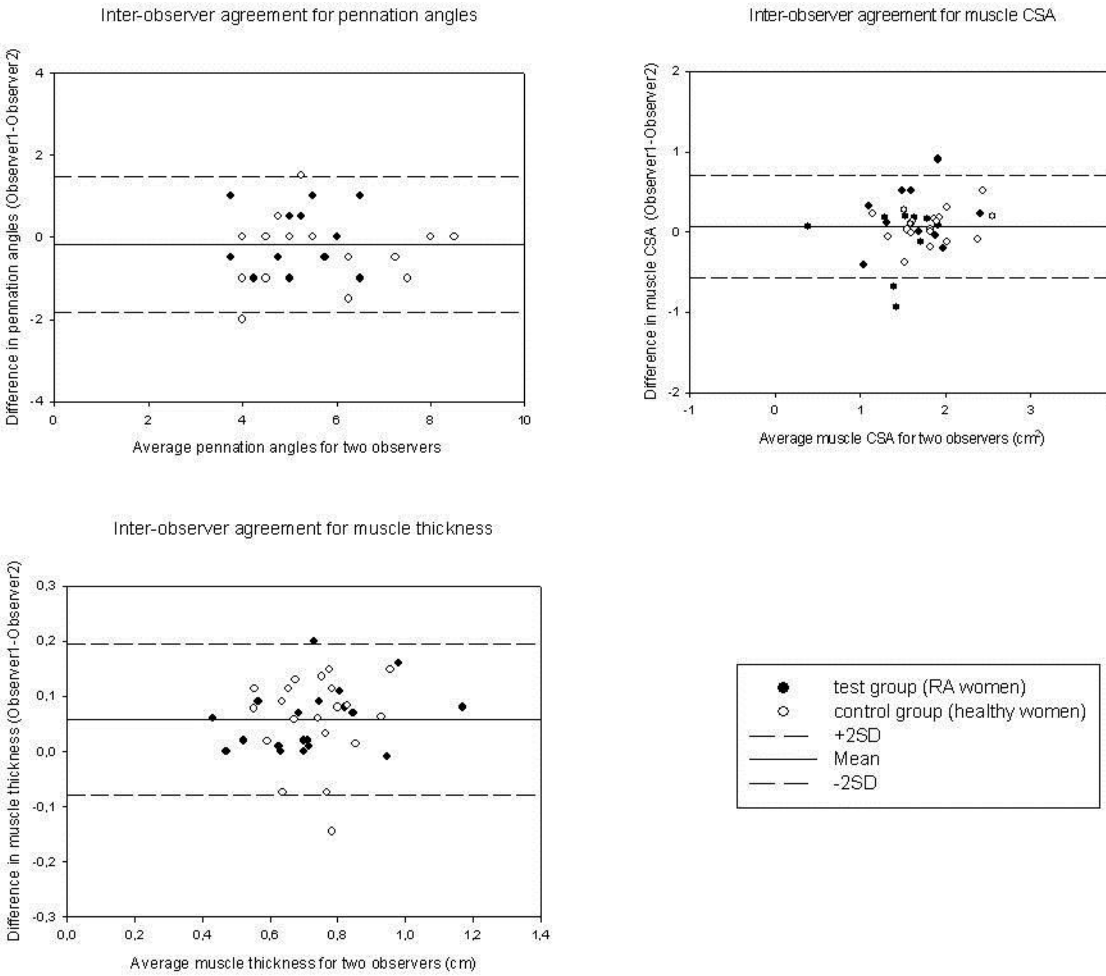


*Fig. 3-Inter-observer agreement in US measurements of muscle pennation angles, muscle CSA and muscle thickness for each subject.*