ORIGINAL PAPER
PŮVODNÍ PRÁCE

Central Motor Deficits of the Deltoid Muscle in Patients with Chronic Rotator Cuff Tears

Centrální motorický deficit m.deltoideus u pacientů s chronickou lézí rotátorové manžety

A. BERTH[1], G. PAP[2], F. AWISZUS[1], W. NEUMANN[1]

[1] Department of Orthopaedic Surgery, Otto-von-Guericke-University, Magdeburg, Germany
[2] Centre of Orthopaedics and Traumatology, Park-Hospital Leipzig, Leipzig, Germany

ABSTRACT

PURPOSE OF THE STUDY

Previous surface EMG studies have shown that chronic rotator cuff tears (RCT) may be associated with a altered activation of adjacent shoulder muscles. The effect of RCT on central neuromuscular control mechanisms of the shoulder girdle muscles such as the deltoideus muscle (MD), a key muscle of shoulder function, has as yet not been studied in detail. This study investigated the cortico-spinal excitability of the MD to assess the effects of RCT on the central neuromuscular function of upper limb muscles.

MATERIAL AND METHODS

The motor evoked potentials (MEP) in response to transcranial magnetic stimulation of MD and first dorsal interosseus muscle (FDI) on both sides were obtained of six right-handed men with chronic, symptomatic, full-thickness RCT on the dominant sides. Stimulus response curves at four different levels were measured at two tasks (MD at rest and during activity).

RESULTS

Different interactions were found between stimulus intensity, task and side for MEP of the MD (F = 3.9, P = 0.03), indicating that MD excitability on the affected side were lower when compared with the non-affected side. No correlation was found between the correspondent MEP amplitudes of MD and FDI at rest (r = 0.1, P = 0.44) and MD activation (r = 0.3, P = 0.05) on the affected side whereas a correlation existed on the non-affected side at rest (r = 0.5, P = 0.007) and during activation (r = 0.8, P < 0.001).

CONCLUSIONS

These decreased cortico-motoneuronal excitability of the MD on the affected side seems to related to adaptive changes in motor cortex as a consequence of chronic RCT. The data suggest an involvement of central mechanisms and seem to precede severe changes of osteoarthritis of the shoulder.

Key words: transcranial magnetic stimulation, motor evoked potentials, deltoid, rotator cuff tear, shoulder.

INTRODUCTION

The rotator cuff plays an important role in stabilisation and control of the complex course of motion of the gleno-humeral joint (GHJ) . Lesions of the rotator cuff are a common source of pain, impairment and disability of the shoulder, especially in people aged 60 years and older . The prognosis and therapy of a full thickness rotator cuff tear (RCT) depends on the location, size and genesis of the lesion (10, 20, 29).

However, many patients with RCT have no discomfort due to the lesion (17). The influence of the superficial shoulder muscle activity, especially of the deltoid muscle (MD) on the kinematic of the GHJ and the presence or absence of symptoms remains unclear. Previous electromyography (EMG) studies have shown, that the shoulder muscle activity is altered in patients with RCT (15, 26). This points toward impaired neuromuscular control mechanisms of the surrounding shoulder muscles. However, the definitive origin of these neuromuscular deficits remains to be investigated. Especially, the central changes of neuromuscular control mechanisms contributing to the functional alteration associated with chronic RCT has, as yet not been studied in detail.

Transcranial magnetic stimulation (TMS) is a noninvasive technique to investigate the human motor cortex. It has been used for the assessment of excitability, representation and function of the motor system (16).

Therefore, the purpose of this study was to investigate the neuromuscular alterations of MD in patients with a unilateral chronic RCT and in subjects without any shoulder pathologies with TMS to provide a better understanding of adaptive changes in the motor cortex after chronic RCT.

METHODS

Patients

Six right-handed men with chronic, symptomatic, full-thickness RCT on the dominant side were selected for this study. Full RCT were diagnosed preoperatively with magnetic resonance imaging. Non of these subjects reported about discomfort in the shoulder of the non-dominant side. The non-affected shoulder was examined clinically and showed no signs of a RCT. Additionally, the investigation by ultrasound showed moderate signs of tendon degeneration but no full-thickness RCT. Anteroposterior, axial and scapular view radiographs on the affected side were performed to exclude that considerable osteoarthritis of the shoulder was present. All patients had symptoms longer than 6 month before surgery and underwent a course of conservative treatment including anti-inflammatory medication and home-based physical therapy. At time of surgery, subjects ranged in age from 55 to 66 years (mean, 62.7 years; SD ± 3.8 years). No other significant neuromuscular or skeletal pathologies were present. All patients underwent an open rotator cuff repair after an antecedent diagnostic arthroscopy. On the basis of the arthroscopic findings the tear configuration was analyzed and other shoulder pathologies were excluded. During the open rotator cuff repair the tear size were measured in both the anteroposterior and the mediolateral dimension. All subjects gave their informed consent to the TMS investigation, which were approved by the local ethic committee.

Clinical assessment

Patients were assessed using the Constant-Score, non-adjusted with respect to age and the Dash-Score (5). In addition, the Waterloo Handedness Questionnaire (WHQ) (4) were examined in order to determine the degree to which hand dominance may influence the usage of the arm. The WHQ is comprised of 36 questions, which ask individuals to indicate their preferred hand for a variety of unimanual tasks. A total composite score was calculated for the subject by summing all items. Right-handers would be expected to have positive scores on the questionnaire, while left-handers were expected to have negative scores.

EMG recordings

Conventional silver/silver chloride electrodes (3 M Red Dot) were used to record the surface electromyographic (EMG) activity of MD and first dorsal interosseus muscle (FDI). For both muscles the recording electrode was mounted on the muscle belly, whereas the reference electrode was placed on a bony landmark close to target muscle (deltoid tuberosity of the humerus for MD, proximal phalanx of index finger for FDI). The surface EMG signal was amplified by a conventional electromyograph (Counterpoint, Dantec, Skovlunde, Denmark) with a bandpass filter (20 Hz to 5 kHz). The amplified signal was digitised by a laboratory computer with an analog-digital (AD)-conversion card at a sampling rate of 25 kHz per Channel.

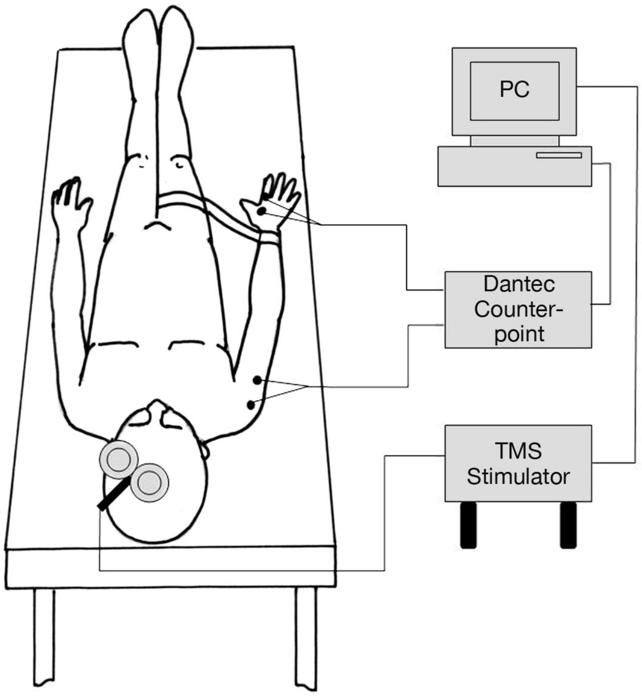

Figure 1. Experimental set-up of the study (investigation of the right, affected side). The MEP of the MD and FDI were recorded after TMS over the scalp during rest and slight voluntary activation of the MD. Voluntary effort of MD was exerted with a constant abduction of the arm against resistance (strap) in an angle of 40°.

Transcranial magnetic stimulation

A high-power Magstim 200 stimulator and a Magstim figure-of-eight-coil (PIN 9925, Magstim Co., Whitland, Wales, UK) was used to apply monophasic TMS. The coil was orientated that the induced current had a posterior-anterior direction (the handle pointing backwards). The coil was held tangentially to the skull and positioned at 45° in relation to the nasion-inion line. According to the study of Tyč et al. (27) the junction of the coil was placed over the maximal peak location of the elicited motor evoked potentials (MEP) of the MD, which was located about 2 cm in front and 3 cm left (right) of the vertex. Coil movement during the recording sessions was minimised by drawing a line on the skull which mark the optimal position of the coil. The stimulator had a remote-control interface, allowing to control the stimulus timing and stimulus strength by a laboratory computer (Fig. 1).

Experimental protocol

Patients lay in supine position and were instructed to relax as completely as possible. The order of investigation of the affected and non-affected side of the patients was randomised counterbalanced between subjects. The experimental procedure was started by estimating the resting motor threshold (RMT) of the FDI by using the maximum likelihood procedure with 15 stimuli (2). The RMT is the basic unit of TMS dosing and provides a non-invasive global index of cortical excitability of a target muscle. Determining the correct RMT is important for determining the proper TMS dose for each subject and also is important with respect to safety. The RMT is then defined as the TMS stimulus strength at which the response (the elicited motor evoked potentials, MEP) probability equals 0.5. The threshold determination of FDI was used for a proper modulation of stimulus intensities in the following stimulus-response experiments of the MD, because the muscle responses to corticospinal inputs generated by TMS in proximal muscles are generally more difficult to elicit than in distal muscles (24). Furthermore, FDI and MD have overlapping central muscle representations, suggesting co-ordination in control of these muscles (6). After RMT determination, the stimulus-response experiment was conducted the evaluation of the MEP of the medial division of the MD and the FDI of the affected and the non-affected side of the subjects after transcranial magnetic stimulation of the motor cortex on both hemispheres. The relationship between the increased magnetic stimulus intensity and rise in the evoked MEP can be distinguished in stimulus response curves (or input – output curves, I / O curves). The progression of the I / O curves offers an information about the cortico-spinal excitability of a given motor representation (22, 23). These I / O curves can be estimated under resting condition as well as under a well defined voluntary activation of the target muscle (the so called „facilitation"). These facilitation leads under physiological conditions to an increased neuronal (corticospinal) excitability and thus to a clear increase of the MEP amplitude and shortening of the MEP latency by a central stimulation (13). The subjects received 5 single stimuli at 4 different stimulus levels. The magnetic stimulus intensity at each stimulus level (expressed in percentage of the maximum stimulator output) increased from the threshold value in 5% steps up to 15% above the estimated threshold value. The order of application of these 25 stimuli and the interstimulus interval (distributed between 9 and 11 s) was randomised by the laboratory computer. The 5 evoked MEP at the 4 different stimulus levels were averaged and stored for analysis. Mappings for MD and FDI were done during rest and low -level muscular activity of the MD in slight voluntary abduction of the shoulder against resistance. The patients were examined 1 day prior to surgery.

Statistical analysis

Analysis of variance for repeated measures was performed to compare the excitability of MD and FDI on the affected and non-affected side of the patients. The innersubject factors were stimulus strength (4 Levels), task (rest, activity of MD) and side (affected, non-affected). Regression analysis was performed of MEP of the MD and FDI on both sides at each stimulus intensity and the Spearman's rank coefficient of correlation was calculated. A significance level less than 0.05 was assumed. We used SPSS statistical software, version 12.0, for Windows, for all calculations. Unless specified otherwise, results are given as mean ± standard deviation.

Table 1. Mean MEP amplitudes of the deltoid muscle (MD) and first dorsal interosseus muscle (FDI) of the affected and non-affected side of the patients during rest (Session 1) and low -level muscular activity of the MD in slight voluntary abduction of the shoulder against resistance (session 2) after TMS at 4 different stimuli levels (RMT, RMT ± increasing magnetic stimulus intensities given in % of the stimulator output).

		MD		FDI	
		Affected (µV)	Non-Affected (µV)	Affected (µV)	Non-Affected (µV)
Session 1	RMT	3.1 ± 3.8	24.0 ± 11.1	33.3 ± 21.6	56.0 ± 61.8
	RMT + 5 %	15.6 ± 4.4	30.0 ± 28.7	168.6 ± 124.9	404.6 ± 614.5
	RMT + 10 %	17.2 ± 8.9	67.0 ± 73.9	543.4 ± 518.4	640.4 ± 630.6
	RMT + 15 %	41.2 ± 26.9	93.7 ± 65.2	1037.4 ± 986.8	1583.2 ± 1310.9
Session 2	RMT	152.2 ± 82.1	310.4 ± 175.7	43.8 v 44.8	97.7 ± 107.5
	RMT + 5 %	184.6 ± 87.97	384.6 ± 280.6	112.1 ± 125.6	338.7 ± 240.1
	RMT + 10 %	228.7 ± 106.7	557.6 ± 387.2	349.8 ± 308.2	730.6 ± 405.1
	RMT + 15 %	298.8 ± 216.3	786.6 ± 477.4	828.0 ± 614.6	1417.5 ± 656.6

Data are given as mean standard deviation. (µV = Microvolt, RMT = resting motor threshold, MEP = motor-evoked potentials)

RESULTS

Clinical assessment

Before surgery, the Constant-Score of the subjects ranged from 20 to 49 points (mean, 34.8 points, SD ± 10.8 points), the WHQ score ranged from 22 to 53 points (mean, 40.5 points, SD ± 11.9 points) and the Dash-Score ranged from 19.1 to 62.5 points (mean, 46.3 points, SD ± 17.2 points).

The intraoperative evaluation of location and size of the rotator cuff tear showed that in all subjects the rotator cuff tears were located in the supraspinatus- and / or infraspinatus-tendon and the size of the defect ranged from 4 to 9 cm^2 (mean, 6.3 cm2; SD ± 2.7 cm^2).

Stimulus response experiments

The data of the MEP obtained from the MD and FDI on both sides during rest and slight voluntary activation of the MD are summarized in Table 1.

The results of the stimulus response experiments shows that there is a strong correlation between the increase in stimulus intensity and the rise in MEP amplitudes for MD ($F = 14.5$, $P < 0.001$) and FDI ($F = 17.\ 6$, $P < 0.001$) on both sides.

Furthermore, the EMG recordings demonstrated a facilitation of the elicited MEP of the MD during voluntary activation of the MD on both sides ($F = 19.8$, $P = 0.007$). On the other hand, we could not detect a significant influence of MD activation on the MEP of the FDI ($F = 0.18$, $P = 0.685$).

The pre-stimulus muscle activation of the MD of the affected and non-affected side shows no significant dif-

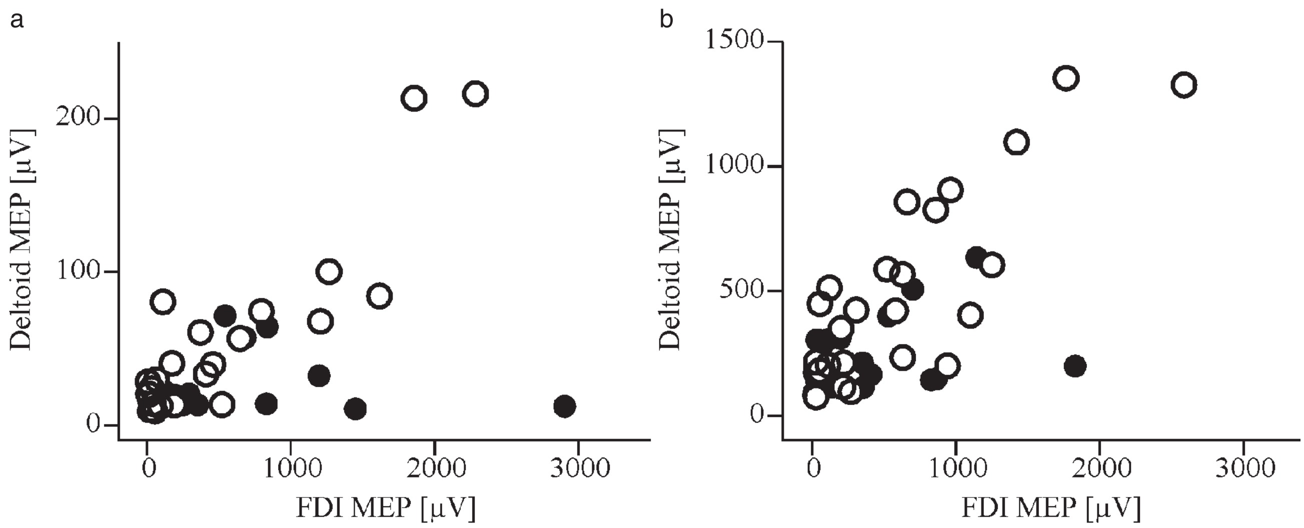

Figure 2. Relationship between the elicited MEP of the MD to the correspondent MEP of the FDI at rest (Fig. 2 a) and during slight activation of the MD (Fig. 2 b) of the affected (filled circles) and non-affected side (open circles) of the patients.

ference before the beginning of the stimulus response experiments at rest (F = 3.07, P = 0.14) as well as before session 2 with slight voluntary activation of the MD (F = 2.6, P = 0.166).

Additionally, we found a significant 3-way interaction between TMS stimulus intensity, task (MD at rest, MD activity) and side for MEP of the MD (F = 3.9, P = 0.03), which indicate that the MD of the affected side were significantly lower when compared with the non-affected side. In contrast, the stimulus – task – side interaction for the FDI MEP was not significant (F = 0.086, P = 0.966). These results suggest, that the MD of the affected side has a different behaviour as the MD of the non-affected side during activation.

Figure 2 shows the relationship of the elicited MEP of the MD to the correspondent MEP of the FDI at rest (Fig. 2a) and during slight activation of the MD (Fig. 2b) of the affected (filled circles) and non-affected side (open circles) of the patients. A strong correlation exists between the MEP of the MD and FDI on the non-affected side during rest (r = 0.5, P = 0.007) and activation (r = 0.8, P < 0.001) of the MD. In contrast, the MEP of MD and FDI on the affected side showed no correlation at rest (r = 0.1, P = 0.44) as well as in activation of the MD (r = 0.3, P = 0.05).

DISCUSSION

This study investigated the effects of chronic RCT on the neuromuscular function of the MD with TMS to provide a better understanding of central changes in the pathomechanics of chronic RCT. Measurements were performed with TMS, an established technique for the evaluation of human motor cortex (11). TMS is an non-invasive method and allows the researchers to investigate adaptive changes in the central human motoneurone system. The relationship between the MEP amplitude and stimulus intensity reflects the excitability of motor cortex and subcortical structures. In a recent study using TMS Héroux et. al. could demonstrate asymmetries at the corticomotor level in the excitability of lower limb muscles in patients with unilateral knee dysfunction due to an anterior cruciate ligament injury (12). They showed, that the resting motor threshold of the quadriceps femoris muscle, which gives an information about the neuronal excitability of the muscle, was significantly reduced on the side of the injured leg.

The present study demonstrates that the cortical excitability of the MD on the affected side in patients with unilateral chronic RCT is different as compared to the non-affected side. This result needs to be emphasized because in healthy persons the cortical excitability of motoneurons show no major inter-hemispheric difference (18). Furthermore, the input-output properties of the MD on the affected side was significantly lower when compared with the non-affected side due to a 3-way interaction between stimulus intensity, side and task. Thus in contrast to often encountered descriptions of enhanced activity of the MD (15), we could show that the cortical excitability of the MD on the affected side is significantly decreased.

Especially the biomechanics of the GHJ requires a combination of high mobility with stability. The superficial shoulder muscles are responsible in the transportation and positioning of the forearm and hand in the space for several task, whereas the rotator cuff serves as a primary stabilizer of the GHJ. The motor cortex is responsible for the coordination of these multi-joint movements and the control of multiple muscle tasks. Recent anatomical and physiological studies verify the assumption that the human motor cortex controls the upper limb segments as a whole rather than the single muscles separately (25). For instance, TMS studies could demonstrated that the central recruitment of motoneurons of hand muscles is influenced by the activity of shoulder muscles or changes in static shoulder positions (7, 8). Additionally, investigations of primary motor cortex showed that distal and proximal muscles of the arm have overlapped cortical representations, suggesting co-ordination in the control of these muscles (6). Therefore, in healthy persons the pattern of MEP of muscles of the arm tend to be symmetrical between both sides .

Surprisingly, the major finding of the present study demonstrates no correlation between the MEP of the MD and FDI of the affected side during voluntary motor task. This indicates, that the physiologic movement related synergy of proximal and distal upper limb muscles are disrupted. Interestingly, on the non-affected side we could show the task dependent correlation between the activity of the FDI and MD (see fig. 2). We suggest, that the findings on the affected side have been attributed to the altered afferent input from the GHJ, which causes a central reprogramming of the cortical excitability and representation of the MD. We hypothesized, that this kind of deafferentation of the shoulder can probably attribute to a non-specific central reaction, functioning as an mechanism to prevent further joint or soft tissue damage. With respect to the pre-stimulus activity of MD, we found no differences between both sides. This indicates that the reduced MEP of the affected side is related to adaptive changes in the motor cortex as a consequence of the RCT and is not an artificial effect of the estimation procedure. Furthermore, it can be speculated that the constant pull of the MD at rest and not during activity is one responsible factor for the superior translation of the humerus head often seen in massive RCT.

A limitation of the current study is that our investigation has solely focused on the central changes of the MD and it still remains unclear if the cortical excitability of several additional shoulder muscles especially the depressors of the humeral head such as the latissimus, pectoralis major or teres major et minor muscle are influenced as well.

The recent study might have also some implication for the physical therapy (PT) in conservative treatment of several shoulder pathologies or after shoulder surgery. Our results indicate, that rehabilitation programs which base on voluntary activation of the shoulder muscles are less sufficient. It is unclear whether other modalities in PT such as biofeedback, proprioceptive training or TMS (28) have an effect on neuromuscular dysfunction of the MD. To what extent such PT influences the muscle activation remains to be investigated.

In conclusion, from the present study it seems, that chronic RCT leads to a cortico-spinal excitability alteration of the MD. Although speculative, our data suggest an involvement of central mechanisms and seem to precede severe changes of osteoarthritis of the shoulder joint such as the rotator cuff tear arthropathy. Further studies will have to prove this hypothesis and should study the role of other shoulder muscles.

ZÁVĚR

Předcházející EMG studie prokázaly, že chronická léze rotátorové manžety (RCT) může být spojena s poruchou aktivace přilehlých ramenních svalů. Efekt RCT na neuromuskulární mechanismus ovládání svalů pletence ramenního, zejména m. deltoideus, nebyla ještě podrobně studována. Naše studie zkoumala kortikospinální excitabilitu m. deltoideus kvůli zhodnocení efektu RCT na centrální neuromuskulární funkci svalů horní končetiny. U skupiny šesti mužů – praváků s chronickou symptomatickou úplnou lézí rotátorové manžety na dominantní straně byly vyšetřeny motorické evokované potenciály (MEP) v odpovědi na transkraniální magnetickou stimulaci m. deltoideus a prvního dorzálního interosálního svalu. Byly hodnoceny odpovědní krivky na stimuly ve čtyřech různých úrovních ve dvou modech zatížení m. deltoideus – v klidu a při aktivitě.

Byly nalezeny různé závislosti mezi intenzitou stimulu, mírou zátěže a snímanou stranou. Excitabilita m. deltoideus na postižené straně byla nižší vzhledem ke zdravé straně. Snížená koritiko-motoneurální excitabilita m. deltoideus na postižené straně se jeví závislá na adaptivních změnách v motorické kůře jako následek chronické RCT. Zjištěná data prokazují účast centrálních mechanismů, které předcházejí výraznější změny vývoje osteoartrózy ramena.

References

1. ABBRUZZESE, G., TROMPETTO, C.: Clinical and research methods for evaluating cortical excitability. J. Clin. Neurophysiol., 19:307–321, 2002.
2. AWISZUS, F.: TMS and threshold hunting. Suppl. Clin. Neurophysiol., 56:13–23, 2003.
3. AWISZUS, F.: Quantification of Motoneurone Pool Responses to Transcranial Magnetic Stimulation with Surface Electromyography. Biocybernetics and Biomedical Engineering, 25:3–10, 2005.
4. BRYDEN, M. P.: Measuring handedness with questionnaires. Neuropsychologia, 15:617–624, 1977.
5. CONSTANT, C. R., MURLEY, A. H.: A clinical method of functional assessment of the shoulder. Clin. Orthop., 214:160–164, 1987.
6. DEVANNE, H., CASSIM, F., ETHIER, C., BRIZZI, L., THEVENON, A., CAPADAY, C.: The comparable size and overlapping nature of upper limb distal and proximal muscle representations in the human motor cortex. Europ. J. Neurosci., 23:2467–2476, 2006.
7. DEVANNE, H., COHEN, L. G., KOUCHTIR-DEVANNE, N., CAPADAY, C.: Integrated motor cortical control of task-related muscles during pointing in humans. J. Neurophysiol., 87:3006–3017, 2002.
8. GINANNESCHI, F., DOMINICI, F., BIASELLA, A., GELLI, F., ROSSI, A.: Changes in corticomotor excitability of forearm muscles in relation to static shoulder positions. Brain Res., 1073–1074:332–8. Epub; 2006 Feb. 2.:332–338, 2006.
9. GOHLKE, F.: Biomechanics of the shoulder. Orthopäde, 29:834–844, 2000.
10. HABERMEYER, P., LEHMANN, L., LICHTENBERG, S.: Rotator cuff tears: diagnosis and therapy. Orthopäde, 29:196–208, 2000.
11. HALLETT, M.: Transcranial magnetic stimulation and the human brain. Nature, 406:147–150, 2000.
12. HEROUX, M. E., TREMBLAY, F.: Corticomotor excitability associated with unilateral knee dysfunction secondary to anterior cruciate ligament injury. Knee Surg. Sports Traumatol. Arthrosc., 2006.

13. HESS, C. W., MILLS, K. R., MURRAY, N. M.: Responses in small hand muscles from magnetic stimulation of the human brain. J. Physiol., 388:397–419, 1987.
14. HUDAK, P. L., AMADIO, P. C., BOMBARDIER, C.: Development of an upper extremity outcome measure: the DASH (disabilities of the arm, shoulder and hand) (corrected). The Upper Extremity Collaborative Group (UECG). Amer. J. Ind. Med., 29:602–608, 1996.
15. KELLY, B. T., WILLIAMS, R. J., CORDASCO, F. A., BACKUS, S. I., OTIS, J. C., WEILAND, D. E., ALTCHEK, D. W., CRAIG, E.V., WICKIEWICZ, T. L., WARREN, R. F.: Differential patterns of muscle activation in patients with symptomatic and asymptomatic rotator cuff tears. J. Shoulder Elbow Surg., 14:165–171, 2005.
16. MALCOLM, M. P., TRIGGS, W. J., LIGHT, K. E., SHECHTMAN, O., KHANDEKAR, G., GONZALEZ ROTHI, L. J.: Reliability of motor cortex transcranial magnetic stimulation in four muscle representations. Clin. Neurophysiol. 117:1037–1046, 2006.
17. MILGROM, C., SCHAFFLER, M., GILBERT, S., van HOLSBEECK, M.: Rotator-cuff changes in asymptomatic adults. The effect of age, hand dominance and gender. J. Bone Jt Surg., 77-B: 296–298, 1995.
18. MILLS, K. R., NITHI, K. A.: Corticomotor threshold to magnetic stimulation: normal values and repeatability. Muscle Nerve, 20:570–576, 1997.
19. MURRELL, G. A., WALTON, J. R.: Diagnosis of rotator cuff tears. Lancet, 357:769–770, 2001.
20. MUSIL, D., SADOVSKY, P.: Massive tears of the rotator cuff--comparison of mini-open and arthroscopic techniques. Part 2. Arthroscopic repair. Acta Chir. orthop. Traum. čech., 74:318–325, 2007.
21. NORWOOD, L. A., BARRACK, R., JACOBSON, K. E.: Clinical presentation of complete tears of the rotator cuff. J. Bone Jt Surg., 71:499–505, 1989.
22. RIDDING, M. C, ROTHWELL, J. C.: Stimulus/response curves as a method of measuring motor cortical excitability in man. Electroencephalogr. Clin. Neurophysiol. 105:340–344, 1997.
23. ROTHWELL, J. C.: Techniques and mechanisms of action of transcranial stimulation of the human motor cortex. J. Neurosci. Methods, 74:113–122, 1997.
24. ROTHWELL, J. C., THOMPSON, P. D., DAY, B. L., BOYD, S., MARSDEN, C. D.: Stimulation of the human motor cortex through the scalp. Exp. Physiol., 76:159–200, 1991.
25. SCOTT, S. H.: Role of motor cortex in coordinating multi-joint movements: is it time for a new paradigm? Can. J. Physiol. Pharmacol., 78:923–933, 2000.
26. STEENBRINK, F., De GROOT, J. H., VEEGER, H. E., MESKERS, C. G., Van De SANDE, M. A., ROZING, P. M.: Pathological muscle activation patterns in patients with massive rotator cuff tears, with and without subacromial anaesthetics. Man. Ther., 11:231–237, 2006.
27. TYC, F., BOYADJIAN, A., DEVANNE, H.: Motor cortex plasticity induced by extensive training revealed by transcranial magnetic stimulation in human. Europ. J. Neurosci., 21:259–266, 2005.
28. URBACH, D., BERTH, A., AWISZUS, F.: Effect of transcranial magnetic stimulation on voluntary activation in patients with quadriceps weakness. Muscle Nerve, 32:164–169, 2005.
29. URBANEK, L., VANECEK, V., VASEK, P., KUBELA, R.: Arthroscopic palliative resection of the rotator cuff in patients with unreconstructible lesions. Acta Chir. orthop. Traum. čech., 74:268–272, 2007.

Alexander Berth, M.D.,
Orthopädische Universitätsklinik,
Leipziger Str. 44,
39120 Magdeburg
Germany
Phone: 0049-391-6714031
Fax: 0049-391-6714029
E-mail: alexander.berth@med.ovgu.de

Acknowledgements: This research was supported by Deutsche Arthrose Hilfe e. V.