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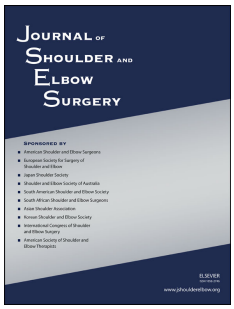

Electromyographic analysis of selected shoulder muscles during shoulder rehabilitation exercises in patients after reversed shoulder arthroplasty

Dominiek Vandenbosch, PT, MSc, Alexander Van Tongel, MD, PhD, Lieven De Wilde, MD, PhD, Ann M. Cools, PT, PhD

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Electromyographic analysis of selected shoulder muscles during shoulder rehabilitation exercises in patients after reversed shoulder arthroplasty

Running Title: EMG after shoulder arthroplasty

Dominiek Vandenbosch, PT, MSc[1,2], Alexander Van Tongel, MD, PhD[3], Lieven De Wilde, MD, PhD[3], Ann M Cools, PT, PhD[1]

[1] Department of Rehabilitation Sciences, Faculty of Medicine and Health Sciences, Ghent University, Campus UZ Gent, Corneel Heymanslaan 10, B3, entrance 46, 9000 Ghent, Belgium

[2] Department of Physical Health and Rehabilitation, Ghent University Hospital, C Heymanslaan 10, 9000 Ghent, Belgium

[3] Department of Orthopaedic Surgery and Traumatology, Ghent University Hospital, C Heymanslaan 10, 9000 Ghent, Belgium

Corresponding author: Dominiek Vandenbosch, PT, MSc, Department of Rehabilitation Sciences, Faculty of Medicine and Health Sciences, Ghent University, Campus UZ Gent, C Heymanslaan 10, B3, entrance 46, 9000 Ghent, Belgium, Dominiek.Vandenbosch@UGent.be

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Abstract 264/400

Abstract:

Background: Reversed shoulder arthroplasty (RSA) aims to restore function in patients with rotator cuff failure and joint arthropathy. After surgery, patients are routinely referred to a rehabilitation specialist to regain range of motion, strength, and function. A key element in these programs is active exercises. The exercises are often selected based on assumed muscle activity, investigated by electromyography (EMG). In particular, in this patient population, activation of the deltoid and the scapular muscles is the focus of exercise therapy. Currently, most studies investigating muscle activity levels during exercises are performed on healthy individuals. To our knowledge, no study exists analyzing EMG activity during exercises in a population of shoulder arthroplasty patients. Therefore, the study aimed to analyze activity in the shoulder girdle muscles during 6 commonly used rehabilitation exercises 12 weeks after RSA surgery.

Methods: Forty-four patients (50 shoulders) participated in this cross-sectional study, 12 weeks postoperatively (mean 99.18±12.8 days), aged 68.9±7.75 years. Surface EMG activity was measured in 10 shoulder girdle muscles: the 3 trapezius parts, serratus anterior, the 3 deltoid parts, latissimus dorsi, and 2 pectoralis major parts during 6 exercises, 3 in a closed chain, and 3 open chain elevation exercises.

Results: Gravity- minimized exercises (horizontal plane) show low activity for almost all muscles. Vertical closed kinetic chain exercises show an increased activity compared to horizontal plane exercises. Open kinetic chain exercises against gravity showed the greatest

activity in Deltoid and Upper trapezius. For the other muscles no consistency in progression was found.

Conclusion: This study offers a progression of exercises for patients after reversed shoulder arthroplasty based on increased muscle activity.

Level of evidence: Basic Science Study; Kinesiology

KEYWORDS: *shoulder, surgery, reversed, arthroplasty, EMG, rehabilitation, exercises,*

Abstract: 264/400 word

Introduction:

Reverse shoulder arthroplasty (RSA) is a frequently used procedure to resolve functional limitations in patients with massive irreparable cuff tears[21, 23, 41, 43, 46, 47], cuff tear arthropathy[21, 41, 43, 45, 54] and osteoarthritis with a deficient rotator cuff[36, 42, 59]. Besides patients with cuff disorders, RSA is also used in patients with primary osteoarthritis[21, 28, 54, 56], for revision of failed arthroplasty[1, 8, 10, 11], failed conservative or surgical treatment for fracture[2, 3, 7, 15, 16], acute fracture in the elderly[52, 57, 58]or tumor[22, 26, 32]. The reversed design allows patients to move the arm in a functional range, without the rotator cuff[12, 25]. Biomechanical principles of the RSA are a medialized center of rotation, a large glenosphere, a small humeral cup almost horizontally orientated, and lengthening of the arm, increasing tension on the deltoid[12]. After RSA, the deltoid muscle will provide both stability and function[12, 17, 24]. Additionally, strong scapular muscles are mandatory to provide proximal stability and dynamic range of motion (ROM) above 90° of elevation[6].

In vitro research by Ackland et al[4] showed an increased moment arm of the anterior deltoid (AD) and clavicular part of the pectoralis major (PMc) for forward flexion movement, both becoming

potential initiators of movement. In vivo electromyography (EMG) research[39, 40, 44, 48, 53] demonstrated that in patients with RSA the shoulder muscle activity is significantly different from normal shoulders. Most studies focus on muscle recruitment of the deltoid, as this muscle is considered the prime mover after RSA[12, 25]. However, recent research by Pelletier-Roy et al [40] demonstrated a significant contribution of the Upper Trapezius (UT) during uniplanar motions. They concluded that the UT is a main activator for all movements after RSA.

After surgery, patients are referred to a rehabilitation specialist, who selects the appropriate exercises to increase Range of Motion (ROM), strength, and function. In this time- and stage-based progressive exercise program, the patient often starts with low load closed chain exercises, such as bench- and wall-slides, because they are assumed to be easier to perform and safe during the protective phase[18], before progressing towards more functional open chain exercises such as reaching and elevation exercises[33, 37, 55]. In rehabilitation research, numerous studies have been performed on various exercises, examining muscle activity levels measured by EMG. This allows the clinician to select an exercise based on high (when the goal is strengthening) or low (when the goal is to protect a muscle from damage) EMG activity[9, 13, 19, 20]. However, most of these studies have been performed on healthy individuals. Cools et al[20] explored a progression of bench- and wall-slides with increasing activity in AD and the scapular muscles and maintaining low activity in the rotator cuff. Although this study also included an older population (up to 60 years), all participants were free of any shoulder complaint at the moment of testing, which was acknowledged as a limitation. No study exists examining muscle activity levels of the shoulder- and scapular muscles during commonly used rehabilitation exercises in the specific RSA population in the first 12 weeks after surgery. Existing studies in a RSA population explore EMG

activity only after at least 6 months[40, 48] (i.e., at the end of rehabilitation), moreover, except Cools et al [20], most studies do not use AD as the target muscle to be activated during the exercise progression. Therefore, this study aimed to explore EMG activity levels in 10 shoulder and scapular muscles at 12 weeks after surgery to identify a science-based progression for exercises based on activity levels of AD as a primary target. A secondary goal was to describe muscle recruitment in other muscles relevant for RSA patients, such as the 3 trapezius parts (Upper Trapezius (UT), Middle Trapezius (MT), Lower Trapezius (LT)), serratus anterior (SA), latissimus dorsi (LD), Pectoralis Major sternal part (PMs) and clavicular part (PMc), Middle Deltoid (MD) and Posterior Deltoid (PD).

Methods

Participants

This cross-sectional study was conducted at the Department of Rehabilitation Sciences (Faculty of Health Sciences) of Ghent University, in collaboration with the Ghent University Hospital. A single surgeon (LDW) operated on all recruited patients at Ghent University Hospital. A deltopectoral approach was used to access the joint. A Delta-Xtend prosthesis (DePuySynthes, Warsaw, IN, USA) was implanted in all patients. Following the surgeon's guidelines, patients did not use a sling to immobilize the shoulder after surgery, and active physical and occupational therapy was started on the first day after surgery. After discharge, patients were advised to use their operated arm in daily activities and to follow physical therapy 2 times/week with an emphasis on active exercise therapy. Patients were screened for eligibility during the 12 weeks of post-surgery medical follow-up at the hospital and were invited to participate if they were 55 years or older, had a primary reversed arthroplasty on one or both sides, and had an active ROM

for the elevation of at least 120°. Patients were excluded in case of revision surgery, neurological disease, known fracture or tumor in the history, anatomic arthroplasty, poor active ROM (<120° of active elevation), and in case of adverse events which could interfere with study participation, such as recurrent dislocation or fracture of acromion or humerus. The active ROM for forward flexion was measured with the EasyAngle (Meloqdevices AB, Sweden) in standing position, starting with the arm beside the trunk and extended elbow. Movements were performed bilaterally to minimize compensational movements. Patients performed a forward flexion with the arm in neutral rotational position. The EasyAngle was aligned with the lateral humerus, pointing proximal to the lateral middle point of acromion and distal to lateral epicondyle. Intra-rater reliability for the Easy-angle was found to be 0.93 (95% Confidence Interval (CI) 0,87 - 0,97), inter-rater reliability 0.82 (95% CI 0,71 - 0,95), and test-retest repeatability 0.89 (95% CI 0,63 - 0,96)[51]. Based on an a priori analysis, the power for this study was set at 80%, based on an α level of .05, resulting in a minimal total sample size of 35 to detect a between-exercise difference in muscle activity based on the largest minimal detectable change error value, and a target difference between exercises of 10% Maximal Voluntary Isometric Contraction(MVIC)[19].

Instrumentation

The skin was shaved with a disposable razor, scrubbed with a cotton ball and scrubbing gel, and cleaned with diethyl ether on a cotton ball to become an impedance of maximum five kΩ, on the areas of electrode placement. Self-adhesive circular surface electrodes (Ambu BlueSensor P – ECG electrodes; P-00-S/50) were placed, with an interelectrode distance of 1 cm, over the muscle bellies, in line with the orientation of muscle fibers. The same investigator was responsible for electrode placement, thus enhancing consistency. The SENIAM (Surface

Electromyography for the Non-invasive Assessment of Muscle) recommends surface EMG (http://www.seniam.org)[30]. For the PMs and the PMc, the electrodes were centrally placed according to Król et al [34].

MVIC recordings were performed using the Noraxon Ultium ESP 16-channel system. The EMG data during exercises was collected using the Qualisys Track Manager Software (QTM 2021.1).

Testing procedure

After consenting, a brief explanation of the MVIC measurement was provided. For this study and to allow for maximal safety during the MVIC procedure, the MVICs were performed in 7 different directions. In 6 directions, patients were seated on a chair without a backrest and had both feet on the ground with the arm in the neutral position held against the thorax. The elbow was bent, the hand held in a fist with the thumb facing upward. For the forward flexion, extension, abduction, and adduction the resistance was provided just proximal of the elbow, whereas for the external and internal rotation the resistance was given just proximal of the wrist. The 7th direction was lifting upward with extended elbow in scaption position against resistance just proximal of the wrist. Patients stood upright, the extended arm held at 90 ° elevation and 30° forward to the frontal plane and the hand in a fist (palm downward). For all MVIC recordings, a contraction for 5 sec, repeated 3 times, with a rest of 30 sec between contractions, was asked. To obtain maximal contraction, standardized encouragement was provided.

Selected Exercises

After MVIC procedure, the selected exercises were randomly performed to exclude systematic fatigue. The exercises were selected based on literature[20], and clinical experience. They

consisted of 3 closed chain (where the hand is supported on the wall or a towel or a ball), and 3 open chain exercises (where the hand is moving freely in space). All 6 exercises are described in Table 1 and illustrated in Figures 1 to 12. All patients randomly performed these 6 exercises while electromyographic activity was measured in 10 shoulder girdle muscles. For the closed chain exercises, the patients used a hand-held massage ball (Kaytan Sports, Amazon.com), facilitating gliding on the bench and wall. For the Seated Bench Slide with Resistance (BSTB), a red TheraBand (Hygenic Corp., Akron, OH, USA) with standardized initial length and tension for all patients was used. Each exercise was performed 5 times, with a rest between repetitions of 30 seconds. All exercises had the same time format of 4 seconds of (recorded) rest, 4-second concentric phase, 1-second hold, and 4 seconds to return to the starting position, thus making comparison between exercises and patients possible. In between each type of exercise, a longer rest period of 3 minutes was held. All exercises started with the upper arm in a neutral position along the trunk and had a maximal ROM of 120°. Before testing, a stop marker was placed on the bench, the wall, or an external pole to mark 120°.

<Table 1 around here>

Signal processing and data analysis

MVIC and exercise recordings were processed using the MyoResearch software (Noraxon MR3 3.18.18). First, an electrocardiogram reduction (manually selected interval), a full wave rectification, and a signal smoothing with a Root Mean Square (RMS) algorithm of a 100 ms window were performed for the EMG recordings of MVIC and exercises. The mean MVIC for each muscle was calculated based on the middle 3 seconds-window analysis of all tested directions[14]. The MVIC value of each muscle, used to normalize the EMG signal (100%), was the highest average mean of the 7 tested directions. A marker was placed manually for the

exercises at the start of the movement. Across the 3 intermediate repetitions, data for each muscle and each participant were averaged. MVIC value of each muscle was used to normalize the EMG values of the exercises.

Statistical analysis

For the exercises, the average value of the middle 3 repetitions for each muscle per participant was used for further analysis. After calculating the average and standard deviations, the data were checked for normal distribution using the Shapiro-Wilk test. The data were not normally distributed, therefore, the Related Samples Friedman's Two-Way Analysis of Variance by Ranks ($p < 0.05$), with the (included) Dunn's Multiple Comparison test and Bonferroni correction for multiple testing was performed for all tested muscles and all exercises, using the Statistical Package for the Social Sciences (SPSS version 29.0.0.0; IBM Corp., Armonk, NY, USA). Besides the comparative analyses between exercises, a ranking of exercises was performed for all muscles according to increasing muscle activity in the 10 muscles of interest.

Results

Between 03/09/2021 and 03/04/2023, LDW performed 242 arthroplasty surgeries. 164 were excluded according to in- and exclusion criteria. 78 were eligible for inclusion of whom 25 did not want to participate, leaving 49 unique patients (55 shoulders). For the analysis data of 5 patients (5 shoulders) were excluded due to missing data caused by technical issues.

<Flowchart 1 around here>

EMG recordings of 44 patients (50 shoulders) were included in the final analysis. Demographics are represented in Table 2.

<Table 2 around here>

Table 3 summarizes the mean normalized values of the EMG as %MVIC for the 10 muscles and 6 exercises. The corresponding number between parentheses indicates a significant increase (<0.05) between exercises in %MVIC. The table with the exact *P* value for statistical relevance can be found in the appendix (Table 5).

<Table 3 around here>

Muscular activity levels during BS and BSTB were low for all muscles except for SA, while UT, with 19.8, nearly reaching the criteria for moderate.

Adding resistance (BSTB) to the BS only significantly increased activity for PMc and PMs. For the majority of the muscles (except PD and LD), a significant increase in activity was found comparing gravity-minimized (horizontal plane - BS and BSTB) movements with movements against gravity (vertical plane - WS and open chain exercises). Comparing closed (WS) with open (REACH, FF, SCAP) chain exercises against gravity revealed ambiguous results. Whereas for AD, MD, PD, LD, and UT, a significant increase of EMG activity occurred moving from a closed to an open chain, no significant increase was found for PMc, PMs, MT, LT and SA.

Based upon these results a progression in exercises may be described for each muscle. A ranking of the exercises based upon the increased %MVIC is represented in table 4 for each of the 10 muscles of interest.

<Table 4 around here>

Discussion

The purpose of this study was to examine EMG activity in 10 shoulder girdle muscles during 6 commonly used rehabilitation exercises in patients, 12 weeks after a RSA procedure. To our

knowledge, this is the first study analyzing EMG activity during exercises in a group of RSA patients this early in rehabilitation. The results of our study may assist the clinician in clinical reasoning and exercise choice when treating patients with RSA.

Since the deltoid is considered an extremely important muscle for stability and movement in this population[12, 17, 24], we may suggest, based on our results, that for deltoid activation, a favorable progression could be from BS over BSTB towards WS, followed by the open chain exercises. In the latter, there was no consistency regarding increasing activity between REACH, FF, and SCAP concerning the 3 deltoid muscle parts (AD, MD, PD). However, it was clear that for all scapular muscles the highest activity was found during SCAP. PMc and PMs activity on the contrary was lower during SCAP. As a physical therapist the exercises could be selected based on patients' needs.

It would be interesting to compare our EMG values with similar studies in the literature. However, comparison between studies is difficult as a result of, amongst others, different sets of exercises, different populations (age and healthy controls), and a different MVIC procedure. Gaunt et al[27] also demonstrated a significantly increasing activity for AD between gravity-minimized, upright-assisted, and active forward elevation in a healthy population. Comparing our results with the Cools et al [20] study for the 3 deltoid parts and the 4 scapular muscles during BS, BSTB, WS, and SCAP, our values are slightly higher than in the oldest age group (47-60 years) in their study. However, we must acknowledge a younger age, having no shoulder disorders, and a different method for determining MVIC values as a possible explanation for these differences. Nevertheless, the progression over the exercises with increasing activity in the muscles involved, going from BS over BSTB towards WS and open chain elevation, is similar in both studies.

Another variable to consider is the effect of the plane of movement. Whereas REACH and FF are performed in the sagittal plane, SCAP is performed in the scapular plane. Our results are inconsistent, with some muscles having the highest activity during SCAP and others performing FF or REACH. Since all movements in the Cools et al [20] study were performed in the scapular plane, we cannot compare our results with similar exercises from their study. PMc and PMs are significantly more active during FF compared to SCAP. These results are comparable to a healthy population[29] and patients with RC tears[5]. Ackland et al [4] previously demonstrated the importance of PMc as the most effective shoulder flexor (together with AD) in patients with RSA. Therefore, based on our results, for PMc activation, exercises in the sagittal plane should be preferred over the scapular plane. Also, UT becomes an important muscle after RSA[40]. In all open chain exercises in our study, UT shows a high activity (%MVIC > 40%), and a significant increase was found from BS and BSTB towards WS in a vertical plane up to 56,5%. Similar increases in UT activity from closed chain horizontal, over closed chain vertical, to open chain vertical plane, and from open chain sagittal to open chain scapular plane have previously been demonstrated [13, 20, 29, 31]. However, it is unclear what effect the UT has on their function.

The major strength of this study is the fact that we analyzed muscle activity of the shoulder girdle muscles during the early active rehabilitation stage after RSA. To our knowledge, this is the first study focusing on exercises to be performed during the first 12 weeks of rehabilitation. In addition, previous studies mainly examined open-chain exercises, whereas we also focused on closed kinetic chain exercises. Based on our results, we suggest that closed kinetic chain exercises may safely be performed in an early stage of rehabilitation from the perspective of muscle activation. Moreover, our study included a substantial sample size of 50 shoulders (44 patients), which may strengthen the value of the findings and significant differences.

However, this study has some limitations. We included only patients with RSA with active mobility up to 120° for forward flexion, as this was mandatory to perform the selected exercises. This might have biased our selection of patients with a "good" recovery after surgery and maybe not covered the total population after RSA. Moreover, in our hospital setting patients start physical therapy on day 1, which is not common in other clinical settings, however advised by the responsible shoulder surgeon (LDW). Therefore, our cohort could not be generalized to all RSA. Secondly, we did not include a control group or a control side. Our patients were tested unilaterally for several reasons. Our testing already took 2.5 hours, which is a challenge for our study population, given their age.

Moreover, the contralateral shoulder often had pathological conditions, such as a previous RSA, joint arthropathy, or documented full-thickness tears. A healthy control group was not included either as many persons at the age of 55 and more are suspected to have minor or explicit RC pathology[35, 50]. Furthermore, electrode placement for SA was challenging in female and obese participants. To optimize standardization, the same examiner always placed electrodes. We also have to acknowledge using an alternative way of measuring MVIC, which was used to provide safety. Also, in previous studies, alternative MVIC positions and procedures were selected for specific patient populations to avoid pain and discomfort[38, 49]. Activity levels never exceeded 60% MVIC for any examined muscles during the selected exercises. Although this could be considered a limitation for strengthening exercises, we want to refer to the typical elderly population in this study, in which endurance is probably more relevant than strength as a condition to perform activities in daily life. In this case, a high number of repetitions at a lower % MVIC may be preferable.

Conclusion

Our study demonstrates changes in muscle activity levels in the glenohumeral and scapulothoracic muscles during a proposed progression of closed and open-chain rehabilitation exercises. Based on our results, the exercise with in general, the lowest levels of EMG activity is the BS, and the highest levels of activity, depending on the specific muscle of interest the open chain exercises FF, REACH and SCAP.

REFERENCES

1. Abdel MP, Hattrup SJ, Sperling JW, Cofield RH, Kreofsky CR, Sanchez-Sotelo J. Revision of an unstable hemiarthroplasty or anatomical total shoulder replacement using a reverse design prosthesis. Bone Joint J 2013;95-B(5):668-72. doi:10.1302/0301-620X.95B5.30964
2. Acevedo DC, Mann T, Abboud JA, Getz C, Baumhauer JF, Voloshin I. Reverse total shoulder arthroplasty for the treatment of proximal humeral fractures: patterns of use among newly trained orthopedic surgeons. J Shoulder Elbow Surg 2014;23(9):1363-7. doi:10.1016/j.jse.2014.01.005
3. Acevedo DC, Vanbeek C, Lazarus MD, Williams GR, Abboud JA. Reverse shoulder arthroplasty for proximal humeral fractures: update on indications, technique, and results. J Shoulder Elbow Surg 2014;23(2):279-89. doi:10.1016/j.jse.2013.10.003
4. Ackland DC, Roshan-Zamir S, Richardson M, Pandy MG. Moment arms of the shoulder musculature after reverse total shoulder arthroplasty. J Bone Joint Surg Am 2010;92(5):1221-30. doi:10.2106/JBJS.I.00001
5. Alenabi T, Dal Maso F, Tétreault P, Begon M. The effects of plane and arc of elevation on electromyography of shoulder musculature in patients with rotator cuff tears. Clin Biomech (Bristol, Avon) 2016;32:194-200. doi:10.1016/j.clinbiomech.2015.11.011
6. Ameln DJD, Chadwick EK, Blana D, Murgia A. The Stabilizing Function of Superficial Shoulder Muscles Changes Between Single-Plane Elevation and Reaching Tasks. IEEE Trans Biomed Eng 2019;66(2):564-72. doi:10.1109/TBME.2018.2850522

7. Baudi P, Campochiaro G, Serafini F, Gazzotti G, Matino G, Rovesta C, et al. Hemiarthroplasty versus reverse shoulder arthroplasty: comparative study of functional and radiological outcomes in the treatment of acute proximal humerus fracture. Musculoskelet Surg 2014;98 Suppl 1:19-25. doi:10.1007/s12306-014-0322-3
8. Beekman PD, Katusic D, Berghs BM, Karelse A, De Wilde L. One-stage revision for patients with a chronically infected reverse total shoulder replacement. J Bone Joint Surg Br 2010;92(6):817-22. doi:10.1302/0301-620X.92B6.23045
9. Berckmans KR, Castelein B, Borms D, Parlevliet T, Cools A. Rehabilitation Exercises for Dysfunction of the Scapula: Exploration of Muscle Activity Using Fine-Wire EMG. Am J Sports Med 2021;49(10):2729-36. doi:10.1177/03635465211025002
10. Boileau P. Complications and revision of reverse total shoulder arthroplasty. Orthop Traumatol Surg Res 2016;102(1 Suppl):S33-43. doi:10.1016/j.otsr.2015.06.031
11. Boileau P, Melis B, Duperron D, Moineau G, Rumian AP, Han Y. Revision surgery of reverse shoulder arthroplasty. J Shoulder Elbow Surg 2013;22(10):1359-70. doi:10.1016/j.jse.2013.02.004
12. Boileau P, Watkinson DJ, Hatzidakis AM, Balg F. Grammont reverse prosthesis: design, rationale, and biomechanics. J Shoulder Elbow Surg 2005;14(1 Suppl S):147S-61S. doi:10.1016/j.jse.2004.10.006
13. Castelein B, Cagnie B, Parlevliet T, Cools A. Scapulothoracic muscle activity during elevation exercises measured with surface and fine wire EMG: A comparative study between patients with subacromial impingement syndrome and healthy controls. Man Ther 2016;23:33-9. doi:10.1016/j.math.2016.03.007
14. Castelein B, Cagnie B, Parlevliet T, Danneels L, Cools A. Optimal Normalization Tests for Muscle Activation of the Levator Scapulae, Pectoralis Minor, and Rhomboid Major: An Electromyography Study Using Maximum Voluntary Isometric Contractions. Arch Phys Med Rehabil 2015;96(10):1820-7. doi:10.1016/j.apmr.2015.06.004
15. Chambers L, Dines JS, Lorich DG, Dines DM. Hemiarthroplasty for proximal humerus fractures. Curr Rev Musculoskelet Med 2013;6(1):57-62. doi:10.1007/s12178-012-9152-9
16. Chivot M, Lami D, Bizzozero P, Galland A, Argenson JN. Three- and four-part displaced proximal humeral fractures in patients older than 70 years: reverse shoulder arthroplasty

or nonsurgical treatment? J Shoulder Elbow Surg 2019;28(2):252-9. doi:10.1016/j.jse.2018.07.019

17. Collin P, Matsukawa T, Denard PJ, Gain S, Lädermann A. Pre-operative factors influence the recovery of range of motion following reverse shoulder arthroplasty. Int Orthop 2017;41(10):2135-42. doi:10.1007/s00264-017-3573-4

18. Cools A. SHOULDER REHABILITATION, A Practical Guide for the Clinician. Skribis; 2020. (ISBN No. 9789463969314)

19. Cools AM, Borms D, Cottens S, Himpe M, Meersdom S, Cagnie B. Rehabilitation Exercises for Athletes With Biceps Disorders and SLAP Lesions: A Continuum of Exercises With Increasing Loads on the Biceps. Am J Sports Med 2014;42(6):1315-22. doi:10.1177/0363546514526692

20. Cools AM, Tongel AV, Berckmans K, Spanhove V, Plaetevoet T, Rosseel J, et al. Electromyographic analysis of selected shoulder muscles during a series of exercises commonly used in patients with symptomatic degenerative rotator cuff tears. J Shoulder Elbow Surg 2020;29(10):e361-e73. doi:10.1016/j.jse.2020.03.019

21. Craig RS, Goodier H, Singh JA, Hopewell S, Rees JL. Shoulder replacement surgery for osteoarthritis and rotator cuff tear arthropathy. Cochrane Database Syst Rev 2020;4:CD012879. doi:10.1002/14651858.CD012879.pub2

22. Cundy WJ, McArthur MS, Dickinson IC, Rowell PD, Sommerville SMM. Constrained or unconstrained shoulder replacement for musculoskeletal tumor resections? J Shoulder Elbow Surg 2020;29(10):2104-10. doi:10.1016/j.jse.2020.02.006

23. Cvetanovich GL, Waterman BR, Verma NN, Romeo AA. Management of the Irreparable Rotator Cuff Tear. J Am Acad Orthop Surg 2019;27(24):909-17. doi:10.5435/JAAOS-D-18-00199

24. De Wilde L, Audenaert E, Barbaix E, Audenaert A, Soudan K. Consequences of deltoid muscle elongation on deltoid muscle performance: a computerised study. Clin Biomech (Bristol, Avon) 2002;17(7):499-505. doi:10.1016/s0268-0033(02)00065-7

25. De Wilde L, Walch G. Humeral prosthetic failure of reversed total shoulder arthroplasty: a report of three cases. J Shoulder Elbow Surg 2006;15(2):260-4. doi:10.1016/j.jse.2005.07.014

26. Dieckmann R, Liem D, Gosheger G, Henrichs MP, Höll S, Hardes J, et al. Evaluation of a reconstruction reverse shoulder for tumour surgery and tribological comparision with an anatomical shoulder arthroplasty. Int Orthop 2013;37(3):451-6. doi:10.1007/s00264-012-1771-7
27. Gaunt BW, McCluskey GM, Uhl TL. An electromyographic evaluation of subdividing active-assistive shoulder elevation exercises. Sports Health 2010;2(5):424-32. doi:10.1177/1941738110366840
28. Haritinian EG, Belgaid V, Lino T, Nové-Josserand L. Reverse versus anatomical shoulder arthroplasty in patients with intact rotator cuff. Int Orthop 2020;44(11):2395-405. doi:10.1007/s00264-020-04754-z
29. Hawkes DH, Khaiyat OA, Howard AJ, Kemp GJ, Frostick SP. Patterns of muscle coordination during dynamic glenohumeral joint elevation: An EMG study. PLoS One 2019;14(2):e0211800. doi:10.1371/journal.pone.0211800
30. Hermens HJ, Freriks B, Disselhorst-Klug C, Rau G. Development of recommendations for SEMG sensors and sensor placement procedures. J Electromyogr Kinesiol 2000;10(5):361-74.
31. Ishigaki T, Ishida T, Samukawa M, Saito H, Hirokawa M, Ezawa Y, et al. Comparing trapezius muscle activity in the different planes of shoulder elevation. J Phys Ther Sci 2015;27(5):1495-7. doi:10.1589/jpts.27.1495
32. Kaa AK, Jørgensen PH, Søjbjerg JO, Johannsen HV. Reverse shoulder replacement after resection of the proximal humerus for bone tumours. Bone Joint J 2013;95-B(11):1551-5. doi:10.1302/0301-620X.95B11.31545
33. Kibler WB, McMullen J, Uhl T. Shoulder rehabilitation strategies, guidelines, and practice. Orthop Clin North Am 2001;32(3):527-38.
34. Król H, Sobota G, Nawrat A. Effect of electrode position on EMG recording in pectoralis major. Journal of Human Kinetics 2007;17:105-12. No doi
35. Lawrence RL, Moutzouros V, Bey MJ. Asymptomatic Rotator Cuff Tears. JBJS Rev 2019;7(6):e9. doi:10.2106/JBJS.RVW.18.00149
36. Lindbloom BJ, Christmas KN, Downes K, Simon P, McLendon PB, Hess AV, et al. Is there a relationship between preoperative diagnosis and clinical outcomes in reverse

shoulder arthroplasty? An experience in 699 shoulders. J Shoulder Elbow Surg 2019;28(6S):S110-S7. doi:10.1016/j.jse.2019.04.007

37. McMullen J, Uhl TL. A kinetic chain approach for shoulder rehabilitation. J Athl Train 2000;35(3):329-37.

38. Michener LA, Sharma S, Cools AM, Timmons MK. Relative scapular muscle activity ratios are altered in subacromial pain syndrome. J Shoulder Elbow Surg 2016;25(11):1861-7. doi:10.1016/j.jse.2016.04.010

39. Pegreffi F, Pellegrini A, Paladini P, Merolla G, Belli G, Velarde PU, et al. Deltoid muscle activity in patients with reverse shoulder prosthesis at 2-year follow-up. Musculoskelet Surg 2017;101(Suppl 2):129-35. doi:10.1007/s12306-017-0516-6

40. Pelletier-Roy R, Ratté-Larouche M, Laurendeau S, Pelet S. Electromyographic and kinematic study of reverse total shoulder arthroplasty: an observational prospective cohort study. J Shoulder Elbow Surg 2021;30(1):165-71. doi:10.1016/j.jse.2020.04.053

41. Petrillo S, Longo UG, Papalia R, Denaro V. Reverse shoulder arthroplasty for massive irreparable rotator cuff tears and cuff tear arthropathy: a systematic review. Musculoskelet Surg 2017;101(2):105-12. doi:10.1007/s12306-017-0474-z

42. Raiss P, Zeifang F, Pons-Villanueva J, Smithers CJ, Loew M, Walch G. Reverse arthroplasty for osteoarthritis and rotator cuff deficiency after previous surgery for recurrent anterior shoulder instability. Int Orthop 2014;38(7):1407-13. doi:10.1007/s00264-014-2325-y

43. Ramirez MA, Ramirez J, Murthi AM. Reverse total shoulder arthroplasty for irreparable rotator cuff tears and cuff tear arthropathy. Clin Sports Med 2012;31(4):749-59. doi:10.1016/j.csm.2012.07.009

44. Rienmuller A, Maffiuletti N, Schwyzer H, Eggspuhler A. Shoulder Muscle Strength and Neuromuscular Activation 2 Years after Reverse Shoulder Prosthesis-An Experimental Case Control Study. Journal of Clinical Medicine 2020;9(2). doi:10.3390/jcm9020365

45. Rugg CM, Gallo RA, Craig EV, Feeley BT. The pathogenesis and management of cuff tear arthropathy. J Shoulder Elbow Surg 2018;27(12):2271-83. doi:10.1016/j.jse.2018.07.020

46. Schmidt CC, Jarrett CD, Brown BT. Management of rotator cuff tears. J Hand Surg Am 2015;40(2):399-408. doi:10.1016/j.jhsa.2014.06.122

47. Sellers TR, Abdelfattah A, Frankle MA. Massive Rotator Cuff Tear: When to Consider Reverse Shoulder Arthroplasty. Curr Rev Musculoskelet Med 2018;11(1):131-40. doi:10.1007/s12178-018-9467-2

48. Smith RA, Woolley K, Mazzocca A, Feinn R, Cote M, Gomlinski G, et al. Kinematics and EMG activity in Reverse Total Shoulder Arthroplasty. J Orthop 2020;22:165-9. doi:10.1016/j.jor.2020.04.017

49. Spanhove V, Calders P, Berckmans K, Palmans T, Malfait F, Cools A, et al. Electromyographic muscle activity and three-dimensional scapular kinematics in patients with multidirectional shoulder instability. Arthritis Care Res (Hoboken) 2020. doi:10.1002/acr.24525

50. Tempelhof S, Rupp S, Seil R. Age-related prevalence of rotator cuff tears in asymptomatic shoulders. J Shoulder Elbow Surg 1999;8(4):296-9.

51. Van De Velde S, Van de Vyvere C, Van Muylem A, Cools A. Measuring shoulder rotational strength and range of motion: a comprehensive intra-rater, inter-rater and test-retest reliability and validity study of several testing protocols. Ghent: Ghent University; 2019.

52. van der Merwe M, Boyle MJ, Frampton CMA, Ball CM. Reverse shoulder arthroplasty compared with hemiarthroplasty in the treatment of acute proximal humeral fractures. J Shoulder Elbow Surg 2017;26(9):1539-45. doi:10.1016/j.jse.2017.02.005

53. Walker D, Wright TW, Banks SA, Struk AM. Electromyographic analysis of reverse total shoulder arthroplasties. J Shoulder Elbow Surg 2014;23(2):166-72. doi:10.1016/j.jse.2013.05.005

54. Waterman BR, Dean RS, Naylor AJ, Otte RS, Sumner-Parilla SA, Romeo AA, et al. Comparative Clinical Outcomes of Reverse Total Shoulder Arthroplasty for Primary Cuff Tear Arthropathy Versus Severe Glenohumeral Osteoarthritis With Intact Rotator Cuff: A Matched-Cohort Analysis. J Am Acad Orthop Surg 2020;28(23):e1042-e8. doi:10.5435/JAAOS-D-19-00493

55. Wise MB, Uhl TL, Mattacola CG, Nitz AJ, Kibler WB. The effect of limb support on muscle activation during shoulder exercises. J Shoulder Elbow Surg 2004;13(6):614-20. doi:10.1016/j.jse.2004.04.006

56. Wright MA, Keener JD, Chamberlain AM. Comparison of Clinical Outcomes After Anatomic Total Shoulder Arthroplasty and Reverse Shoulder Arthroplasty in Patients 70 Years and Older With Glenohumeral Osteoarthritis and an Intact Rotator Cuff. J Am Acad Orthop Surg 2020;28(5):e222-e9. doi:10.5435/JAAOS-D-19-00166

57. Yahuaca BI, Simon P, Christmas KN, Patel S, Gorman RA, Mighell MA, et al. Acute surgical management of proximal humerus fractures: ORIF vs. hemiarthroplasty vs. reverse shoulder arthroplasty. J Shoulder Elbow Surg 2020;29(7S):S32-S40. doi:10.1016/j.jse.2019.10.012

58. Young SW, Segal BS, Turner PC, Poon PC. Comparison of functional outcomes of reverse shoulder arthroplasty versus hemiarthroplasty in the primary treatment of acute proximal humerus fracture. ANZ J Surg 2010;80(11):789-93. doi:10.1111/j.1445-2197.2010.05342.x

59. Zeman CA, Arcand MA, Cantrell JS, Skedros JG, Burkhead WZ. The rotator cuff-deficient arthritic shoulder: diagnosis and surgical management. J Am Acad Orthop Surg 1998;6(6):337-48.

List of abbreviations

AD: Anterior Deltoid

BS: Seated Bench Slide 120°

BSTB: Seated Bench Slide with Theraband Resistance (red) 120°

CI: Confidence Interval

ECG: ElectroCardioGram

EMG: ElectroMyoGraphy

FF: Standing Forward Flexion 120°

LD: Latissimus Dorsi

LT: Lower Trapezius

MD: Middle Deltoid

MT: Middle Trapezius

MVIC: Maximal Voluntary Isometric Contraction

PD: Posterior Deltoid

PMc: Pectoralis Major clavicular part

PMs: Pectoralis Major sternal part

QTM: Qualisys Track Manager Software

REACH: Standing Reach 120°

RMS: Root Mean Square

ROM: Range Of Motion

RSA: Reverse Shoulder Arthroplasty

SA: Serratus Anterior

SCAP: Standing Scaption 120°

SENIAM: Surface Electromyography for the Non-invasive Assessment of Muscle

UT: Upper Trapezius

WS: Standing Wall Slide 120°

Table list

Table 1: Description of the six selected shoulder exercise, instructions given to the patients, with illustrative picture.
BS: Seated Bench Slide 120°; BSTB: Seated Bench Slide with Theraband Resistance (red) 120°; WS: Standing Wall Slide 120°; REACH: Standing Reach 120°: FF: Standing Forward Flexion 120; SCAP: Standing Scaption 120°.

Table 2: Demographics of included patients/shoulders.
♂: male, ♀: female, Y: years, d: days, R: right-side dominant, L: left-side dominant, DS: dominant side, NDS: non-dominant side.

Table 3: EMG results for all muscles (%MVIC) and exercises with statistical differences ($p<0.05$).
UT: Upper Trapezius, MT: Middle Trapezius, LT: Lower Trapezius, LD: Latissimus Dorsi, SA: Serratus Anterior, PD: Posterior Deltoid, MD: Middle Deltoid, AD: Anterior Deltoid, PMc: Pectoralis Major clavicular part, PMs: Pectoralis Major sternal part, BS: Bench Slide, BSTB: Bensch Slide with TheraBand, WS: Wall Slide, REACH: reaching movement, FF: Forward Flexion, SCAP: scaption, (1): signifant higher to BS, (2): significant higher to BSTB, (3): significant higher to WS, (4): significant higher to REACH, (5): significant higher to FF, (6): significant higher to SCAP.

Table 4: Exercises ranked by muscle and by increasing value of %MVIC.
White: %MVIC 0-20, light grey: %MVIC 20-40, dark grey: %MVIC 40-60.

Table 5: Exact *P* values for Dunn's Multiple Comparison test with Bonferroni correction after Friedman's test, with indication of highest value when statistically significant ($p<0.05$).

UT: Upper Trapezius, MT: Middle Trapezius, LT: Lower Trapezius, LD: Latissimus Dorsi, SA: Serratus Anterior, PD: Posterior Deltoid, MD: Middle Deltoid, AD: Anterior Deltoid, PMc: Pectoralis Major clavicular part, PMs: Pectoralis Major sternal part, BS: Bench Slide, BSTB: Bench Slide with TheraBand, WS: Wall Slide, REACH: Reaching movement, FF: Forward Flexion, SCAP: Scaption, vs: versus (pairwise comparison),$^{(1)}$: BS has highest value, $^{(2)}$: BSTB

has highest value, [3]: WS has highest value, [4]: REACH has highest value, [5]: FF has highest value, [6]: SCAP has highest value

Flowchart list

Flowchart 1: Inclusion flowchart with number of in- and exclusion according to in- and exclusion criteria.

ATSA: Anatomical Total Shoulder Arthroplasty, Y: Years, ROM: Range of Motion, pt: patients

Figure list

Table 1 Description of the six selected shoulder exercises, instructions given to the patients, with illustrative picture.

Exercise (name + description)	Illustrative picture
1. Seated Bench Slide 120° (BS) Starting with elbow bent and shoulder in neutral, hand supported on handheld massage ball → Keep the hand on the ball and roll forward until fingers touch the 'stopmark' at 120° elevation, then return	<Figure 1 > <Figure 2 >
2. Seated Bench Slide with Theraband® Resistance (red) 120° (BSTB) Starting with elbow bent and shoulder in neutral, hand supported on handheld massage ball withh a Theraband® around 4 fingers → Keep the hand on the ball and roll forward until fingers touch the 'stopmarker' at 120° elevation, then return	<Figure 3> <Figure 4 >
3. Standing Wall Slide 120° (WS) Starting with the hand on a handheld massage ball against the wall and the elbow 90° flexed → Keep the hand on the ball and roll upward until fingers touch the 'stopmark' at 120° elevation, then return	<Figure 5> <Figure 6>
4. Standing Reach 120° (REACH) Starting with the shoulder in neutral, and the elbow flexed 90°, fist, thumb facing upward → perform simultaneous extension in elbow and forward flexion in shoulder until fingers touch the 'stopmark', then return	<Figure 7 > <Figure 8>

5. Standing Forward Flexion 120° (FF) Starting with the extended arm in neutral, fist, thumb facing forward → lift the extended arm in the sagittal plane until fingers touch the 'stopmark', then return	<Figure 9 > <Figure 10 >
6. Standing Scaption 120° (SCAP) Starting with the extended arm in neutral, fist, thumb facing forward → lift the extended arm in the scapular plane (30° anterior of the frontal plane) until fingers touch the 'stopmark', then return	<Figure 11> <Figure 12>

4

5

Table 2: Demographics of included patients/shoulders.

44 patients	22 ♂, 22 ♀, 40 R, 4 L
50 shoulders	26 ♂, 24 ♀, 36 DS, 14 NDS
Age	68,9 Y ± 7.7 Y (56 Y - 87 Y)
BMI	28.6 ± 4.8 (20.3 - 39.9)
Days-post operative	99.2 d ±12.8 d (77 d – 144 d)

♂: male, ♀: female, Y: years, d : days, R: right-side dominant, L: left-side dominant, DS: dominant side, NDS: non-dominant side

1 Table 3: EMG results for all muscles (%MVIC) and exercises with statistical differences ($p<0.05$) where appropriate.

	BS (1)	BSTB (2)	WS (3)	REACH (4)	FF (5)	SCAP (6)
AD	15,6±8,63	19,2±9,64	36,4±11,74 (1,2)	40,5±12,27 (1,2,3)	39,2±11,84 (1,2)	39,8±12,06 (1,2)
MD	17,8±10,02	19,3±9,54	29,2±12,21 (1,2)	34,2±12,64 (1,2,3)	36,1±17,70 (1,2,3)	39,4±14,30 (1,2,3,4,5)
PD	16,7±7,14	15,7±7,21	18,9±13,61	23,8±12,60 (1,2,3)	22,8±10,52 (1,2,3)	31,2±14,39 (1,2,3,4,5)
PMc	11,3±7,17	18,2±10,69 (1)	29,6±14,51 (1,2,6)	32,2±15,25 (1,2,6)	33,5±14,89 (1,2,6)	20,6±11,64 (1)
PMs	8,8±5,46	11,9±7,62 (1)	16,0±9,53 (1,2,6)	17,2±10,94 (1,2,6)	17,8±10,61 (1,2,6)	12,6±7,68 (1)
LD	11,7±6,94	12,0±9,18	14,5±11,78	15,7±10,37 (1,2,3,6)	15,4±10,63 (1,2,3)	14,1±10,07
UT	19,8 ± 10,48	21,0±12,73	36,5±12,85 (1,2)	40,6±13,04 (1,2,3)	40,8±14,73 (1,2)	42,9±15,97 (1,2,3)
MT	16,8±8,99	15,5±8,67	23,4±11,24 (1,2)	26,0±14,38 (1,2)	23,1±12,25 (1,2)	37,4±16,54 (1,2,3,4,5)
LT	9,6±5,59	8,5±5,72	30,4±15,13 (1,2)	30,2±14,51 (1,2)	27,3±12,59 (1,2)	34,6±11,83 (1,2,5)
SA	28,9±17,63	34,7±16,62	55,8±31,48 (1,2)	58,6±26,02 (1,2)	57,1±25,26 (1,2)	54,1±26,11 (1,2)

2

UT: Upper Trapezius, MT: Middle Trapezius, LT: Lower Trapezius, LD: Latissimus Dorsi, SA: Serratus Anterior, PD: Posterior Deltoid, MD: Middle Deltoid, AD: Anterior Deltoid, PMc: Pectoralis Major clavicular part, PMs: Pectoralis Major sternal part, BS: Bench Slide, BSTB: Bench Slide with TheraBand®, WS: Wall Slide, REACH: Reaching movement, FF: Forward Flexion, SCAP: Scaption, (1): significant higher to BS, (2): significant higher to BSTB, (3): significant higher to WS, (4): significant higher to REACH, (5): significant higher to FF, (6): significant higher to SCAP, MVIC: Maximal Voluntary Isometric Contraction, EMG: electromyography.

Table 4: Exercises ranked by increasing value of %MVIC for each muscle of interest. White: %MVIC 0-20, light grey: %MVIC 20-40, dark grey: %MVIC 40-60.

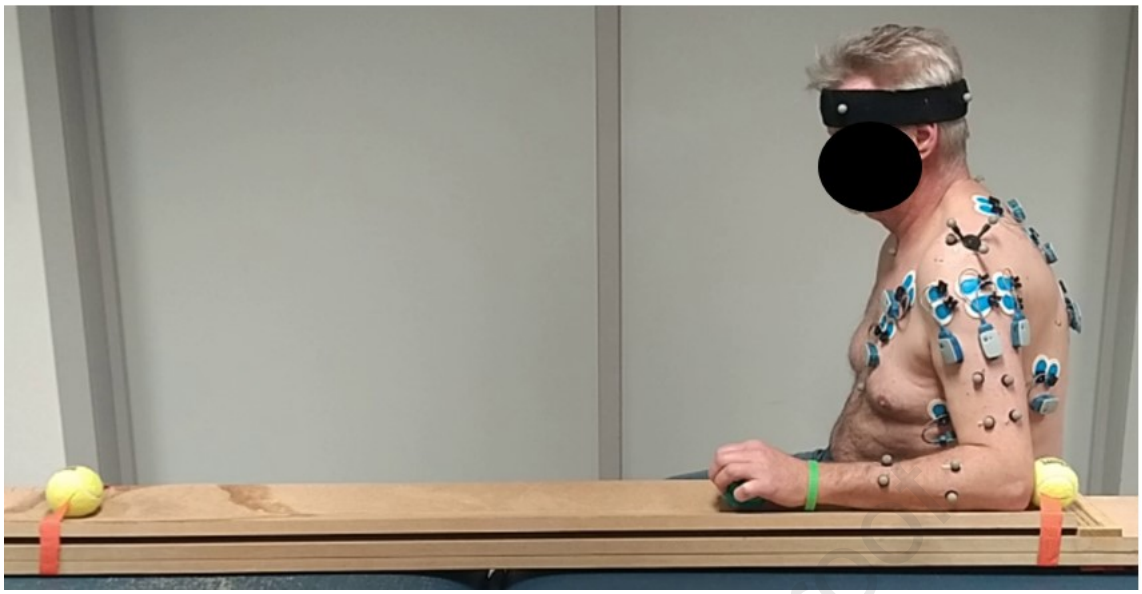
AD	BS	BSTB	WS	FF	SCAP	REACH
MD	BS	BSTB	WS	REACH	FF	SCAP
PD	BSTB	BS	WS	FF	REACH	SCAP
PMc	BS	BSTB	SCAP	WS	REACH	FF
PMs	BS	BSTB	SCAP	WS	REACH	FF
LD	BS	BSTB	SCAP	WS	FF	REACH
UT	BS	BSTB	WS	REACH	FF	SCAP
MT	BSTB	BS	FF	WS	REACH	SCAP
LT	BSTB	BS	FF	REACH	WS	SCAP
SA	BS	BSTB	SCAP	WS	FF	REACH

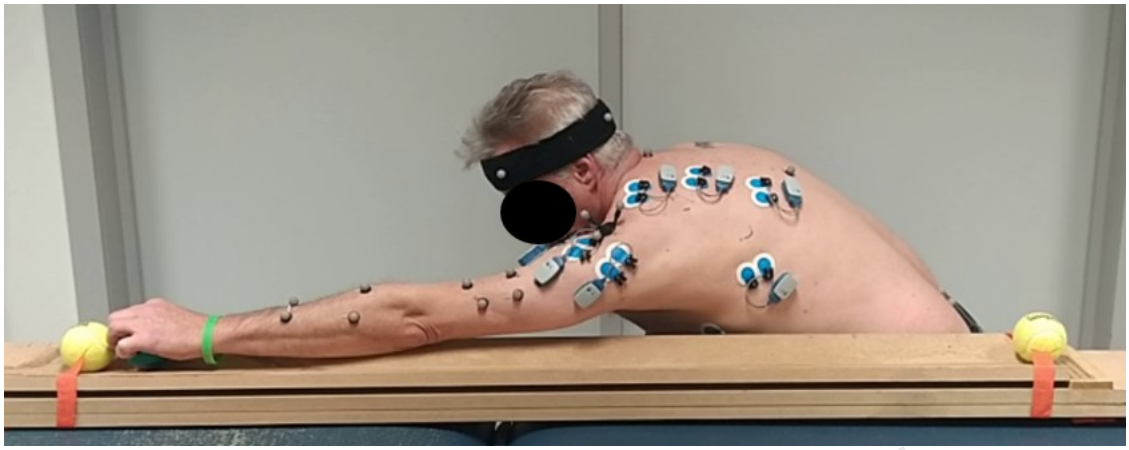
AD: Anterior Deltoid, MD: Middle Deltoid, PD: Posterior Deltoid, PMc: Pectoralis Major clavicular part, PMs: Pectoralis Major sternal part, LD: Latissimus Dorsi, UT: Upper Trapezius, MT: Middle Trapezius, LT: Lower Trapezius, SA: Serratus Anterior, BS: Bench Slide, BSTB: Bench Slide with TheraBand®, WS: Wall Slide, REACH: Reaching movement, FF: Forward Flexion, SCAP: Scaption, MVIC: Maximal Voluntary Isometric Contraction

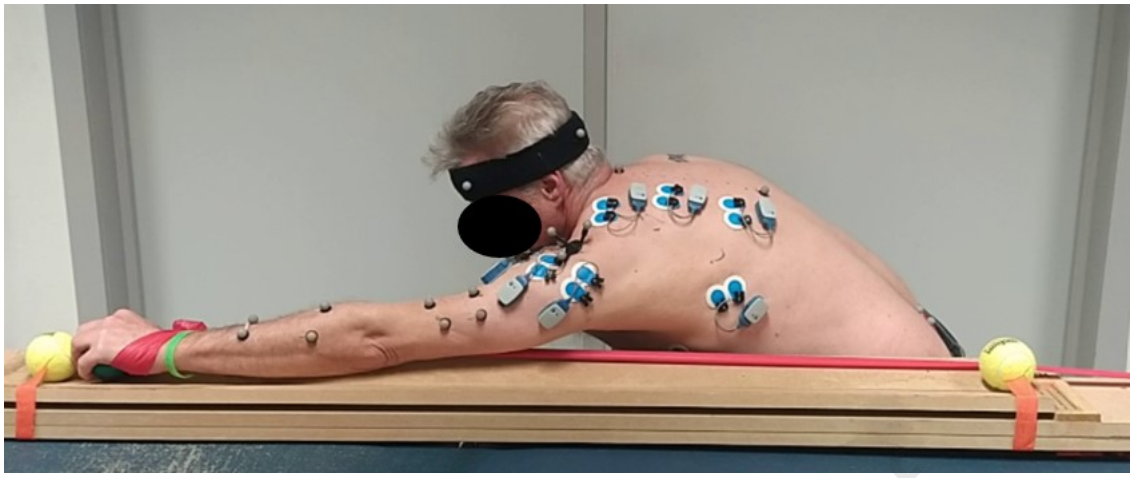
Table 5: Exact p-values for Dunn's Multiple Comparison test with Bonferroni correction after Friedman's test, with indication of highest value when statistically significant ($p<0.05$).

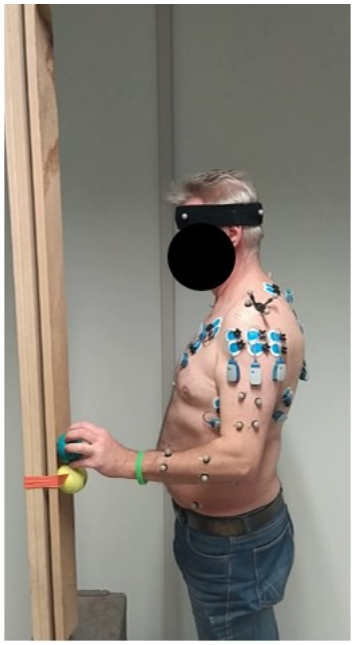
	AD	MD	PD	PMc	PMs	LD	UT	MT	LT	SA
BS vs BSTB	p=1.000	p=1.000	p=1.000	p=0.003$^{(2)}$	p=0.002$^{(2)}$	p=1.000	p=1.000	p=1.000	p=1.000	p=0.069
BS vs WS	p=0.000$^{(3)}$	p=0.001$^{(3)}$	p=1.000	p=0.000$^{(3)}$	p=0.000$^{(3)}$	p=1.000	p=0.000$^{(3)}$	p=0.006$^{(3)}$	p=0.000$^{(3)}$	p=0.000$^{(3)}$
BS vs REACH	p=0.000$^{(4)}$	p=0.000$^{(4)}$	p=0.004$^{(4)}$	p=0.000$^{(4)}$	p=0.000$^{(4)}$	p=0.000$^{(4)}$	p=0.000$^{(4)}$	p=0.000$^{(4)}$	p=0.000$^{(4)}$	p=0.000$^{(4)}$
BS vs FF	p=0.000$^{(5)}$	p=0.000$^{(5)}$	p=0.002$^{(5)}$	p=0.000$^{(5)}$	p=0.000$^{(5)}$	p=0.000$^{(5)}$	p=0.000$^{(5)}$	p=0.032$^{(5)}$	p=0.000$^{(5)}$	p=0.000$^{(5)}$
BS vs SCAP	p=0.000$^{(6)}$	p=0.000$^{(6)}$	p=0.000$^{(6)}$	p=0.000$^{(6)}$	p=0.000$^{(6)}$	p=0.104	p=0.000$^{(6)}$	p=0.000$^{(6)}$	p=0.000$^{(6)}$	p=0.000$^{(6)}$
BSTB vs WS	p=0.000$^{(3)}$	p=0.004$^{(3)}$	p=1.000	p=0.000$^{(3)}$	p=0.001$^{(3)}$	p=1.000	p=0.000$^{(3)}$	p=0.000$^{(3)}$	p=0.000$^{(3)}$	p=0.000$^{(3)}$
BSTB vs REACH	p=0.000$^{(4)}$	p=0.000$^{(4)}$	p=0.000$^{(4)}$	p=0.000$^{(4)}$	p=0.000$^{(4)}$	p=0.000$^{(4)}$	p=0.000$^{(4)}$	p=0.000$^{(4)}$	p=0.000$^{(4)}$	p=0.000$^{(4)}$
BSTBS vs FF	p=0.000$^{(5)}$	p=0.000$^{(5)}$	p=0.000$^{(5)}$	p=0.000$^{(5)}$	p=0.000$^{(5)}$	p=0.000$^{(5)}$	p=0.000$^{(5)}$	p=0.000$^{(5)}$	p=0.000$^{(5)}$	p=0.000$^{(5)}$
BSTB vs SCAP	p=0.000$^{(6)}$	p=0.000$^{(6)}$	p=0.000$^{(6)}$	p=1.000	p=1.000	p=0.089	p=0.000$^{(6)}$	p=0.000$^{(6)}$	p=0.000$^{(6)}$	p=0.000$^{(6)}$
WS vs REACH	p=0.018$^{(4)}$	p=0.009$^{(4)}$	p=0.000$^{(4)}$	p=1.000	p=1.000	p=0.000$^{(4)}$	p=0.041$^{(4)}$	p=1.000	p=1.000	p=1.000
WS vs FF	p=0.194	p=0.003$^{(5)}$	p=0.000$^{(5)}$	p=1.000	p=1.000	p=0.001$^{(5)}$	p=0.634	p=1.000	p=0.921	p=1.000
WS vs SCAP	p=0.280	p=0.000$^{(6)}$	p=0.000$^{(6)}$	p=0.000$^{(3)}$	p=0.011$^{(3)}$	p=1.000	p=0.011$^{(6)}$	p=0.000$^{(6)}$	p=0.488	p=1.000
REACH vs FF	p=1.000	p=1.000	p=1.000	p=1.000	p=1.000	p=1.000	p=1.000	p=1.000	p=1.000	p=1.000
REACH vs SCAP	p=1.000	p=0.020$^{(6)}$	p=0.000$^{(6)}$	p=0.000$^{(4)}$	p=0.000$^{(4)}$	p=0.032$^{(4)}$	p=1.000	p=0.000$^{(6)}$	p=0.242	p=1.000
FF vs SCAP	p=1.000	p=0.049$^{(6)}$	p=0.001$^{(6)}$	p=0.000$^{(5)}$	p=0.000$^{(5)}$	p=0.347	p=1.000	p=0.000$^{(6)}$	p=0.001$^{(6)}$	p=1.000

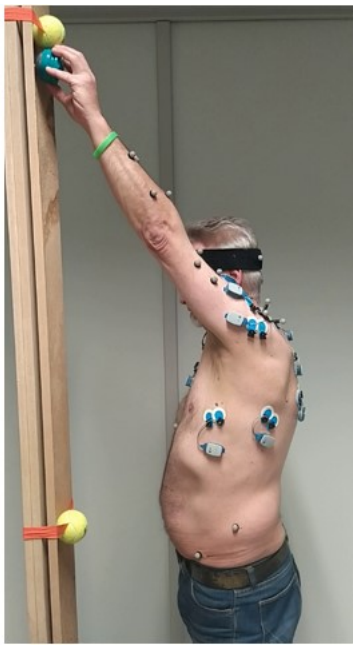
UT: Upper Trapezius, MT: Middle Trapezius, LT: Lower Trapezius, LD: Latissimus Dorsi, SA: Serratus Anterior, PD: Posterior Deltoid, MD: Middle Deltoid, AD: Anterior Deltoid, PMc: Pectoralis Major clavicular part, PMs: Pectoralis Major sternal part, BS: Bench Slide, BSTB: Bench Slide with TheraBand®, WS: Wall Slide, REACH: Reaching movement, FF: Forward Flexion, SCAP: Scaption, vs: versus (pairwise comparison),$^{(1)}$: BS has highest value, $^{(2)}$: BSTB has highest value, $^{(3)}$: WS has highest value, $^{(4)}$: REACH has highest value, $^{(5)}$: FF has highest value, $^{(6)}$: SCAP has highest value

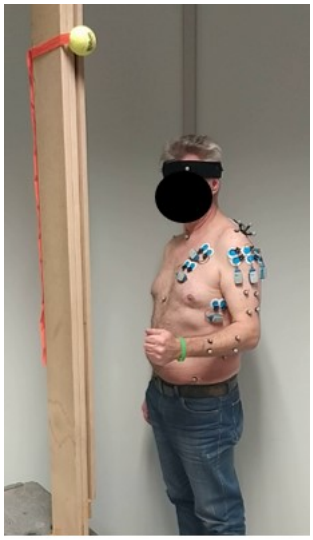


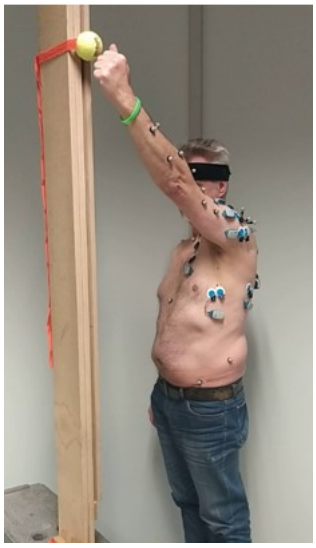


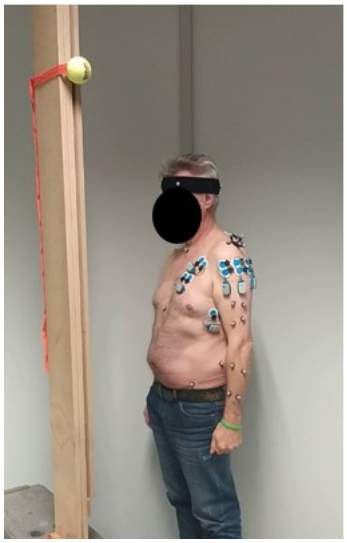


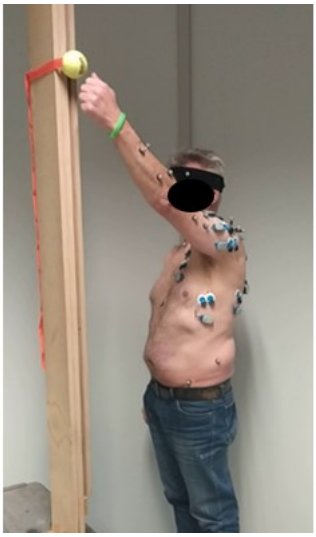


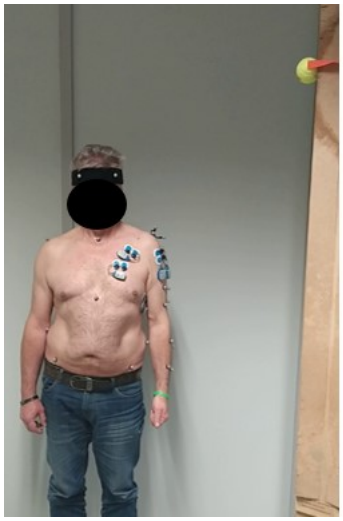


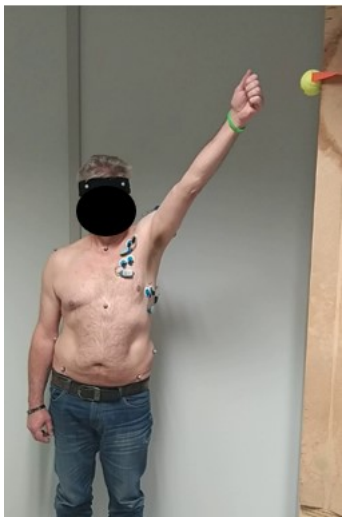




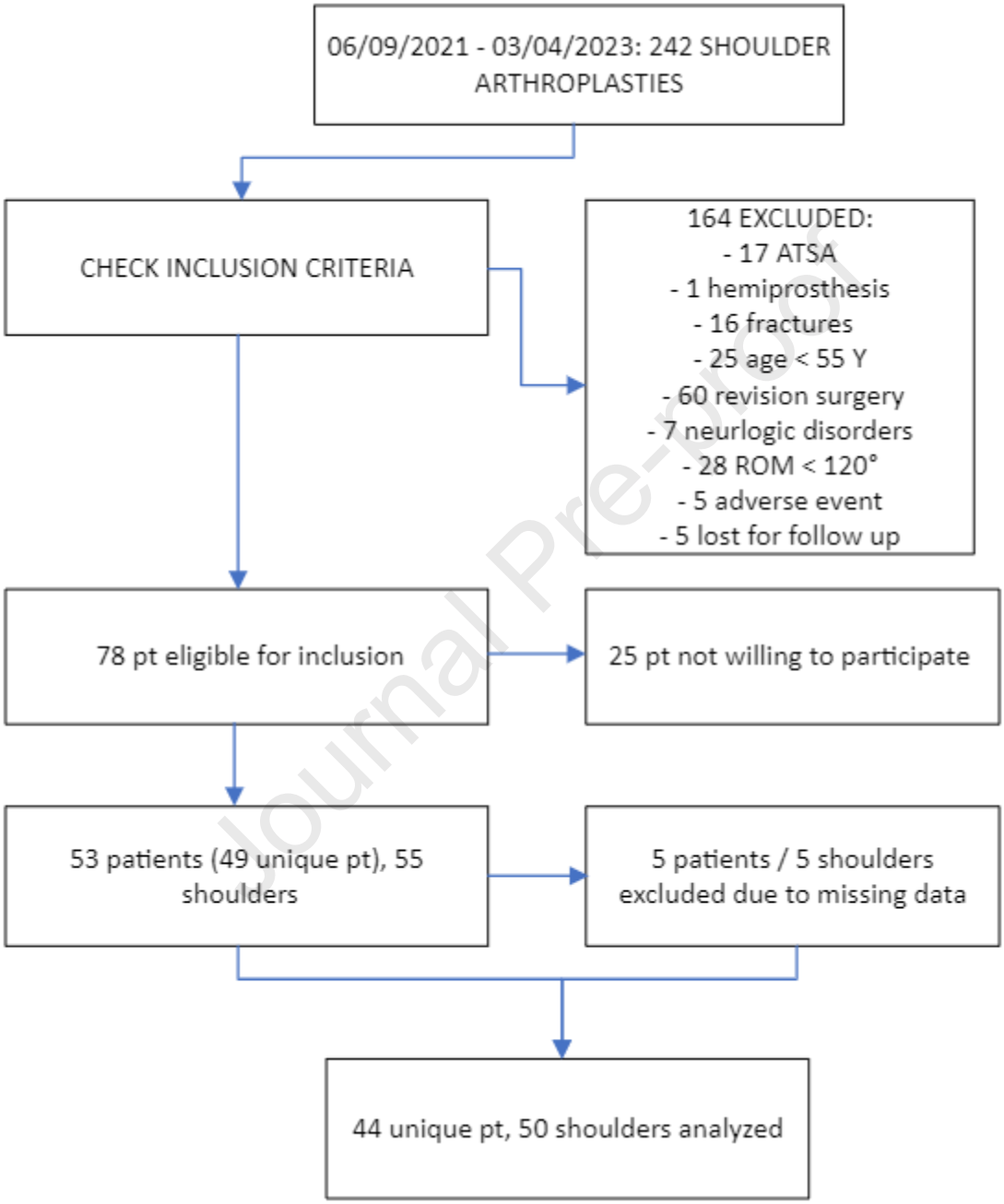








Flowchart 1: Inclusion flowchart with number of in- and exclusion according to in- and exclusioncriteria.



ATSA: Anatomical Total Shoulder Arthroplasty, Y: Years, ROM: Range of Motion, pt: patients