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Intermediate biomechanical analysis of the effect of physiotherapy only compared to capsular shift and physiotherapy in multidirectional shoulder instability

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Abstract

Purpose: The aim of study is to compare the kinematic parameters and activity pattern of muscles around the glenohumeral joint in multidirectional instability (MDI) treated by only physiotherapy and by capsular shift and physiotherapy, before and after treatment.

Materilal and method: The study was carried out on 32 patients with MDI treated with only physiotherapy (29 patients after 2 years, and 21 patients after 4 years), 19 patients with MDI treated by capsular shift and physiotherapy (19 patients after 2 and 4 years), and 50 healthy subjects as control group. The investigated kinematic parameters were the range of the humeral elevation (HE) in the scapular plane, the scapulothoracal and glenohumeral angle, the scapulothoracal (ST) and glenohumeral (GH) rhytms, and relative displacement between the rotation centers of the humerus and the scapula. The muscle activity was modeled by the on-off pattern of muscles around the shoulder.

Results: Before treatment the increased relative displacement between the rotation centers of the scapula and the humerus and different ST and GH rhythms were observed in MDI patients. The physiotherapy strengthened the rotator cuff, biceps brachii, triceps brachii, deltoid muscle, but ST and GH rhytms remained monolinear. Capsular shift and physiotherapy resulted bilinear ST and GH rhytms and normal relative displacement between the rotation center of scapula and humerus was restored. After surgery and physiotherapy the activity pattern of muscles around the shoulder was almost normal.

Conclusion: The significant alterations in kinematic parameters in MDI patients cannot be restored by physiotherapy only. After the capsular shift and postoperative physiotherapy the bilinear ST and GH rhytm (angulation at 60 degree), the normal relative displacement between the rotation centers of scapula and humerus and the normal muscular activity pattern can be restored.

Keywords: multidirectional instabiliy; shoulder joint; kinematics; physiotherapy; capsular shift; muscular activity; middle-term results

Introduction

MDI of the shoulder is a complex condition, it is characterized by symptomatic global laxity of glenohumeral joint[4,15]. It may or may not be caused by trauma, may be uni-, or bilateral. Subjects with MDI subluxate or dislocate anteriorly, posteriorly or inferiorly, with current reproduction of symptoms in at least two directions[2,18]. Most authors agree that patients with MDI initially should be treated by physiotherapy to increase the muscle strenght and coordination[1,4,16,18].

Neer and Foster in 1980 first recognized the MDI as a separate condition from unidirectional instability (frequency of MDI is undepended from the age, the sex, or physical activity)[17]. They developed the inferior capsular shift for the treatment of MDI. Nowadays if the physiotherapy is unsuccessful, the widely accepted surgical treatment is the anterior-inferior capsular shift (open or arthroscopic), followed by physiotherapy [7,13].

The aim of this study was to compare the changes in motion before and after different treatment, by kinematic and elektromyographic analyses during humerus elevation in the plane of the scapula. Three groups were investigated: the healthy control group (1), MDI patients treated with physiotherapy only ("physiotherapy group") (2) and MDI patients treated with open capsular shift followed by physiotherapy ("surgery group") (3). On the base of the previous investigation our hypothesis was that the "surgery group" is going to demonstrate better kinematic and muscle activity that is more consistent to the normal characteristics, compared to the "physiotherapy group".

Materials and methods

Patients

Thirty-two patients with MDI were treated non-surgically, by physiotherapy only (physiotherapy group), 19 patients with MDI were treated by open capsular shift followed by postoperative physiotherapy (surgery group), and 25 control subjects with normal, healthy shoulders participated the study.

The control group was tested once. The physiotherapy group was tested before starting the conservative treatment, 36 weeks, 2 and 4 years after the rehabilitation was started. The surgery group (capsular shift with postoperative physiotherapy) was tested before the surgery, 42 weeks, 2 and 4 years after surgery. Compared to the first investigation in the physiotherapy group after 2 years one patient died, other two patient (one male and one female) required surgical treatment. After 4 years additional eight patient (six male and two female) required surgery.

Anthropometric data of each group is summarized in *Table 1*.

Physiotherapy

The program[13] concentrated on proprioceptive input to improve the sense of joint position, and on relearning correct movement patterns with the development of strength and endurance in the scapulothoracic and glenohumeral muscles. Increased stability

	Control group		Physiotherapy group		Surgery group	
	Male	*Female*	*Male*	*Female*	*Male*	*Female*
Number (N)	32	18	15	12	5	9
Age (years)	28.1 ± 5.1	24.6 ± 6.12	24.5 ± 3.4	23.5 ± 4.5	26.4 ± 4.8	28.4 ± 3.6
Height (cm)	175.9 ± 14.9	168.9 ± 22.3	176.2 ± 4.7	158.4 ± 5.2	170.4 ± 6.7	165.3 ± 8.5
Mass (kg)	77.1 ± 8.4	66.1 ± 5.5	79.9 ± 2.1	58.4 ± 2.5	70.1 ± 1.7	58.4 ± 4.9
Duration of symptoms (months)	–	–	13.2 ± 2.2	12.9 ± 2.5	69.1 ± 11.5	75.9 ± 17.1

Table 1. Patient characteristics (no significant differences compared to the control group)

of muscle balance and proprioception were targeted by using strengthening exercises, closed-chain exercises, and stamina training. Home exercise program were used to promote and maintain the functional capacity of the shoulder.

Capsular shift with postoperative physiotherapy

The patients underwent Neer type antero-inferior capsular shift[17] performed by the same surgeon.The shoulder was immobilized by a sling for 3 weeks in tied up position. The post-operative rehabilitation program for the group began on the first postoperative day. Elbow movement and gentle pendulum exercises were allowed during the first 3 weeks. After 3 weeks assisted active elevation and gradual external rotation were allowed. After 6 weeks a maximal, pain-free external rotation position was allowed. The 36-week rehabilitation protocol was identical to the one described above.

Method of biomechanic measurement

The structure of the Zebris CMS-HS movement analysis system (Zebris, Medizintechnik GmbH, Germany) and of the measurement control software enabled us to measure changes in electric potential generated in muscles in the course of movement simultaneously with recording the kinematic characteristics of movements (without subsequent synchronization) by surface electromyography. The measurement was performed at the Biomechanical Laboratory of the Department of Applied Mechanics at the Budapest University of Technology and Economics, and Szolnok Hospital of Hungarian Railways. The detailed ultrasound-based shoulder kinematic and electromyographic measurement method is described by the same authors previously[8,9].

Assessment parameters

The range of humeral elevation (HE), scapulothoracic angle (ST), and glenohumeral angle (GH) were used for motion. For the dynamic analysis of motion, the position of the scapula and the humerus relative to each other was analyzed in terms of the relative displacement of rotation centers. The motion parameters are described in *Table 2.*

The kinematic and muscular parameters were calculated at the motion cycle where the final humerus elevation was around 80°. The number of cycles taken into account was more than 6 at all subjects.

Parameter	**Definition**
Humeral elevation (HE)	Angle formed by spatial vectors between the proximal and distal points of the sternum, and between the insertion points of deltoid muscle and radial humeral epicondyle
Range of humeral elevation	Differences in the humeral angle at initial and final positions
Scapulothoracic angle (ST)	Angle formed by spatial vectors between the proximal and distal points of the sternum, and the angulus acromialis and trigonum spinae
Range of scapulothoracic angle	Differences in the scapulothoracic angle at initial and final positions
Glenohumeral angle (GH)	Angle formed by spatial vectors between the insertion points of deltoid muscle and the radial humeral epicondyle, and the angulus acromialis and trigonum spina
Range of glenohumeral angle	Differences in the glenohumeral angle at initial and final positions
Glenohumeral rhythm	Glenohumeral angle as a function of humeral elevation
Scapulothoracic rhythm	Scapulothoracic angle as a function of humeral elevation
Relative displacement between the rotation centers of the humerus and scapula (ε_{SH})	Difference between the maximal and minimal distance of the rotation centers projected to a unit of length (calculation method is described in[16])

Table 2. Characteristic parameters describing motion patterns

The five parameters representing the bilinear regression line of a scapulothoracic and glenohumeral rhythm. The calculation method of these curves are described by the same authors previously[9,10].

Electromyographic analysis, time-based processing had to be applied and the purpose was to generate a linear cover curve to determine the motion pattern of each muscle group during movement.

Statistical analyses

Data processing was carried out using a Microsoft Excel™-based software which was developed by Illyés Á and Kiss R[9]. The average and standard deviation were calculated from the measurement results of the motion cycles. The parameters of the dominant and non-dominant shoulder were averaged (i.e., dominance was not considered).

The data were analyzed using two-factor ANOVA with one repeated measure; processing was carried out using a "Statistica" (v.7.0 StatSoft) software. Two factors were involved in these experiments: the groups and the time of observations. The factor of the groups had three levels, namely the control group, the physiotherapy group and the surgery group. The time of observations was the repeated factor, and had up to three levels: the control group was observed once, and the physiotherapy and surgery group was observed four times (before treatment, after 36-weeks physiotherapy, resp. 2 and 4 years after the rehabilitation came to an end); The post hoc comparison was made by a Student t-test for multiple comparisons. The significance level at statistical analysis (p) was set at 0.05.

Results

For the sake of transparency, the results of angular kinematics are summarized in *Figure 1* and *Figure 2*. The results of relative displacement are visible in *Figure 3* and *Figure 4.* The parameters of regression lines are shown in *Table 3. a* and *3. b,* and the p-values of different statistical comparisons in *Tables 4. a, 4. b* (in the physiotherapy and surgery group). The average regression lines of scapulothoracic and glenohumeral rhythms in the control group, before treatment, and after 2 and 4 years in each group are shown in *Figure 5.* The duration of muscle activities of each group is shown in *Figure 6.*

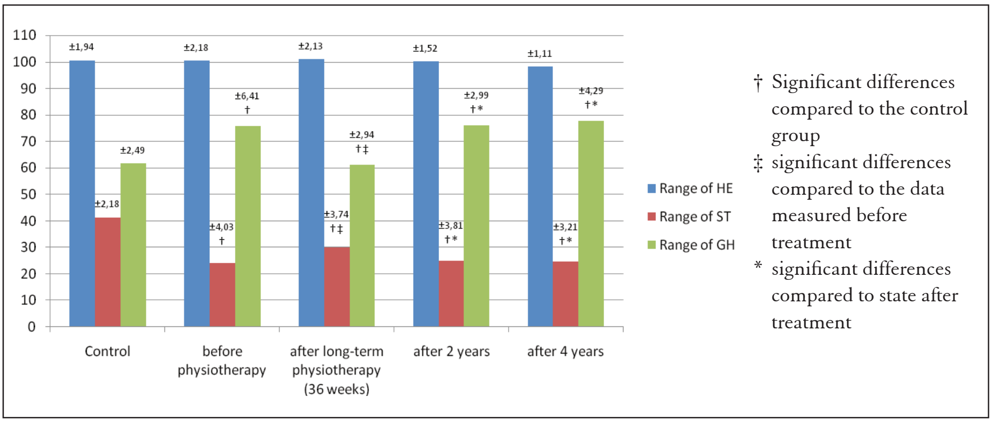

Figure 1. Range of humeral elevation (HE), scapulothoracic angle (ST) and glenohumeral angle (GH) for **physiotherapy group** at different observation times, with the standard deviation values

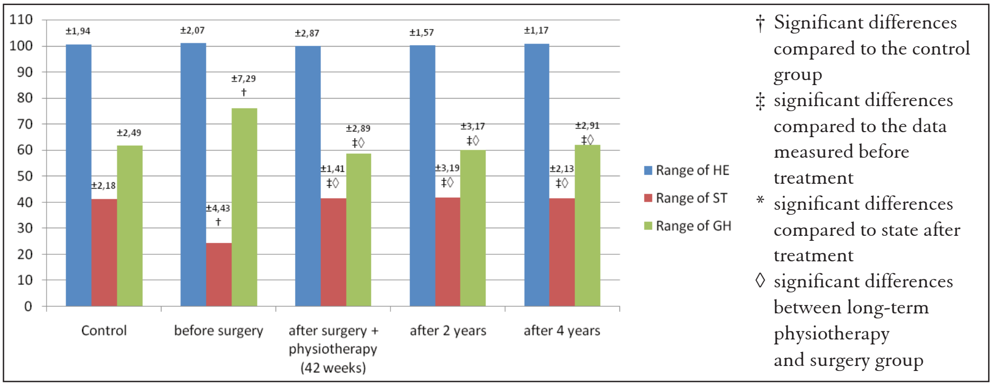

Figure 2. Range of humeral elevation (HE), scapulothoracic angle (ST) and glenohumeral angle (GH) for **surgery group** at different observation times, with the standard deviation values

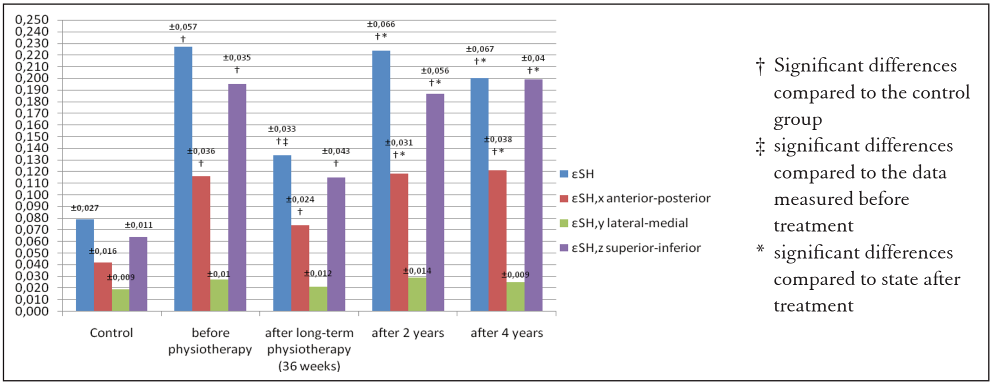

Figure 3. Relative displacement (ε_{SH}) and components in directions X, Y, and z of the relative displacement (ε_{SH}) between the rotation centers of the scapula and humerus for **physiotherapy group** at different observation times, with the standard deviation values

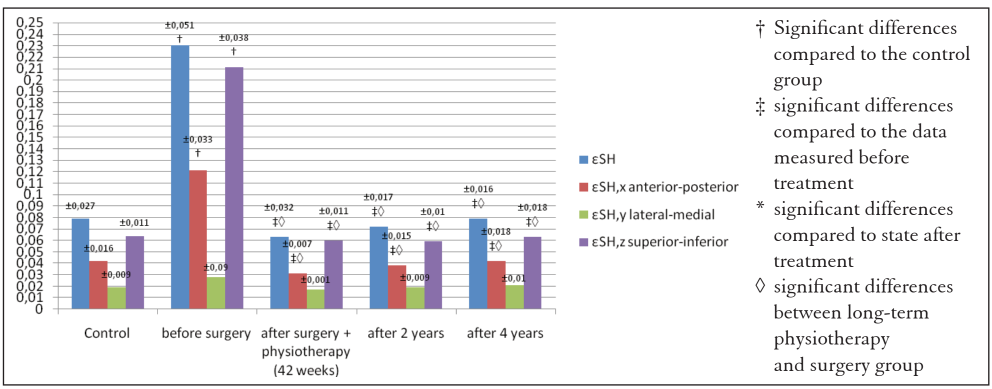

Figure 4. Relative displacement (ε_{SH}) and components in directions X, Y, and z of the relative displacement (ε_{SH}) between the rotation centers of the scapula and humerus for **surgery group** at different observation times, with the standard deviation values

Parameters			Control group	Physiotherapy group			
				before physiotherapy	*after long-term physiotherapy*	*after 2 years*	*after 4 years*
			mean ± SD	mean ± SD	mean ± SD	mean ± SD	mean ± SD
scapulothoracic rthym	until the intersection	m_{ST}	0.303 ± 0.015	0.248 ± 0.023†	0.299 ± 0.024‡	0.252±0.022†,*	0.246 ± 0.029†,*
		b_{ST}	75.08 ± 1.04	98.78 ± 2.15†	81.23 ± 2.11†,‡	99.01 ± 2.18†,*	99.10 ± 2.58†,*
	humeral elevation at intersection		59.87 ± 0.35				
	over the intersection	m_{ST}	0.557 ± 0.025				
		b_{ST}	59.95 ± 0.85				
glenohumeral rthym	until the intersection	m_{GH}	0.673 ± 0.021	0.759 ± 0.037†	0.612 ± 0.027‡	0.761 ± 0.040†,*	0.777 ± 0.042†,*
		b_{GH}	86.86 ± 1.68	57.98 ± 2.19†	60.17 ± 1.88‡	58.15 ± 2.22†,*	56.18 ± 2.49†,*
	humeral elevation at intersection		60.13 ± 0.29				
	over the intersection	m_{GH}	0.547 ± 0.018				
		b_{GH}	94.49 ± 2.28				

Table 3. a Slope and intercept parameters of regression lines characterizing scapulothoracic and glenohumeral rhythms for physiotherapy group at different observation times.

m_{ST}: slope of regression line of scapulothoracic rhythm; m_{GH}: slope of regression line of glenohumeral rhythm; b_{ST}: y-intercept of regression line of scapulothoracic rhythm; b_{GH}: y-intercept of regression line of glenohumeral rhythm; The linear regression line characterized by two parameters (slope and intercept), the other three parameters (humeral elevation in intersection, slope and intercept over the intersection) shown as a blank cell. † Significant differences compared to the control group, ‡ significant differences compared to the state before treatment, * significant differences compared to the state after treatment

Parameters			Control group	Surgery group			
				before surgery	*after surgery + physio.*	*after 2 years*	*after 4 years*
			mean ± SD	mean ± SD	mean ± SD	mean ± SD	mean ± SD
scapulothoracic rthym	until the intersection	m_{ST}	0.303 ± 0.015	0.244 ± 0.028†	0.308 ± 0.020‡	0.307±0.018‡,◊	0.305±0.12‡,◊
		b_{ST}	75.08 ± 1.04	99.14 ± 1.99†	73.22 ± 2.27‡,◊	74.15±1.97‡,◊	75.15±0.98‡,◊
	humeral elevation at intersection		59.87 ± 0.35		60.03 ± 0.72	58.87±0.55	60.10±0.44
	over the intersection	m_{ST}	0.557 ± 0.025		0.535 ± 0.027	0.547±0.023	0.558±0.024
		b_{ST}	59.95 ± 0.85		60.19 ± 0.61	60.02±0.67	59.88±0.74
glenohumeral rthym	until the intersection	m_{GH}	0.673 ± 0.021	0.761 ± 0.040†	0.683 ± 0.029‡,◊	0.679±0.028‡,◊	0.677±0.018‡,◊
		b_{GH}	86.86 ± 1.68	56.12 ± 1.69†	87.87 ± 2.14‡,◊	87.15±1.95‡,◊	86.75±1.12‡,◊
	humeral elevation at intersection		60.13 ± 0.29		59.69 ± 1.07	60.01±0.87	60.69±0.20
	over the intersection	m_{GH}	0.547 ± 0.018		0.550 ± 0.024	0.549±0.024	0.548±0.019
		b_{GH}	94.49 ± 2.28		92.28 ± 2.97	94.96±2.17	94.58±2.31

Table 3. b Slope and intercept parameters of regression lines characterizing scapulothoracic and glenohumeral rhythms for surgery group at different observation times.

m_{ST}: slope of regression line of scapulothoracic rhythm; m_{GH}: slope of regression line of glenohumeral rhythm; b_{ST}: y-intercept of regression line of scapulothoracic rhythm; b_{GH}: y-intercept of regression line of glenohumeral rhythm; The linear regression line characterized by two parameters (slope and intercept), the other three parameters (humeral elevation in intersection, slope and intercept over the intersection) shown as a blank cell. † Significant differences compared to the control group, ‡ significant differences compared to the state before treatment, * significant differences compared to the state after treatment, ◊ significant differences between physiotherapy and surgery group

	Parameters		**Physiotherapy group**			
			before physio-therapy	*after long-term physio-therapy*	*after 2 years*	*after 4 years*
	Range of HE		0.602	0.605	0.588	0.495
	Range of ST		0.005	0.016	0.008	0.004
	Range of GH		0.004	0.037	0.027	0.006
Relative displacement	ε_{SH}		<0.001	0.003	0.002	<0.001
Relative displacement	$\varepsilon_{SH,x}$ *anterior-posterior*		0.003	0.014	0.008	0.001
Relative displacement	$\varepsilon_{SH,y}$ *lateral-medial*		0.654	0.652	0.657	0.581
Relative displacement	$\varepsilon_{SH,z}$ *superior-inferior*		0.001	0.009	0.004	0.001
ST and GH rhythm	*until the intersection*	m_{ST}	0.014	0.054	0.035	0.028
ST and GH rhythm	*until the intersection*	b_{ST}	0.004	0.041	0.005	0.002
ST and GH rhythm	*humeral elevation at intersection*					
ST and GH rhythm	*over the intersection*	m_{ST}				
ST and GH rhythm	*over the intersection*	b_{ST}				
ST and GH rhythm	*until the intersection*	m_{GH}	0.003	0.018	0.007	0.004
ST and GH rhythm	*until the intersection*	b_{GH}	0.001	0.002	0.001	<0.001
ST and GH rhythm	*humeral elevation at intersection*					
ST and GH rhythm	*over the intersection*	m_{GH}				
ST and GH rhythm	*over the intersection*	b_{GH}				
on-off pattern of muscles	*m. deltoideus anterior*		<0.001	0.14	0.005	<0.001
on-off pattern of muscles	*m. deltoideus medius*		<0.001	0.12	0.06	<0.001
on-off pattern of muscles	*m. deltoideus posterior*		0.009	0.004	0.008	0.007
on-off pattern of muscles	*m. supraspinatus*		<0.001	0.001	<0.001	<0.001
on-off pattern of muscles	*m. infraspinatus*		<0.001	<0.001	<0.001	<0.001
on-off pattern of muscles	*m. biceps brachii*		<0.001	0.04	0.003	<0.001
on-off pattern of muscles	*m. triceps brachii*		<0.001	0.008	0.002	<0.001

Table 4. a P-values of difference in biomechanical parameters between the physiotherapy group and the control group

	Parameters		**Surgery group**			
			before surgery	*after surgery + physio.*	*after 2 years*	*after 4 years*
	Range of HE		0.602	0.592	0.588	0.645
	Range of ST		0.006	0.271	0.288	0.228
	Range of GH		0.004	0.225	0.256	0.267
Relative displacement	ε_{SH}		<0.001	0.283	0.274	0.214
Relative displacement	$\varepsilon_{SH,x}$ *anterior-posterior*		0.003	0.333	0.337	0.338
Relative displacement	$\varepsilon_{SH,y}$ *lateral-medial*		0.654	0.681	0.701	0.707
Relative displacement	$\varepsilon_{SH,z}$ *superior-inferior*		0.001	0.367	0.333	0.398
ST and GH rhythm	*until the intersection*	m_{ST}	0.014	0.294	0.301	0.299
ST and GH rhythm	*until the intersection*	b_{ST}	0.004	0.265	0.308	0.278
ST and GH rhythm	*humeral elevation at intersection*			0.346	0.348	0.347
ST and GH rhythm	*over the intersection*	m_{ST}		0.319	0.321	0.328
ST and GH rhythm	*over the intersection*	b_{ST}		0.279	0.288	0.293
ST and GH rhythm	*until the intersection*	m_{GH}	0.003	0.311	0.304	0.312
ST and GH rhythm	*until the intersection*	b_{GH}	0.001	0.397	0.385	0.391
ST and GH rhythm	*humeral elevation at intersection*			0.473	0.460	0.468
ST and GH rhythm	*over the intersection*	m_{GH}		0.282	0.281	0.283
ST and GH rhythm	*over the intersection*	b_{GH}		0.351	0.350	0.346
on-off pattern of muscles	*m. deltoideus anterior*		<0.001	0.136	0.147	0.151
on-off pattern of muscles	*m. deltoideus medius*		<0.001	0.125	0.131	0.126
on-off pattern of muscles	*m. deltoideus posterior*		0.009	<0.001	0.001	0.002
on-off pattern of muscles	*m. supraspinatus*		<0.001	0.24	0.21	0.19
on-off pattern of muscles	*m. infraspinatus*		<0.001	<0.001	<0.001	<0.001
on-off pattern of muscles	*m. biceps brachii*		<0.001	0.35	0.39	0.37
on-off pattern of muscles	*m. triceps brachii*		<0.001	0.41	0.34	0.26

Table 4. b P-values of difference in biomechanical parameters between the surgery group and the control group

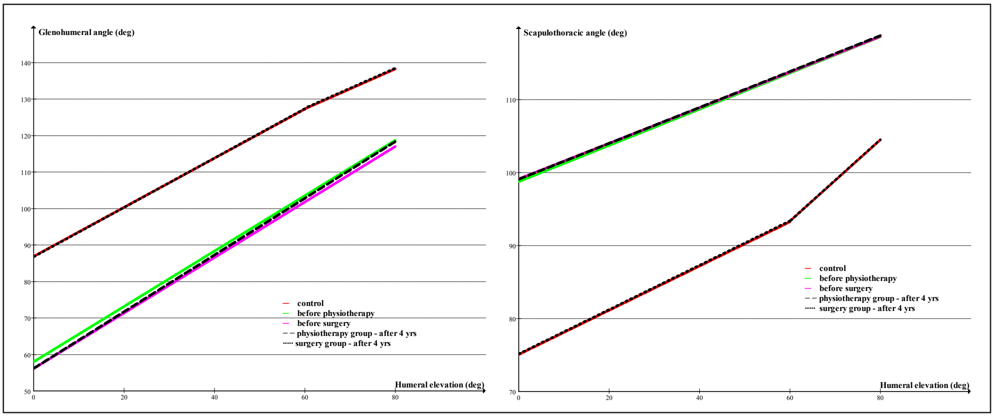

Figure 5. The average of regression lines of glenohumeral and scapulothoracic rhythms in the control group, before treatment and after 4 years in the physiotherapy and surgery group

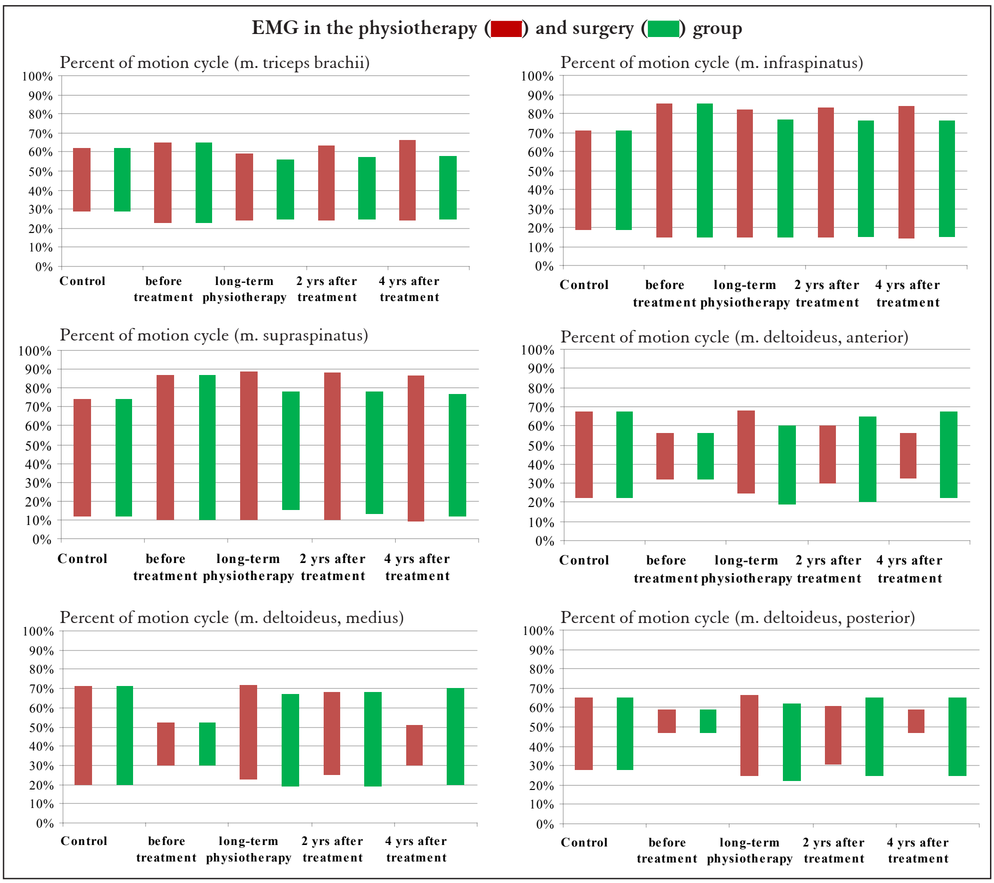

Figure 6. The on-off patterns of muscle activity generated by normalization with modified muscle contraction during elevation in the physiotherapy and surgery group at different times

Discussion

The investigated motion (elevation in the scapular plane) was continuous (motion was not stopped for recording the position of different anatomic points), so we determined potential changes in the motion pattern of skeletal elements and changes in muscle activity. The motion pattern of skeletal elements was characterized by kinematic parameters: range of HE, ST, GH, relative displacement between the rotation centers of the scapula and the humerus, and scapulothoracic and glenohumeral rhythms. The pattern of muscle activity was characterized by the on-off pattern of muscles, which modeled intramuscular coordination. Patients with MDI had significant alterations in shoulder kinematics (up to about 80° elevation) and in muscle activity compared to the controls, which is in accordance with earlier reports[1,10,11,17,18]. The ST and GH rhythms were linear and did not show angulation at 60° as in controls (where ST motion gradually takes over from GH motion during elevation), confirming the hypothesis of An and Friedman[1] and Matsen[14] *(Figure 5)*. Long-term physiotherapy only, by strengthening the rotator cuff, triceps, serratus and deltoid muscles did not restore the motion and duration of the muscular activity of the shoulder joint and at the control in the 2. and 4. years these values were near to the values measured before physiotherapy. In this investigation capsular shift and postoperative physiotherapy restored the motion and the muscular activity pattern of the shoulder joint and at the control in the 2. and 4. years the kinematic parameters approached the control group, respectively these have shown improvement compared to the end-values of the rehabilitation. Our comprehensive set of functional tests indicated that surgery with postoperative physiotherapy resolved ligamentous abnormalities by surgical treatment, and restored impaired muscular control with consequent postoperative rehabilitation, whereas physiotherapy restored muscular control only.

Conclusion

In the MDI patients observed different scapulothoracic and glenohumeral rhythms and increased relative displacement between the rotation centers of the scapula and humerus cannot be restored by physiotherapy only. After 2-4 years the on-off pattern of muscles in the physiotherapy group turns same to EMG in MDI group before treatment. Later was necessary to execute operation on some patients from this group. The duration of kinematic parameters and muscular activity also can be restored to normal after surgery with postoperative physiotherapy and after two and four years the measured biomechanic parameters are nearly similar to control group.

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