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KINEMATICS OF THE CERVICAL-THORACIC SPINE AND THE SHOULDER GIRDLE

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SUMMARY

The work is a pilot study dealing with the kinematics of the cervical-thoracic spine and the shoulder girdle. Upper limb function is linked with the function of the axial system. The muscles of the shoulder girdle are closely related to the muscles of the spine. In clinical practice the external rotators of the humerus are activated for exercise of extension of the thoracic spine. (Jelínková, 2012) This is the subject of the experiment. Kinematic analysis (Qualisys) is used for determining the position of scapula, range of motion of external humeral rotation and extension of thoracic spine. Three persons (female, age 21 years, no regular physical activity, without pathology or injury of the shoulder girdle and spine, weight 56 kg ± 3 kg, height 170 cm ± 2 cm) were recruited. The data were evaluated in the Qualisys track manager, the results are not statistically processed. The same trend was followed at all probands: during the external rotation of the humerus there is the retraction of the scapula and the extension of the upper body.

Key words: shoulder girdle, rotation of humerus, spine, kyphosis

INTRODUCTION

The shape of the axial system is well defined in frontal and transverse plane. In the sagittal plane the spine is double curved, there is the cervical and lumbar lordosis and thoracic kyphosis. What is the optimal posture in upper body? Only a few current studies describe the norm of the ideal posture in sagittal plane, like Harisson who created a new spinal model. (Harrison, 2003) The shape of the spine is not stable, but it is modulated by muscles action, breathing, nervous system… Any change to articular system immediately affects muscle function. This is described as a joint-muscle interplay by Janda. Interaction between the muscular and skeletal system is reversible, muscle loads change the shape of the spine and the shape of the spine may also influence the activity of back muscles. (Janda, 1982) These musculoskeletal interactions are studied in many fields. This work aims to evaluate the external rotation of the humerus and to determine its influence on the shape of the spine from the biomechanical point of view.

Shoulder Girdle – Anatomical and Biomechanical Point of View

Tradicional anatomical description of human shoulder girdle is that it is made up of the clavicle, scapula and the humerus as well as associated muscles, ligaments and tendons. The shoulder complex consists of four articulations: the sternoclavicular joint, the acromioclavicular joint, the glenohumeral joint and the scapulothoracic articulation. These four articulations act simultaneously to provide a greater range of motion than any individual articulation and than any other joint complex in the human body. (Lovern, 2009) Shoulder function is a compromise between mobility and stability. The stability of the joint is mainly based on active muscle control with a role of the glenohumeral capsule, labrum and ligaments. (Veeger, 2007) The most important component of the shoulder girdle is the blade, which indicates the setting of other segments of the girdle. (Štěpán, 2009) Between the blade and the trunk can be seen many flexible connection from which to characterize the potential impacts on the shape scapulothoracic region. (Véle, 1997)

The main function of the shoulder blade is the right orientation of the joint socket for optimal contact with the humeral head. The neutral anatomic position of the scapula is flat and flush on the rib cage and centered on the upper back of the rib cage, with the inside border of the scapula between 2.5 and 3 inches from the spine. The scapula lies between the second and seventh thoracic vertebra. In ideal alignment, the scapula lies directly over the posterior ribcage with the upper back in good neutrally alignment about 30° orientated with the frontal plane. (Bryan, 2003) The position of the blades is determined with the stresses exerted muscles, gravitational, frictional force and the resistance forces of other soft tissues. (Chalupová, 2004)

From biomechanical point of view the shoulder joint includes 4 fixed parts (thorax, clavicle, scapula, humerus), 16 muscles, 3 joints and scapulothoracic connection. Each of the joints has 3 degrees of freedom (DOF) in the shoulder girdle. For four joints it is $4 \times 3 = 12$ DOF. The clavicle and scapula act together during some movements. The result is 7 DOF for the arm, 4 DOF for the shoulder girdle and 3 DOF for the shoulder joint. When comparing the size of muscle strength during the movements of the shoulder the highest values are for adductors and the least values are for external rotators. (Janura, 2004)

Architectonics of the muscle affects the muscle function. Muscle force is proportional to the physiological cross-sectional area (PCSA). PCSA is the sum of all cross-sections of muscle fibers, gives the muscle capacity to generate power and is given by

$$\mathbf{PCSA = (M \times \cos\theta)/(\rho \times L_f),}$$

where ρ is density of muscle in formalin 1.055 g/cm^3, M mass of muscle, θ angle of pennation, L_f length of muscle fibers. The inner rotators are longer than the outer rotators in fiber length and values of PSCA. (Altobelli, 2005)

Table 1. Values PSCA and L_f for muscles of shoulder girdle. Source image (Altobelli, 2005)

Muscles of shoulder girdle	PSCA [cm^2]	Length of muscle fibers [mm]
Internal rotators	12	109
External rotators	8	74
Scapulothoracic	7	111
Glenohumeral	12	91

If the movement of the upper limbs is applied to the axial system, the thoracic vertebra is the final segment of the kinematic chain: humerus – glenohumeral joint – scapula – scapulothoracic connection (created with muscles, the elastic element of the chain) – processus spinossus of thoracic spine. In this work the dorsal connection of the upper extremity to the spine is only considered.

SCAPULOTHORACIC REGION

Scapulothoracic region reflects the history of previous stressful. Upper limb function is linked with the function of the axial system. The muscles of the shoulder girdle are closely related to the muscles of the spine. DiVeta was interested in position of the scapula in relaxed standing. He assumed that forward shoulders can be the results of an imbalance between shortened or stronger pectoralis minor muscles and an elongated or weaker middle trapezius muscles. Electromyographic analysis shows that in relaxed standing muscular activity around the shoulder girdle occurs primarily in supraspinatus and upper fibers of the trapezius muscle. The relationship that was expected between the position of the scapula in standing subjects and the muscular force produced by the middle trapezius and pectoralis minor muscles, was not confirmed. (DiVeta, 1990) Cheshomi concluded that, when thoracic kyphosis curvature increases, scapula bones move away from their normal position and endurance of posterior shoulder girdle muscles decreases. (Cheshomi et al., 2011) Hyperkyphosis develop because of unsuitable postural habits. In this situation m.pectoralis major and minor, serratus anterior, latissimus dorsi become tight and short, contrastly erector spinae, rhomboids and trapezius become stretched and weak. In these individuals therefore both shoulders and upper thoracic spine motions become limited. (Glousman, 1998) As is written above there are various results according to different studies. That is why other studies are needed in this scapulothoracic region.

Kinematic Analysis

Kinematic analysis is the current gold standard for quantification of joint kinematics. (Cutti, 2005) In 2005 the International society of biomechanics (ISB) issued a set of recommended standards for modeling the shoulder complex. The recommendations were based on the work of Grood and Suntay who developed a methodology to calculate relative movement of two body segments. The bones of the body can be viewed as a series of rigid links whose positions can be defined by the location of a point on the bone and the bone's orientation in space. The bony landmarks for modeling the shoulder complex as recommended by the ISB are thorax, clavicle, scapula, humerus, forearm and their segments. Due to the presence of overlying soft tissue, accurate measurement of the kinematics of the scapula is problematic and very difficult using noninvasive methods.

Despite the objective kinematic analysis of the shoulder yield useful function insights to aid clinical practice. (Lovern, 2009) Mostly the elevation of the arm is studied, where the scapulohumeral rhythm is well described. Altered scapular kinematics is influenced by age of the probands (Dayanidhi, 2001), by wether the arm is actively or passively elevated (Ebaugh, 2005), by muscles fatigue during repeated arm movements. (Ebaugh, 2006) Novotny studied the external rotation of the humerus. The glenohumeral kinematics is affected not only with the muscles, but also with ligaments. (Novotny, 2000)

PURPOSE

The purpose of this study is to describe the kinematic of shoulder girdle, thoracic spine and to find the answer for these two questions: What is happened with the position of the scapula during the external rotation of the humerus? What is happened with the shape of the spine during the external rotation of the humerus? This study should help to create other questions for next research.

METHODS

For purpose of this study the kinematic analysis (Qualisys) was chosen. There were 3 persons (female, age 21, with no spine and shoulder pathology, with no sport activities, weight 56 kg ± 3 kg, height 170 cm ± 2 cm) during the measurement. The markers were given on the bony segments as was recommended by ISB (see Tab. 2, Fig. 1) There were 2 tasks for the probands, they do not know the purpose of the study. Firstly the external humeral rotation was tested in standing position (basic anatomical position) with flexed elbows – normal movement. Then the therraband was used as a resistance during external rotation of humerus. During 8 seconds the humerus was rotated externally. Both tasks were done twice. The values were transferred to a computer and evaluated with the Qualisys track manager. The curvature of the spine was given with 3 markers, the angle between C7-TH4-TH8. The olecranon was considered as a stable point around it the rotation was done. The external rotation of the humerus was calculated from the trajectory which was done with the marker on the radial styloid. The position of the scapula was described in relation with the markers on the vertebrae C7, TH8. The results of measurement of each proband were written into the table (Tab. 3). Average values were counted for external humeral rotation, extension of thoracic spine and distances of scapula. Graphs show the results of third proband (Fig. 2).

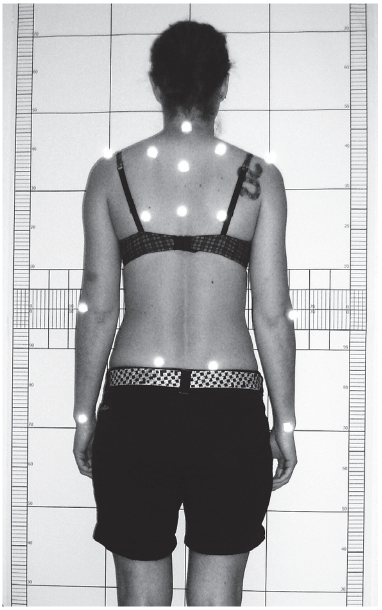


Figure 1. Anatomical landmarks on spine, scapula, humerus, forearm and pelvis.

Table 2. Anatomical landmarks on spine, scapula, humerus, forearm and pelvis.

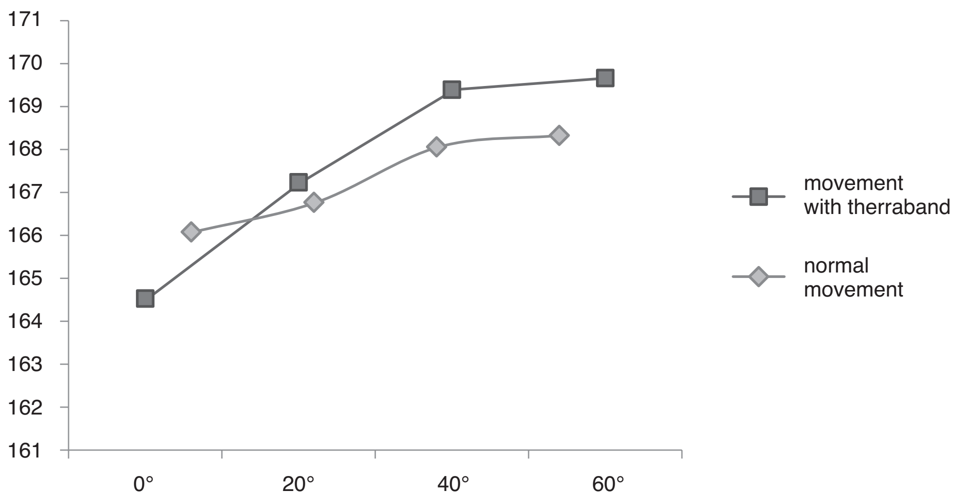
Spine	C7	Spinous process of the seventh cervical vertebra
	TH4, TH8	Spinous process of the fourth, eighth thoracic vertebra
Scapula	AS, AI	Angulus superior, angulus inferior of the scapula
	AA	Angulus Acromialis, most laterodorsal point of the scapula
Humerus	EM	Most caudal point on the lateral epicondyle
Forearm	RS	Most caudal–lateral point on the radial styloid
	US	Most caudal–medial point on the ulnar styloid
Pelvis	SIPS	Spina iliaca posterior superior

RESULTS

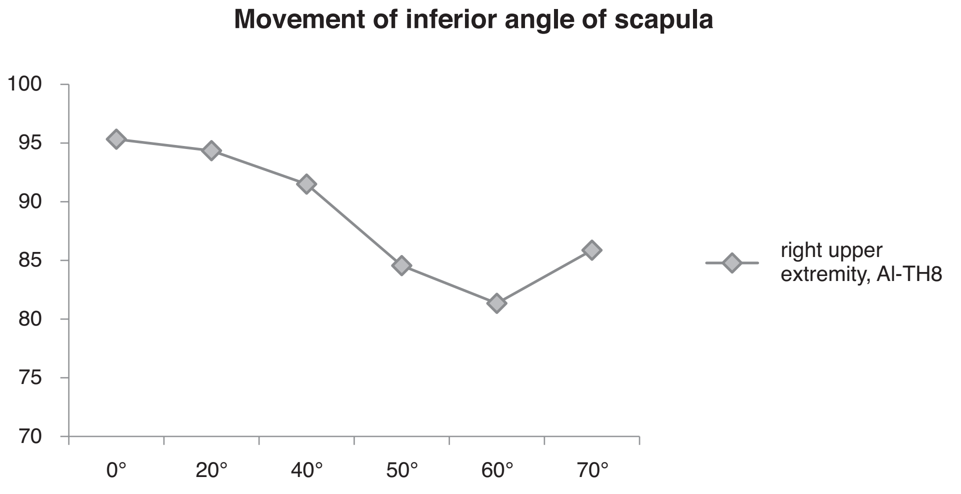
The average external humeral rotation is 66.9° in case of normal movement. During external humeral rotation the average change of the curvature of cervical-thoracic spine is 1.6°. The angulus superior scapulae is approached to C7 averagely 6.6 mm, the angulus inferior scapulae is approached to TH8 averagely 8 mm. In case of using therraband the external humeral rotation is averagely 77.7° and the other values are twice times higher (curvature of the spine averagely 3.2°). The standard deviation was calculated 0.3° for curvature of the spine and 0.3 mm for position of the scapula. The producer specifies the accuracy of the measurement 0.15° for orientation and 0.8 mm for position.

Table 3. Results of the measurements, normal movement

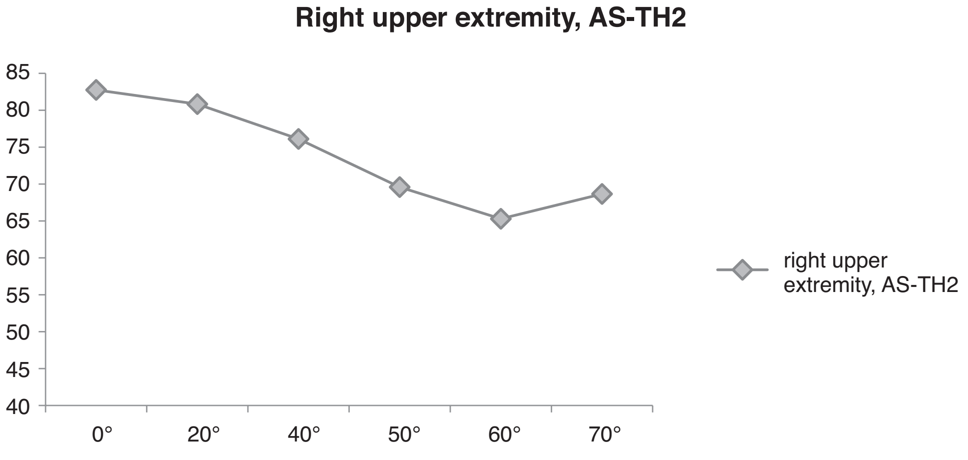
Kinematic analysis	proband 1	proband 2	proband 3
curvature (°) of cervical-thoracic spine in neutral standing	163.3	166.3	166.1
curvature of cervical-thoracic spine with externally rotated humerus	164.9	167.4	168.3
distance (mm) AS-C7 in neutral standing, left upper extremity	89.6	85.4	69.9
distance AS-C7 with externally rotated humerus, left upper extremity	82.9	78.2	63.9
distance AS-C7 in neutral standing, right upper extremity	79.9	74.3	83
distance AS-C7 with externally rotated humerus, right upper extremity	75.2	67.5	74.9
distance (mm) AI-TH8 in neutral standing, left upper extremity	83.4	67.8	102.5
distance AI-TH8 with externally rotated humerus, left upper extremity	73.2	63.2	92.9
distance AI-TH8 in neutral standing, right upper extremity	82.8	108.5	95.2
distance AI-TH8 with externally rotated humerus, right upper extremity	75.9	101.9	85.2
external rotation (°) of humerus, left upper extremity	60.4	73.4	69.3
external rotation of humerus, right upper extremity	61.5	64.4	72.4



a) graph shows the relationship of the external humeral rotation on the curvature of the spine, values of proband 3



b) movement of the inferior angle of the scapula during external humeral rotation, right upper extremity, AI-TH8, AI = inferior angle of the scapula, TH8 = 8.thoracic vertebrae



c) movement of the superior angle of the scapula during external humeral rotation, right upper extremity, AS-TH2, AS = the superior angle of the scapula, TH2 = 2.thoracic vertebrae

Figure 2. Graphs of kinematics values of 3 proband (a–c). The graphs show that the largest changes occur in the middle of the range of the motion.

DISCUSSION

According to results during the external humeral rotation there is adduction of the medial border of the scapula and its inner rotation of the inferior angle. This movement is described as retraction of the scapula. Markers which determine the position of scapula, were used as in Lovern's study. He concluded the using skin-mounted markers to measure dynamic scapula movement is viability. The scapula locator is the accepted standard by which alternative non-invasive techniques of scapula tracking are validated. (Lovern, 2009)

During humeral external rotation is activated m.trapezius pars medialis and mm. rhomboids which retract the scapula, but the inner rotation of the inferior angle causes mm.rhomboids. The same findings are described in Pratt's study. (Pratt, 1994) Holubářová (according to Kendal's technique) in the scapula region describes synergistic, antagonistic functional muscle reflex chains that interact with facilitatory or inhibitory. All the muscles of the shoulder blade in one function work as synergists, but in another function as antagonists. (Holubářová, 2007)

Trapezius muscle medial part acts against m. pectoralis minor. DiVeta did not confirm the relationship that he expected between the position of the scapula in standing subjects and the muscular force produced by the middle trapezius and pectoralis minor muscles. (DiVeta, 1990) He used an isomectric make test for evaluate the muscles and tape measurement for describing the position of scapula. This methodology is questionable, the muscles act together as is described above, it is not possible to test muscles separately with using clinical test. Cheshomi (2011) concluded that, when thoracic kyphosis curvature increases, scapula bones move away from their normal position and endurance of posterior shoulder girdle muscles decreases. This is explained by the increased prominence of the ribs dorsally and the increased anteroposterior diameter of the thorax evident in subjects with a mid-thoracic curve. The angulation of scapula and/or the clavicle must increase to accommodate the greater anteroposterior thoracic diameter. His conclusion agrees with the results. If the scapula is adducted, the posterior shoulder girdle muscles are activated and the thoracic kyphosis curvatures decreases. Cheshomi recommended scapulas retraction exercise to deal with hyperkyphosis. The same movement as in this study can be used too.

For upright posture in scapulothoracic region there must be equilibrium between internal and external rotators of humerus. Altobelli described that the inner rotators are longer than the outer rotators in fiber length and values of PSCA, suggesting both a larger capacity for force production and higher excursion. This is largely due to the design of the pectoralis major muscle. (Altobelli, 2005) On the other hand in Tsai's study the external rotator muscles of the shoulder are more fatigued than other shoulder muscles during the arm movements. (Tsai et al., 2004) The scapula is a stable base for glenohumeral movements. This was seen at the probands in this study, firstly the scapula does not move during the external humeral rotation. (Fig. 2)

Thoracic spine is used to be rigid due to ribs, bigger movements is possible in cervical or lumbar spine. The extension of the upper thoracic spine in this study is 1–3°. Ebaugh has shown that 4° differences in kinematics are meaningful – altered scapular kinematic is associated with shoulder impingement and decrease subacromial clearence. (Ebaugh,

2005) In subjects with hyperkyphosis, the range of glenohumeral motion and subacromial space are reduced. The external humeral rotation provokes the extension of the upper thoracic spine. This could be done by the deep spinal muscles and by the superficial scapulothoracic muscles. Superficial muscles change the trajectory of the motion and global shape of the region. (Otáhal et al., 2010) The probands did not know the reason of the measurement for eliminating activity of deep muscles spine extensors.

Kinematic analysis is standard method, its bigger problem is the presence of overlying soft tissue. This problem was solved by many authors. The effect of soft tissue was quantified during three dimensional motion capture. Zhang et al. concluded that the kinematic noise caused by skin movement artifact during external rotation of the arm does not follow a sinusoidal pattern and cannot be effectively eliminated by an optimalization model. (Zhang et al., 2011) To reduce soft tissue artifact Cappello et al. recommended a double-calibration method, markers should be on the bony segment immediately under the skin, probands should not have a lot of adipose tissue. (Cappello, 1997) The kinematics of the spine, scapula or humerus is very difficult using noninvasive methods. These methods are used in case of measurements on cadavers (Warner, 2011) or an artificial arm (Zhang et al., 2011). In this case the movements are not influenced with cardiovascular, central nerve, lymph and other systems as at alive persons. Activation of muscles during movement is individual and depends on how their individual movement patterns developed. Despite of the effect of soft tissue the objective kinematic analysis of the shoulder yield useful function insights to aid clinical practice. (Lovern, 2009)

There are a few limitations to this study that should be noted. Breathing influences the thoracic spine and the probands did not know any instruction about breathing. In next study more markers should be used to determined curvature of the spine. The curvature should be counted mathematically to know the curvature in each segment of spine. More markers should be used on the sternum, upper ribs to know the anteroposterior diameter of a thorax. Compensatory movements in cervical and lumbar spine were seen during external humeral rotation, so other markers should be used on lumbar and cervical spine. A fixation of the cervical and lumbar spine is not satisfactory solution for eliminating compensatory movements of spine. Isometric force should be used for eliminating individual stereotyping movements.

CONCLUSION

In this pilot study the exact results cannot be confirmed, because of many limitations which were written above. The same tendencies were only seen at all the probands: during the external humeral rotation the scapula is retracted, there is adduction of the medial border of the scapula and inner rotation of the inferior angel of the scapula. With the humeral external rotation and retraction of the scapula the upper thoracic spine is extended. Better results were achieved with the use of the therraband. The results of this work should be confirmed with next studies to know if the exercise of humeral external rotation has really the effect on extension of upper thoracic spine that is used in physiotherapy and treatment for patients with hyperkyphosis.

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KINEMATIKA CERVIKOTHORAKÁLNÍHO PŘECHODU A PLETENCE RAMENNÍHO

IVANA JELÍNKOVÁ

SOUHRN

Práce je pilotní studií zabývající se kinematikou cervikothorakálního přechodu páteře a pletence ramenního. Funkce horní končetiny je svázána s funkcí axiálního systému, stejně tak svalstvo pletence ramenního má úzký vztah ke svalům páteře. V klinické praxi jsou používány cviky aktivující zevní rotátory humeru k napřímení hrudní páteře. To je předmětem i tohoto experimentu. K určení polohy lopatky, rozsahu pohybu zevní rotace humeru a extenze páteře je použito kinematické analýzy (Qualisys). Měření podstoupili tři probandi (ženy, věk 21 let, bez pravidelné pohybové aktivity, bez předchozí patologie, či úrazu pletence ramenního a páteře). Data byla vyhodnocena v programu Qualisys track manager a nebyla statisticky zpracována. U všech probandů byly sledovány stejné tendence: při zevní rotaci humeru dochází k retrakci lopatky a extenzi horní části trupu.

Klíčová slova: pletenec ramenní, rotace humeru, páteř, kyfóza

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