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KINEMATICS OF UPPER THORACIC SPINE DURING SIMULATED ROPE SKIPPING

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SUMMARY

Poor posture negatively influences the function of organs. With the use of the skipping rope, the external and internal rotators of the shoulder can be activated. Functions of upper limb and of the axial system are linked. The external rotators, scapulothoracic muscles, help to erect the upper body. This pilot study tries to analyse kinematics of upper thoracic spine during simulated rope skipping. Three female subjects aged 28 ± 2 years, weight 56 kg ± 2 kg, height 167 cm ± 8 cm (mean ± SD) without pathology or injury of the shoulder girdle and spine were recruited. Subjects rotated the special training jump rope in two directions (forward and backward) at two different rotation speeds. Kinematic analysis (Qualisys) was used for determining the range of motion of external humeral rotation and extension of thoracic spine. During maximum speed forward rope rotation, curvature of upper thoracic spine was decreased.

Key words: kinematic analysis, internal and external rotation of humerus, kyphosis, jump rope

INTRODUCTION

The spine is a complex of vertebrae, intervertebral discs, joints and ligaments. The motion of the vertebrae to each other is determined with these structures. Sum of the partial range of motion creates the total range of motion of the whole spine (see Table 1). The physiological range of motion of thoracic spine varies between authors (Table 2). Due to the complex kinetic link between vertebrae, different movements are associated, which can be compensated in another part of the spine. The range of motion is influenced with age, gender and regular physical activity (Ryšávková, 2004). Coupling patterns of the spine are complex movements, which are determined with biomechanical characteristics between two segments. During translational and rotational movement of the spine in one geometric plane, there are also translational and rotational movements in a different plane. According to White (1998), the coupling patterns of the spine are minimal in the thoracic spine (White, 1998).

Table 1. Range of spine flexion and extension (White, 1998)

Spinal segment	Range of flexion + extension
C7–Th1	9°
Th1–Th2, Th2–Th3, Th3–Th4, Th4–Th5, Th5–Th6	4°
Th6–Th7	5°
Th7–Th8	6°

Table 2. The range of motion of thoracic spine according to different authors (Norkin, White 1998; Kapandji, 1974; Kolář, 2009; Lewit, 2003)

Joint	Motion	Am. Acad. Ortho. Surg	Kapandji	Kolář	Lewit
Thoracic spine	Flexion	0–80°	0–105°	0–35°	0–45°
Thoracic spine	Extension	0–25°	0–60°	0–20°	0–25°

The lordosis and kyphosis of the spine provide flexibility and strength of the whole spine. The strength of the spine is defined as $C^2 + 1$, where C is the number of curvatures. Human spine has 2 lordosis, 2 kyphosis, the spine is 17 times stronger than if the spine had only one curvature (Dylevský, 2009). The number of curvatures increases the resistance against the compressive force acting in the axial axis. The significance of this phenomenon describes Delmas's index. The value of Delmas's index has a functional significance, the spine with raised curves is a dynamic type, while the spine with reduced curves is a static type (Jalovcová, 2009).

The shape of the spine is not stable, but it is modulated by a number of forces. During the breathing, the inspiration leads to elevation of the ribs, the anteroposterior and craniocaudal diameter of the thorax rises and thoracic spine is extended (Véle, 1997). Every change of the thoracic spine or shape of the thorax leads to a change of breathing. Breathing influences the shape, movement and dynamic characteristic of thoracic spine and thorax (Janda, 1982). Lewit describes the vertebra-visceral relationship. In case of upper thoracic spine, the heart influences the segments C3–TH8, the liver TH6–10, the stomach TH4–12. The spinal segments can influence the organs, too (Lewit, 2003).

Posture

What is the optimal posture in upper body? Only a few studies describe the norm of the ideal posture in sagittal plane. Harrison (2002) created an ideal geometrical spinal model. It is the geometric path of the posterior longitudinal ligament from the occiput to the back of S1. All three spinal regions (cervical lordosis, thoracic kyphosis and lumbar lordosis) are arcs of circles. The Delmas Height to Length ratio, H/L = 0.95 index is ideal for the each region of the sagittal spine. This model was compared with the radiograph. Harrison created new full spine normal model which is composed of separate ellipses for the different spinal regions. Ideal lumbar model was an arc of an ellipse, with b/a = 0.4 (minor axis to major axis of ellipse ratio). Thoracic spine model has b/a ratio of ellipse 0.7 (Harrison, 2002). Harrison's model is not widely used, the upright posture used to be compared with the vertical line. A plumb line used to be used from the head or from foot (Kendall, 2005).

Development of spinal lordosis and kyphosis is due to phylogenesis and ontogenesis. The change of walking from ape to human bipedal walking determines the spinal curvatures in sagittal plane (Tobias, 2003). Kolář (2001) concluded that almost 30% of children do not have optimal static settings of spinal segments. While child grows, the mobility of thoracic and lumbar spine decreases and the thoracic kyphosis reduces (Cil, 2004). Widhe (2001) concluded, the thoracic kyphosis is dependent on physical activity. The posture changes, thoracic kyphosis increases by 6° at children without sports activity. The mobility of thoracic spine decreases by 27° (Widhe, 2001). Thoracic kyphosis has ellipsoidal shape, bigger curvature is in the upper part of kyphosis and the lower part of kyphosis is flatter. The shape of kyphosis is the same at adults male and female, except children till 5 years and old people over 65 years (Harrison, 2002).

The shape of the thoracic spine influences the movement of shoulder blades and upper extremities. Poor posture with thoracic hyperkyphosis decreases muscular strength of the upper limbs and conversely (Kebaetse, 1999). The protraction of the head and shoulder leads to hyperkyphosis (Penha, 2008). The decrease of the thoracic hyperkyphosis is described by Wang (1999) whose patients were trained in retraction and elevation of the scapula, abduction and external humeral rotation.

Architectonics of the muscle affects the muscle function. Muscle force is proportional to the physiological cross-sectional area (PCSA). The inner rotators of the shoulder are longer than the outer rotators in fiber length and values of PCSA (Altobelli, 2005). The scapulothoracic muscles must act together with external humeral rotators to be equal with inner rotators of the shoulder. 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, 1990). DiVeta was interested in poor posture. Forward shoulders are the result 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. Cheshomi et al. (2011) concluded that increasing of the curvature of thoracic kyphosis causes the protraction of the scapula and endurance of posterior shoulder girdle muscles decreases. Hyperkyphosis develop because of unsuitable postural habits. In this situation m. pectoralis major and minor, serratus anterior, latissimus dorsi become tight and short, conversely erector spinae, rhomboids and trapezius become stretched and weak. In persons with hyperkyphosis both shoulders and upper thoracic spine motions become limited (Glousman, 1998).

PURPOSE

External humeral rotation with the retraction of shoulder blades extends the thoracic spine. The same starting position of upper extremities is seen while holding the skipping rope. This study was interested in internal and external humeral rotation and its effect on the thoracic spine during skipping over the rope. The purpose of this study was to determine the change of curvature of thoracic spine during forward and backward self-paced and maximum speed rope rotation.

METHODS

In this pilot study we randomly selected three female subjects. All were without pathology or injury of the shoulder girdle, or spine, aged 28 ± 2 years, weight 56 kg ± 2 kg, height 167 cm ± 8 cm (mean ± SD). The quantitative or qualitative methods can be used for postural description. The standard quantitative method is X-ray, commonly used qualitative method is an optical method (Penha, 2008). The aspection of thoracic kyphosis using in clinical practice is unreliable (Fedorak, 2003), that is why some other methods should be used. In this study, the markers were placed on the anatomical landmarks as recommended by Lovern (2009) and on a handle and the end of the rope (see Table 3). Probands did not know the purpose of the study. Simulated rope skipping was performed with special training device, made of a handle, 30 cm long rope and attached ball. The ball was a plastic ball with holes, standard ball used in floor-ball sport. Subjects rotated the ball in sagittal plane in two directions (see Figure 1).

Subjects were instructed to perform following tasks:

– Bend your elbows, so that your forearms aim forward,
– slowly rotate your arms outwards,
– rotate the rope forward at a comfortable speed, than after 20 seconds,
– rotate the rope forward at a maximum speed, after 20 seconds,
– rotate the rope backward at a comfortable speed, after 20 seconds,
– rotate the rope backward at a maximum speed.

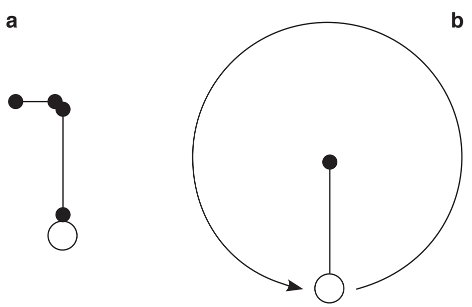

Figure 1. Schema of the jump-rope-like device used in experiment. a) front view on rope in subjects left hand, horizontal line is a handle, vertical line is a rope with a ball attached at the end b) side view on the left hand (from subjects left side) turning forwards; centre of rotation is in the attachment of the rope to the handle, circle is a trajectory of a ball attached to the end of the rope, arrow depicts direction of a rotation.

The probands did the procedure only once. The curvature of the spine was given with 3 markers (C7, Th4, Th8), calculated as the geometrical extrinsic curvature (multiplicative inverse of radius) of a circle fitted into these markers positions. The fit was done with Total least squares curve fitting function tlscirc in Matlab (Davis, 2002). During the external rotation from default position, the olecranon was considered as a stable point around which the rotation was done. The external rotation of the humerus was calculated from the trajectory of the marker on the radial styloid.

Table 3. Placement of markers

Spine	Spinous process of the seventh cervical vertebra
	Spinous process of the fourth and eighth thoracic vertebra
Scapula	Angulus superior, angulus inferior of the scapula
	Angulus acromialis, most laterodorsal point of the scapula
Humerus	Most caudal point on the medial and lateral epicondyle
	Insertion of deltoid muscle
Forearm	Olecranon ulnae
	Most caudal–lateral point on the radial styloid
	Most caudal–medial point on the ulnar styloid
Rope handle	Rotational joint of rope handle at the most lateral point
Rope end	The most distal part of the rope, attached to the ball

RESULTS

In the second task – external humeral rotation – thoracic spine was extended. For range of motion of external humeral rotation, see Table 4. On average, maximum rotation speed was 68 % and 47 % faster than self paced rotation speed during forward and backward rotation, respectively (see Table 5). In case of forward rotation of the rope, the extension of upper thoracic spine increased, markedly it was seen with fast rotation of the rope. In case of backward rotation of the rope, the upper thoracic spine was slightly extended, but not at all cases (see Table 6).

Table 4. External humeral rotation range in right and left arm. Starting position was with forearms aiming forward.

	subject 1	**subject 2**	**subject 3**
right arm	80°	93°	85°
left arm	73°	85°	82°

Table 5. Angular velocity of rope rotation. Subjects were instructed to turn at a comfortable (self-paced) speed for 20 seconds and at a maximum speed for 20 seconds, both forwards and backwards.

direction	speed	subject 1	subject 2	subject 3
forwards	self-paced	17 rad/s	17 rad/s	10 rad/s
	maximal	22 rad/s	26 rad/s	26 rad/s
backwards	self-paced	14 rad/s	13 rad/s	19 rad/s
	maximal	20 rad/s	21 rad/s	26 rad/s

Table 6. Mean curvature of upper thoracic spine. There were six conditions – two static (forearms aiming forwards, forearms aiming outwards) and four dynamic (rope turning forwards slow and fast and rope turning backwards slow and fast).

		subject 1	subject 2	subject 3
holding forearms	forwards	2.76	2.87	2.27
	outwards	2.98	2.77	2.21
turning forwards	slow	2.46	2.84	2.04
	fast	2.12	2.30	2.15
turning backwards	slow	2.78	2.64	2.45
	fast	2.67	2.67	2.53

DISCUSSION

The ability of upright posture is important for right spinal function. Erect posture determines the performance of sportsmen, minimalizes the negative effects of the overload of axial system, it is economically and it looks well from esthetic point of view (Kolář, 2006). Extension of thoracic spine is energy-intensive, that's why the ligaments are more used in case of standing at rest (Véle, 1996). The external humeral rotation with retraction of scapula leads to extension of the thoracic spine (Jelínková, 2012). Extension of thoracic spine was moderate during the second task, it was not expected more, because the external rotation of the rope was not done powerfully. The bigger external humeral rotation, the bigger is the retraction of the shoulder blades and extension of thoracic spine (Cheshomi et al., 2011). The first proband externally rotated the arms less than the other probands, there was not the extension of thoracic spine, but with next task, with more muscle activity, more extension of thoracic spine was seen.

This pilot study does not deal with extension of the spine as a complex movement. It is interested in the upright posture which is provided with the activity of deep dorsal muscles together with the external humeral rotators. Muscles infraspinatus, supraspinatus, teres minor and posterior part of deltoid mostly do the external humeral rotation. Muscles rhomboids and medial part of the trapezius do the retraction of the scapula. These muscles act together to cause the extension of upper thoracic spine (Altobelli, 2005). Superficial muscles change the trajectory of the motion and global shape of the region (Otáhal et al., 2010).

Bigger extension of thoracic spine was expected during backward rotation of the rope. Greater activity of the external humeral rotators was predicted. That statement was not confirmed. In case of backward rotation of the rope, the upper thoracic spine was slightly extended, but not at all cases and not as much as in case of forward rotation. There are several assumptions of the causes. Backward rotation of the ropes was made as the last task that can be energetically demanding. The probands had to change the direction of rotation. The external humeral rotators had to be active for holding the upright posture and in the same time for doing external rotation. Electromyographic analysis shows that in standing muscular activity around the shoulder girdle occurs primarily in an external humeral rotator – supraspinatus (Cheshomi et al., 2011). On the other hand there was still the extension of thoracic spine compared with the starting position in case of the second and the third proband. Recording EMG in addition to kinematic analysis could be another method to provide valuable insight into muscle activation.

The motion of the vertebrae to each other is small during this extension of thoracic spine. White (1998) and other authors (Norkin, 1998; Kapandji, 1974; Kolář, 2009; Lewit, 2003) describe the values in each spinal segments during the extension in whole range of motion. Thoracic spine is relatively rigid due to ribs, bigger movements is possible in cervical or lumbar spine. Due to difficult kinematic link between vertebrae, the motions are associated with other movements which can be compensated in other part of the spine. This fact could also play role in curvature changes, hiding some effect of performed activities. More markers on the spine should be used in next studies to know what happened with the cervical and lumbar spine during this tested movement. Using more markers would increase curve fitting accuracy.

Human movement is individual and it is influenced with many factors which were discussed above (Janda, 1982; Véle, 1997; Lewit, 2003). Limited number of available subjects might cause statistical bias. Effect of simulated rope skipping on thoracic spine was, at least in this pilot study, rather inconclusive. Although differences were statistically significant, relatively small curvature changes suggest, that the training jump rope would not provide meaningful positive effect in therapeutic praxis. Some other training tools, i.e. rubber band, might be better for this purpose.

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KINEMATIKA HORNÍ HRUDNÍ PÁTEŘE BĚHEM NÁPODOBY SKÁKÁNÍ PŘES ŠVIHADLO

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SOUHRN

Vadné držení těla negativně ovlivňuje funkci orgánů. S využitím švihadla mohou být aktivovány vnitřní a vnější rotátory ramene. Funkce horní končetiny a osového systému jsou propojené. Vnější rotátory, skapulothorakální svaly, pomáhají napřimovat horní část těla. Tato pilotní studie se pokouší analyzovat kinematiku horní hrudní páteře během nápodoby skákání přes švihadlo. Zúčastnily se tři ženy věku 28 ± 2 roků, váhy 56 kg ± 2 kg, výšky 167 cm ± 8 cm (průměr ± směrodatná odchylka) bez patologie či zranění ramene. Subjekty točily speciálním tréninkovým švihadlem ve dvou směrech (vpřed a vzad) dvěma různými rychlostmi (pohodlná a maximální). Pro určení rozsahu pohybu vnější rotace paže a extenze hrudní páteře byl použit systém pro kinematickou analýzu Qualisys. Během točení vpřed maximální rychlostí se křivost horní hrudní páteře zmenšila.

Klíčová slova: kinematická analýza, vnější a vnitřní rotace kosti pažní, kyfóza, švihadlo

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