

Restoring proprioception after sports injuries and pathological states of the shoulder complex

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Summary

Proprioception is a specialized sensory function comprising of movement sense and joint position sense. Coordinated movement and proper functioning of the upper limb are essential in everyday life and in professional sport. Proper functioning proprioceptive integrates the function of static and dynamic stabilizers of the joints. It also provides protection against injury to the joints during movement and contribute to their proper functioning. Injury to tissues containing mechanical receptors may cause proprioceptive disorders and increase the likelihood of reinjury.

Physiotherapy has a rich resource of methods to restore efficiency following sports injuries. However, few programs for physical therapy take into consideration improving proprioception in the course of upper limb rehabilitation. Most of them seek to lessen pain, improve range of motion and restore muscle strength. However, this isn't enough. For the treatment team, a major challenge is to understand the importance of proprioception in conservative as well as surgical treatment of injuries and subsequent dysfunctions of the shoulder joint complex. The team should take into consideration, in planning of program, physiotherapy of the elements improving proprioception.

In the process of regenerating proprioception, the following are recommended: grading of activity: joint position sense (JPS) and kinesthesia, dynamic stabilization of joints, reactive neuromuscular control, specific activity in terms of functionality.

The paper discusses problems involved in restoring proprioception. In addition to variety and specific character of sports injuries, pathological states of shoulder complex have been examined. The significance and necessity of restoring proprioceptive functions and neuro-muscular control in physiotherapeutic programs, as essential elements of prevention of injury, has been outlined. Selected means and methods of restoring proprioception have been presented.

Introduction

Proprioception is a specialized sensory function including feeling of motion (kinesthesia) and joint position sense [1,2]. It is a specialized variant of the sensory modality of touch encompassing sensing of movement and position of the joints [3].

Motor programming of neuromuscular control and emergence of muscle reflex responsible for dynamic stability of joints take place thanks to correctly functioning proprioception. It is represented by a number of neural structures, including peripheral receptors and peripheral nerves, spinal cord transmitting sensory stimuli to the central nervous system (CNS), brain stem, cerebellum, basal ganglia of the brain and the cerebral cortex [4]. Proprioceptive receptors are located in the joint capsules, in the tendons and ligaments connected to

the joint capsule as well as in skeletal muscles. Kinesthetic receptors (joint and tendon) facilitates identification of the position of various body parts relative to one another as well as their movement in space. The following are some of joint receptors: sensory cells (Ruffini end organs), lamellar corpuscles (Pacini's corpuscle) and the free ends of the unmyelinated fibers. Tendons and ligaments comprises of: bulboid corpuscles, sensory corpuscles and free nerve endings. Mechanoreceptors that rapidly adapt and are sensitive to the position of the joint constitute mediators of movement in the joint. They are activated during movement from its initial to the final stage, and also during change of speed and direction of movement [5,6]. Slow adapting receptors mediate in identification of joint position. They are also responsible for the measurement of muscle tension – spindle skeletal muscles

mechanoreceptors [5]. There are four basic types of joint receptors, of which three are mechanoreceptors and the last are receptors receiving nociceptor painful stimuli [7].

Proper neuromuscular control at three levels of activation within the central nervous system is particularly valuable element in the activities of any athlete. Reflexes at the spinal level mediate in the transmission of movement patterns coming from higher levels of the nervous system. The second level of motor control is located in the brainstem. The highest level of interaction of the central nervous system is associated with cognitive awareness, where motor commands responsible for voluntary movements originate. Execution of repeated moves, and stored as central commands, are carried out via cortical routes, without constant reference to consciousness. Kinesthetic and proprioceptive training are the forms of activity that may enhance these effects [3].

External signals, detected by the mechanoreceptors, transfer information to CNS from receptors in: joints, muscles and skin, organ of vision, auricular organ. Processed information act on the muscles as an end organ, through feedback systems, balance controlled by the spinal cord and cognitive system. Information arriving at the CNS from proprioceptive receptors are only slightly conscious. Proprioceptive sensation, conducted to the cortex by posterior subacute system is partly conscious. Proprioceptive impulse, reaching the cerebellum, is not conscious [5].

Unconscious proprioceptive information on the position of the body in space and on the tension generated by skeletal muscle is sent from musculo-ligamentous system and vestibular organs. Sight and skin sensory organs are responsible for providing informed information on the position of the body and limbs. It should be kept in mind that the proper functioning of all elements of motion control system decide on proper, and adequate to the needs and a situation, function of motor organ [4].

Modern physiotherapy comprises of various methods of physiotherapy, kinesiotherapy and massage that help restore efficiency after sport injuries. Scheduling of rehabilitation program is based on medical diagnosis and physiotherapy study conducted. However, very often, due to lack of ability to provide early initiation, continuity and comprehensiveness of rehabilitation, only a few of them are carried out, at times wrongly recognized as only objectives in physiotherapy, for example, elimination of pain, improvement of range of motion, improvement of muscle strength, etc. Due to various types of restrictions or at times ordinary trifling of the problem, the importance of recovering proprioception is overlooked. The objective of the work is to highlight the importance of restoring proprioception in physiotherapy process in athletes who has suffered injuries and alignments of the shoulder complex.

Proprioception as one of the basic conditions for normal joint function

Execution of motion in the right plane of motion in the joint requires maintenance of joint stability. This is guaranteed by

static stabilizers (ligamentous-capsular complex) and dynamic stabilizers (muscular band with muscle tension which influences the function of the joint and is regulated by the nervous system). Proper operation of the proprioception integrates the function of static and dynamic stabilizers of the joints. It provides protection for the joint against injury during movements and affect proper execution of these movements [4].

Injury to tissues containing mechanical receptors can result in partial difference and sub-sequently in proprioceptive disorders. As a result of reduced proprioceptive feedback, probability of re-injury increases [8, 9, 10].

Effects of spinal reflexes or processes within the cerebral cortex and affecting motor control constitute subsequent phenomenon in relation to ligaments pathology, surgical reconstruction and rehabilitation. Impaired proprioception can be assessed in quantitative terms. Evaluation of joint proprioception is divided into two components, i.e. ability to recognize motion (assessed by measuring the threshold of capacity to detect passive motion) and the position of joint (assessed by measuring the ability of passive and active limb positioning) [11,12].

Proper coordination and functioning of the upper limb are of great importance, both in everyday life, as well as competitive sport. Dynamic stabilization of the shoulder provides a synchronized operation of the tissues surrounding the joint and the mechanoreceptors found in them [13,14].

It is a well-known fact that post-traumatic situations, in athletes as well as people not involved in sports, lead to change of sensitivity of joint position [9,15,16]. In basketball players exhibiting instability of the shoulder joint complex, changes occur through cortical changes in electromyographic image. The cause of anterior instability is the drop in neuro muscular activity of the pectoralis major, subscapular and m. latissimus dorsi muscle. This leads to a reduction in the normal rotation force required to execute a move. During attempts to restore anterior stability of the shoulder joint compensation, observed in the EMG, of biceps and supraspinatus muscles ensues. Change in joint kinematics resulting from lack of proper neuromuscular synchronization and activation shoulder girdle muscle leads to microtraumas [17].

By introducing appropriate surgical techniques, such as wrinkling the joint capsule, that cause modification of deep sensation, it is possible to partially restore proprioception of the joint. This causes the intensification of soft tissue tension, which leads to very efficient transmission of afferent, neurological feedback from joint mechanoreceptors [9].

It is therefore important to determine the impact of musculoskeletal trauma, surgical treatment and rehabilitation of joint position sensation and neuromuscular control, and balance in reaching decision on legitimacy of various forms of therapy.

Selected phenomena of injury and afflictions of the shoulder complex in sports

Specific structure of the shoulder complex, its complexity, a very extensive range of motion and constant overloading –

particularly marked in sports or physical activity – could lead to overload inflammation and conflicts, with the involvement of the following, among others: acromion, coracoid process, head of the humerus, capsulolabral-ligamentous systems, muscles and tendons, somatic nerves and vessels (Table 1).

Conflicts in the joint and subacromial humeral joint usually occurs in three arm positions – in extension, abduction and flexion (Table 2).

Painful shoulder syndrome often appear in athletes executing movements of the arm over-head. In sports medicine, most research studies relate to pitchers, swimmers, ground table tennis players, who are most afflicted by this disease [19].

Neuropathy and angiopathy resulting from entrapment constitute special shoulder joint disorder conflicts. They usually accompany pathologies of other tissue (fractures, disloca-

tions and destabilization). This complicates diagnosis and treatment. Sometimes there is a simultaneous pressure (irritation) of the nerves and vessels. In such situations, symptoms from vessels come to the fore. For nerve neuropathy, with a large component of the sympathetic, these are characterized by night pain – this is because inertness increases nerve ischemia. Entrapment and compression of the nerves and vessels from the neck region and those entering chest area occurs in the so-called thoracic outlet syndrome. Symptoms of the syndrome include abnormal perfusion or innervation of the limbs (pale and cool skin, hand fatigue, sensory disorders and paresis). They disappear when in one is in sitting and lying down position. Motor-sympathetic dystrophy (algodystrofia) constitutes a unique diagnostic problem. It takes the form of shoulder-hand syndrome with-

Table 1.

The causes of conflicts in the entire shoulder complex (developmental and acquired anomalies) [18]
<ul style="list-style-type: none"> - anomalies of attachment of sloping muscles (anterior and middle) - rib neck (or its fibrous nucleus) - high position, deformation or hypertrophy of the first rib - hypertrophy of tubercle for scalene muscle on the first rib - anomalies of the anterior scalene muscle (at times cervical rib complex) - deviations of the body, places of departure and course of the brachial plexus - deviation of output and the course of blood vessels - deformations of the chest that change its lateral dimension - anomalies of the acromion or coracoid process (hypertrophy) - fracture - scars - calcification - bursitis and bursa hypertrophy - scarring, calcification of ligaments and tendons - disorders of elasticity of soft tissue - chondro-osseous exostoses in the course of wear of the acromioclavicular joint - direct or indirect injuries of the anterior scalene muscle with subsequent hematoma, edema, and resultant fibrosis - acute infection and inflammation of the scalene muscles - abnormal curvature of the spine

Table 2.

Conflicts in humeral joint and subacromial joint [20]		
Type of conflict	Trigger mechanism	Structures involved in the conflict
Front-upper conflict	lifting the arm forward and abduction in the setting of internal rotation	acromion, ligament complex and acromioclavicular joint
Front-upper conflict	Extension and flexion movements in an abduction position rotated inside the arm	Acromion (rear section), greater nodule of the humerus, the attachment of the supraspinatus muscle and musculus teres minor, rear part of the bursa
Front-lower conflict	lifting the arm forward, combined with retrieving; a factor contributing to conflict is surpassed coracoid process, and longer periods of forced arm position	Coracoid process, bursa and subscapular muscle

in the upper limb. Injuries (wounds, fractures, sprains, bruises and sprains) on the circumference of the limb lead to dysfunction of the shoulder. Even after direct causes of injury has completely disappeared, pain symptoms persist for up to dozen and so months [18,19].

A common cause of shoulder pain and dysfunction are its destabilization. They may be the result of a injury or gradual wear of passive and active stabilizers. Progressive loss of muscle strength of the shoulder girdle muscles comes with age and this also could be a cause of instability. The following move to the fore in the case of traumatic instability: injury to the glenoidale shoulder labrum, injury to the capsular ligament, muscle failure (cone rotator cuff, deltoid muscle, biceps muscles – long head tendon muscle, subscapular muscle), dental humeral head fractures, defects of the acetabulum. Except of injury to the joint ends, similar injuries are incurred due to summing up of microtraumas suffered while performing work or sporting activities [20].

A scar, characterized by different elongation and flexibility, is always left after healing of injured soft tissue. It comes to specific injuries in case of healing of structures with poor blood supply such as acetabular rim, joint capsule and most of the ligaments. There is high probability of injury to the labrum glenoidale in almost all shoulder destabilization [19].

Injuries to the labrum glenoidale occur in up to 83% of athletes participating in weight-throwing events. The prevailing injury is tearing of the anterior-upper labrum. Sixteen percent of injuries to the labrum-biceps complex are accompanied by tearing of rotator cuff. In order to classify the problem of injuries to the labrum glenoidale, a system of classification of injury to the labrum (SLAP – Superior Anterior and Posterior labrum lesion) [21, 22] has been developed.

Glenoidale labrum is a fibrous-cartilage structure that serve as a seal, through which there is a negative suction pressure prevailing in the joint that increases joint stability. It is the place of attachment of glenohumeral ligaments. Upper movement of the humeral head, with abduction in the plane of motion of the shoulder, comes as a result of the loss of operation of the long head tendon of the biceps of the arm. This leads to a collision at the acromion, especially if the acromion is hooked shaped. In the event of injury to the upper labrum, including supraglenoidale attachment of the biceps of the arm, this allows for increased glenohumeral movement in many directions. Usually there is no clear evidence of instability in the joint. However, an athlete may feel a "relaxation", "sliding" or "running away" of the shoulder. Forces generated by the tendon of the biceps muscle of arm, especially during the phase of the „arm following“ a thrown weight, contribute to injury to the labrum. This is a result of eccentrically shrinking of the biceps muscles, in order to reduce acceleration of the elbow, causing the pressure that enable stabilization of the shoulder. The most common complaint is the shoulder pain that intensify during throwing – usually movement of hand over the head. This is accompanied by symptoms often in the form of glitches, crunchy and blocking and feeling of the shoulder ejecting outside. The

patient may feel the need to perform „adjustment“ movements, as in meniscus derangement [23, 24].

Spontaneous shoulder pain is the most common pathology for persons over 50 and for athletes. More often, this is caused by summing up of shoulder complex stresses throughout life, lack of knowledge of ergonomics of the physical efforts, overload as well as disregard to warning signs. The syndrome of spontaneous pain and shoulder dysfunction on the background of summing up of stresses and premature wear of the shoulder tissue structures proceeds in stages. Often a factor causing or accelerating chain of pathological disorders at the level of a group of specialized cells is the abnormal traffic pattern leading to microtraumas [20].

Proprioception training and neuromuscular control in athletes after suffering injuries of the shoulder complex

Training of the proprioception in the case of upper limb is less popular in physiotherapy programs than in the case for lower limb. The main type of upper limb motor activity is motion associated with throwing. Therefore, mechanoreceptors activity plays an important role in movement and dynamic stability of the joint. In the process of regenerating proprioception, the following are recommended: graduation of activity, feeling of the position of the joint and kinesthesia, dynamic stabilization of the joints, reactive neuromuscular control, specific activity in terms of functionality [25]. This makes it possible to take full advantage of the integration of spinal reflexes and cognitive tracts as well as brain stem to achieve scapula, glenohumeral and arm motion stabilization and neuromuscular control.

Activity related to the positional sensitivity serve to restore joint position sense and kinesthesia. This is achieved by performing exercises where we change the normal position of the shoulder joint (with visual control and without its participation), and by strengthening in form of resistance, for example, during movement of the arm [26].

Exercises related to dynamic stabilization of the upper limb stimulate muscle coactivation. Axial load of the shoulder joint fosters coactivation of glenohumeral and scapulo-thoracic forces. This constitutes training of upper extremity balance. Neuromuscular control exercises help bring about integration of the spinal and cognitive level (e.g. plyometric training) [27]. Introduction of functional exercises specific to a given sport discipline is an indispensable element.

Treatment of the shoulder pathology is usually aimed at passive and active restoration of the stabilizing system, or bringing it closer to normality. This is achieved by operation, for example, in case of rotator muscles cuff tear, injury of glenohumeral ligament or capsule labrum glenoidale (Bankarta injury, SLAP, ALPS). Yet in most cases, conservative and physiotherapy treatment is enough. Its aim is to restore full operation of individual kinetic chain sequences as well as restore

biomechanical balance. Due to the fact that all restrictions on movements of the shoulder are compensated in other sections of the motor organ, physiotherapy should include the entire kinetic chain – from the neck up to the crurotalar joint, since exercises in closed kinetic chains are an effective form of rehabilitation for the shoulder. Restoring flexibility of the rear shoulder rotator cuff group, in order to avoid overloading of the labrum glenoidale in the anterior upper section, plays an important role [25].

There are many programs and guidelines on physiotherapy in patients (athletes with shoulder complex injuries) to be found in the literature. However, few of them take improvement of proprioception in the course of rehabilitation into account. One of such program is the schedule procedure conducted in Lexington Sports Medicine Center, Division of Athletic Training University Kentucky in the USA [28], which specializes in rehabilitation of tennis players, in which great importance is attached to proprioception, and program for rehabilitation of patients after arthroscopic treatment of the joint of shoulder dislocation by Czamara [29]. Interesting look at the treatment of shoulder joint and improvement containing principles of progression of exercises and methods of improving proprioception as well as neuromuscular control in painful shoulder has also been presented by Dutka and Sosin [25]. In the programs of conservative treatment of subacromial impingement syndrome, improvement of subacromial arthroscopic decompression after impingement, rotator cuff repair, shoulder instability treated conservatively and surgically, after shoulder arthroplasty, in the treatment of the diseases of the tendon of the long head of the biceps, after arthroscopic repair of SLAP tears, as well as in any disease, injury, which leads to shoulder dyskinesia, great importance to the significance of proprioception and neuromuscular control is attached [30, 31, 32].

The program of Lexington Sports Medicine Center consists of three phases: acute phase, during which final healing of damaged tissue takes place; regeneration phase where overloaded tissues and tissues with biomechanical deficits are taken into account and; strengthening phase in which the athletes are prepared to return to feat performance with minimization of risk of reinjury. Presented concept of rehabilitation in the overloads of shoulder girdle muscle is based on the knowledge of biomechanical and interaction of systems and tissue structures stabilizing the shoulder. Each of these systems is involved in normal shoulder motor mechanisms as damage to any one of them leads to changes in other systems. Basic knowledge of biomechanics allows for understanding the evolvement of shoulder pathology and its appropriate treatment. In the process of training, appreciation of the complexity of the mechanism movement of the shoulder girdle helps in the selection of general development, powerlifting and fitness programs to maintain muscle balance and prevent injuries [28,33,34].

Factors affecting the therapeutic procedure are: presence or absence of additional injuries, age, gender and level and type of physical activity, and patient expectations. If the type of immobilization allows for access to the area of the shoul-

der, then with the consent of a specialist one can start early physiotherapy program developed in collaboration with operating physician-physiotherapist. Instruction of the patient is also important. Not every patient has the conditions for safety healing of injury site, in such situation the doctor may choose to plaster the injury site. Czamara presented similar assumptions in physiotherapy after arthroscopic treatment of anterior dislocation of the shoulder [29].

Analyzing the assumptions of these programs is easy to see their similarities, not only in the chronology of the procedures, but also in the used of therapeutic measures. An invaluable way of shaping proprioception is the use of PNF method [35]. Appropriate selection of techniques and patterns helps reach improvement of deep feeling (traction, approximation, stretch, stabilizing feedback, rhythmic stabilization, continuous dynamic agility). In the proposals programs Kinesio Taping, which constitutes an element for proprioception support (by activating exteroceptors), has been omitted.

Specification of the type of instability of the shoulder joint has a decisive influence in the process of treatment [36]. Atraumatic instability procedure in is different from traumatic instability procedure. The basis of treatment in atraumatic shoulder instability is implementation of exercises aimed at strengthening and improving of the neuromuscular coordination. In the absence of any clinical improvement, surgical treatment is carried out after about 6 months [37].

Importance of proprioception in preventing re-injury of the shoulder complex

The fate of the patient's shoulder joint complex depends on restoration, and then teaching the patient on own proprioceptive neuromuscular control. The real challenge for the treatment team is to understand the importance of proprioception in both conservative as well as surgical treatment of injuries and subsequent motor organ dysfunctions. Each motor response is the result of integration, in the central nervous system, of all types of neurological inputs (afferent conduction), supplied by the peripheral mechanoreceptors (including visual and vestibular receptors). Reflexive muscular stabilization is stimulated by spinal reflexes in case of loading the joint with mechanical stress or gravitational force. Deliberate movements are the result of cognitive programming – the highest level of functioning of the central nervous system (motor cortex, basic ganglia and cerebellum). Proprioceptive feedback determines both the conscious and unconscious (reflexes) perceptions of movement of joints, limb positions, etc. [28].

Joints are innervated by articular branches of the nerves supplying the muscles above the joints. Therefore, in addition to proprioception mechanoreceptors the joint nociceptors structures are responsible for the reception of pain stimuli. Injury destroys the structure containing mechanoreceptors and this in turn leads to change in feeling of the joints settings and kinaesthesia. Reverse aging processes cause the same

phenomenon. Deleterious effect on the functioning of the motor control system causes weakening of the neuromuscular reflex. Activation of the reflex arch, stimulated by mechanoreceptors and muscle spindles sensory receptors, is faster than transmission of stimulation by nociceptors. This means that in acute cases proprioception plays a much greater role in protecting against injury than pain stimuli. From this it follows that recurrent injuries and renewed injuries are the result of disorders, mainly of the proprioception [20,38].

It should be noted that repaired collagen has different elasticity than the healed tissue, hence the different extensibility, poorer proprioception and possibility of conflicts with the parent tissue in case of pressure and stress, and also pain, dysfunction and recurrent injuries [18].

During movement of a painful shoulder, nociceptors are stimulated by compression and stretching of tissues. This further the creation of compensation that allows for maintenance of the painful movement and change of choice of muscles used to execute the movement. For an individual person with stress-induced changes of the supraspinatus muscle accompanied by interruption of the continuity of its fibers, inflammatory response, pain of the tendon muscle – considered the originator of shoulder abduction in the first phase of movement – obstructs the work of the supraspinatus muscle. This comes about via reflex mechanism, the torso tilting towards the painful shoulder causing passive abduction, after which the deltoid muscle activates continuing abduction process. In case of acute failure of the supraspinatus muscle, the head of the humerus may move upwards. This leads to narrowing of the space under the acromial process. Right compensation under natural conditions is different from compensation under pathology. Pain and muscle weakness change movement patterns and reduce replacement mechanisms. Considerable innervation of 15-17 muscles that act on the shoulder is mainly managed by the propriospinal connections in abdominal-medial part of the spinal cord. These muscles work together in a strictly defined, synergistic pattern. Patients after injury or chronic shoulder pain, if treated through immobilization often complain of "clumsiness", poor motor coordination. This consists of limiting the ability to perform rapid, repetitive movements, which results from

changes in the posture reflexes of the central nervous system [40]. Numerous reports [13,18,25,30,40,41,42] indicate that including proprioception in any general rehabilitation program is advisable, since losses via serve-muscle system as well as proprioception disorders may predispose an athlete to reinjury.

Compensations are automatic phenomena managed by the central nerve system, spinal and supraspinal tracts. Inhibition or co-contraction of the muscles around the joint, derived from the supraspinal levels that constitute motor strategy of reducing or avoiding pain, may be caused by the anticipation of intensification of pain by the patients. Disorder in the implementation of strategy of avoiding pain appears in case of presence of proprioception disorders. Research shows that proprioception is more impaired in patients with unstable shoulders than in normal individuals [43]. This is manifested by the lack of adoption of safe position of arm by the former. Stimulated receptors at the marginal positions of the joint in the tendons and the joint capsule may, in case of overload of the joint, lose the ability to transmit kinesthetic information and this in turn could lead to instability or dislocation of the joint. With the disappearance of pain, proprioception and correct interaction of the shoulder girdle anatomical units and correct avoidance of dangerous positions are restored [40].

Conclusions

Motor organs of all athletes are subject identical laws of healing tissues [18]. Injuries to soft tissues never heal without a trace. Healing of the injuries consist of substitution of high-quality tissue (muscle, tendinous, etc.) with defective tissue. This leads to filling of injury space, but minus restoration of the original flexibility and resistance to loads and pressures [19]. The consequence of this is the not so rare permanent loss of proprioception. That is why, in the physiotherapy program for patients after injury and in problems with the shoulder complex, in addition to the elements for restoring range of motion in the joint, muscle strength and endurance, it is essential to carry out activities aimed at restoring proprioception and neuromuscular control.

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