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Quais são as funções dos mecanoreceptores da articulação do ombro? Uma revisão da literatura

What are the functions of the mechanoreceptors in the shoulder joint? A literature review

Marcio José dos Santos[1]

RESUMO: Entre as patologias de ombro em pessoas jovens, a instabilidade glenoumeral não traumática é a mais comum, causando dor e sintomas de Síndrome do Impacto. Esse tipo de instabilidade normalmente acomete atletas que praticam atividades as quais exigem repetidas elevações do braço acima da cabeça, tais como voleibol e natação. A estabilidade glenoumeral é assegurada pela musculatura do manguito rotador e pelas estruturas cápsulo-ligamentares (labrum glenoidal, ligamentos glenoumeral e cápsula). O sistema somato-sensorial localizado na articulação glenoumeral presta um importante papel no sentido de controlar a sinérgica relação entre essas estruturas (músculo, cápsula e ligamentos). Denominados como mecanoreceptores, Pacini, Ruffini e organ tendinoso de Golgi são funcionalmente distribuídos na articulação do ombro, tendo uma complexa relação com a musculatura a qual envolvem. De acordo com as latências obtidas entre estímulos elétricos dados na articulação do ombro e as respostas obtidas na musculatura, considerar-se que os mecanoreceptores não somente estão envolvidos na detecção do movimento e posicionamento articular no espaço, como também podem estar envolvidos no controle dos movimentos e coordenação. Programas de reabilitação usando propriocepção em distúrbios do movimento são absolutamente justificáveis. Adicionalmente, objetivando melhores resultados no programa de reabilitação, maior atenção poderia ser delegada às técnicas proprioceptivas que usam seqüências e coordenação de movimentos.

DESCRITORES: Instabilidade articular/reabilitação. Articulação do ombro/lesões. Mecanorreceptores. propriocepção. Literatura de Revisão.

ABSTRACT: Nontraumatic glenohumeral instability is the most common shoulder pathology among young people causing pain and "impingement syndrome symptoms". This instability usually affects athletes who perform overhand activities such as throwing and swimming. The glenohumeral stability is usually provided by rotator cuff musculature and capsule-ligament structures (glenoid labrum, glenohumeral ligaments and capsule). In order to control the synergistic relationship between muscles and capsuloligamentous structures, the somatosensory system located in the glenohumeral joint plays an essential function. These mechanoreceptors, Pacini, Ruffini and Golgi tendon organs are functionally distributed in the shoulder joints, and they have a complex relationship with the shoulder's musculature. According to the latencies obtained between stimuli in shoulder joints and muscular responses, suggests the consideration that mechanoreceptors not only

[1] PhD in Rehabilitation Science supported by Conselho Nacional de Desenvolvimento Cientifico e Tecnológico - CNPq. Brasília, DF, Brasil. Nro. 200874/00-4 (NV). University of Kansas Medical Center, Department of Physical Therapy and Rehabilitation Sciences, 3056 Robinson, 3901 Rainbow Boulevard, Kansas City, KS 66160-7601, USA.

Endereço para correspondência: Marcio José dos Santos. 4871, Skyline Drive, Kansas City, KS, 66205, United States. e-mail: MSANTOS@kumc.edu

contribute to detection of movement direction and joint position sense, but are also implicated in the control of movements and coordination. Rehabilitation programs for altered movement patterns using proprioceptive techniques appear to be justifiable. Also, to enhance proprioceptive techniques, more attention should be focused on shoulder exercises that use sequences and coordination in their execution.

KEYWORDS: Joint instability/rehabilitation. Shoulder joint/injuries. Mechanoreceptors. Proprioception. Review literature.

INTRODUCTION

Shoulder pain is often observed in individuals who perform repetitive occupational or athletic activities[38,10]. Anatomic abnormalities of the coracoacromial arch or humeral head, overload, ischemia, degeneration of the rotator cuff tendons, decreased muscular activity, proprioceptives deficits, asynchronisms between movements at the glenohumeral and scapulothoracic joints are the principal causes attributed to shoulder pain, which is usually refered to the impingement syndrome[20,25,26,28,31,34]. Specifically, nontraumatic glenoumeral instability is the most common pathology among young people causing pain and impingement syndrome symptoms. This instability usually affects athletes who perform overhand activities such as baseball, volleyball and swimming[2,3,5,16,27].

In the shoulder, joint bone constraints are not sufficient to provide restrictions to functional stability, and it is generally accepted that glenohumeral stability is usually provided by rotator cuff musculature and capsuloligaments structures (glenoid labrum, glenohumeral ligaments and the capsule)[4,6,24,30]. In order to control the synergistic relationship between muscles and capsuloligment structures, the somatosensory system located in the glenouhumeral joint plays an essential function, providing feedback, stability and coordination to the shoulder joint. However the action mechanisms these structures are not completely understood. The purpose of this current review is to collect the principal investigations about the action mechanisms of the shoulder joint mechanoreceptors, highlighting the recent important investigations in this field, and to provide a better understanding of the reflex interactions in the shoulder joint.

MATERIALS AND METHODS

With the aim of covering the recent and principle works in this field, the MEDLINE search was performed for articles published within the last 10 years. The literature search was in any language using the keywords shoulder, joint mechanoreceptors, laxity, instability, reflexes, proprioception, alone or in combination. Additional literatures in support of the principles described in this article have also been used, which do not necessarily follow the above procedure.

Capsuloligaments afferents

There are normally four types of capsuloligament end organs, or "mechanoreceptors", and they are responsible for afferent supply from the periphery to central nervous system (CNS). Three types of receptors are encapsulated, the Ruffini, Pacini and Golgi tendon organs. The fourth type of receptor is not encapsulated and is called "free nerve endings". In a classical definition, Ruffini's receptors act as a detector of the end ranges of rotation and are slow adapting. Pacini's receptors are quick adapting and sensitive to acceleration, vibration and deformation. The Golgi tendon organs are slow adapting elements and are responsible for detecting direction of movement and exact joint position sense[34]. Finally "free nerve endings" are activated by localized noxious and deformation stimuli[29].

The study of Backenkohler and coworkers[1], using microscopic reconstruction of stained and 3-D reconstruction in rats, has shown the topographic distribution and density of the mechanoreceptors in the shoulder joint region. According to this study, most of the Pacini receptors were found in the axillary and ventro medial capsular regions. Ruffini corpuscles were detected within ventral parts of the joint capsule and confined to a narrow area, where they appeared in small numbers. Finally, most Golgi tendon organs were found predominantly in the area of insertion zones of the rotator cuff muscles, biceps and triceps muscles, and in smaller numbers in the capsule tissue.

In studies of human tissue, Gohlke and coworkers[12] have investigated the morphology and distribution of mechanoreceptors the shoulder joints of cadavers. They isolated a single glenohumeral capsule, including the musculature surrounding the joint. Using electron microscopy and antibody staining for neural elements, they found three types of corpuscular and free nerve endings in different distributions. The Ruffini endings were most frequent in the coracoacromial ligament, and Pacini corpuscule were predominantly found in the joint capsule. Analogous with the experiments of Backenkohler and collaborators[1], the Golgi tendon organs were predominantly seen in the musculotendinous junction in this case subscapularis and supraspinatus.

The distribution and quantity of the neuro structures were better addressed in studies by Guanche and coworkers[14], who used staining and light microspopy to localize the Ruffini, Pacini, Golgi tendon organs and free nerve ending receptors in each of the superior, middle and inferior glenohumeral ligaments, as well as the shoulder capsule of the cadaver specimens. In the superior glenohumeral ligament, the most common receptors found were Ruffini and Golgi types. Paccini and Ruffini receptors were most seen in the middle glenohumeral ligment. In the inferior glenohumeral ligament, the receptors were equally distributed between Ruffini, Paccini and Golgi types. In the shoulder capsule (glenohumeral areas) Pacini and Ruffini receptors were the most prevalent as well as free nerve endings. This study confirmed the previous investigations of Wangness and coworkers[36], who have demonstrated abundant mechanoreceptors in the shoulder ligaments, especially Ruffini organs, with vast distribution in the glenohumeral ligments.

From these results we can conclude that the density and localization of these receptors are corresponding to their function. The presence of these structures is greater where sensory control is most important. High concentrations of Paccini and Ruffini receptors were found more in the inferior and anterior in the ventral capsule and glenohumeral ligaments. It is well known that the inferior and anterior shoulder areas are the most susceptible to biomechanical stresses in activities like shoulder elevation and external rotation[30]. The high concentration of these receptors in this region may induce or increase the protection of shoulder structures when an extreme movement is required, for example in throwing sport activities.

Proprioception

Proprioception is defined as the afferent neural input originating from joint mechanoceptores and/or muscles, which are responsible for the information about position and movements of one's own limbs and body without necessarily using vision[8]. Afferent neural inputs may travel by the ascending tracts (dorsolateral and spinocerebelar) directing the information to the higher CNS, such as the cerebellum and somatosensorial cortex through the thalamus, where this information is analyzed and transformed into a response by the motor cortex, with possible corrections performed by cerebellum. On the other hand, the afferent neural input may have synapses directly with the alpha motor neurons, gamma motor neurons or interneurons, and this information is processed at the spinal level[34]

As described above, the presence of many receptors in the shoulder capsule and their proprioceptive properties are acknowledged. However, through experiments with cats resulted in the first evidence of the reflexive relationship between the capsule and muscles of the shoulder joint. Bipolar supramaximal electrical stimulation was performed in three branches of the axillary nerve terminating in the shoulder capsule. The time between the EMG recordings activity of the biceps, subscapularis, supraspinatus, infraspinatus and acromiodeltoide were assessed to characterize the reflex activation. The stimulation of the anterior and inferior axillary articular nerve resulted in reflex activation of the biceps, subscapularis, supraspinatus, infraspinatus in all of the samples tested. The stimulation of the posterior axillary articular nerve resulted in EMG activity only in the acromiodeltoid muscle. When the nerves were cut, the EMG responses were not seen. The time between the peak of the stimulus artifact and the M-wave was characterized as the duration from eliciting an action potential in the nerve. Its conduction time to the spinal cord was measured by way of afferent nerves, passed by synaptic connections in the spine, conducted from the spinal cord to the muscle by way of motor nerves, transmitted across the neuromuscular junction, and finally producing muscle activation. The time required to elicit the reflex was 3.1, 2.7, 2.9, 3.1 msec. for the infraspinatus, biceps, supraspinatus and subscapularis muscles, respectively[13] Performing the same protocol, Knatt and coworkers showed exclusive activation of the biceps muscle from musculocutaneous nerve stimulations (capsule innervation) with a latency of 2.7 milliseconds (Table 1)[21].

TABLE 1- Principal Latencies found between nerves joint stimuli and muscular responses in experiments with shoulder mechanoreceptors.

Latencies (ms)	Muscular response	Joints	Task condition	Authors
3.1	activation	shoulder/felines	relaxed	Guanche et al., 1995
2.7	activation	shoulder/felines	relaxed	Knatt et al., 1995
212	activation	shoulder/humans	relaxed	Jerosh et at., 1997
1 to 8	activation	shoulder/humans	relaxed	Voigt et al., 1998
33/100 to 150	inhibition/activation	shoulder/humans	voluntary contraction	Voigt et al., 1998

From these studies we can conclude that there is a direct correlation between mechanoreceptors from the capsule to the shoulder muscles. Consequently, in cats, there is a synergism between capsule-ligaments and muscles, which play an important function in shoulder protection using a reflex arc and not merely acting in a mechanical or "information" function. In addition, the location and pattern responses found from different capsule and ligaments receptors are likely designed to provide shoulder stability from stress applied from different directions. For example, glenohumeral abduction combined with external rotation movements impose most stress in the inferior and anterior portions of the capsule and ligaments, which, via the reflex arc, activate the rotators cuff (subscapularis, supraspinatus, infraspinatus) to keep the humeral head firmly against the glenoid fossa avoiding excessive anterior translation.

From animal experiments the existence of an automatic protective mechanism from the mechanoreceptors seems evident. However one question should be answered: Are there the same kind of reflex mechanisms in the human shoulder joint? More recent reflex mechanisms were investigated in patients who had arthroscopic surgery for subacromial decompression[15]. Bipolar cardial pacemaker electrodes were inserted into the anterior-superior joint capsule and needle electrodes registered eight shoulder muscle activities. Seven patients were anaesthetized with a neuroleptanalgesic, and one had scalene analgesia. Muscular activities were registered in all seven patients anaesthetized with latencies varied from 100 to 516 ms. (mean 215ms.) (Table 1). For the patients with regional analgesia no muscle activation was registered after stimulation. Performing experiments in awake subjects, Voigt et al.[37], through arthroscopy, inserted pairs of fine implants at different sites in the joint capsule such as the anterior-superior, anterior-inferior and posterior-superior quadrants of the shoulder capsule. Additionally, these implants were also inserted in the inferior glenohumeral ligament and the tendons of the biceps long head and biceps brachi muscles. Following the surgical procedures, implants to register EMG signals were inserted in the supraspinatus, infraspinatus, subscapularis, and three parts of the deltoid muscle, long head of biceps and biceps brachi. After the subjects completely recovered from the anesthesia, non-noxious stimulation was given to the glenohumeral capsule and other structures in relaxed and isometric contraction coditions. Despite the noise of the signals, the authors observed large and short latency EMG responses only in the three parts of the deltoid muscles when the anterior-inferior quadrant was stimulated in the relaxed condition. These latencies were estimated to lie between 1 and 8ms. In one subject, large excitatory responses with long latencies were seen in the subscapularis, infraspinatus and medial part of the deltoid muscle. Conversely, stimuli given under isometric contractions elicited a very strong general inhibition followed by a burst of excitation and one or two cycles of oscillation between inhibition and excitation in all activated muscles around the joint. The average latency of the onset of the inhibition was around 33ms (Table 1). Interestingly, there were no differences in the responses to the stimulation dependent on the contraction strategy.

The results presented in this study demonstrate a consistent feedback pathway through mechanoceptors. Therefore, the most consistent excitatory latencies, subscapularis and infraspinatus muscles, were longer (47 and 52ms.) than those found in the feline shoulder experiments (3.1ms.). According to Guanche and coworkers[13], similar reflexes in humans would be expected to have a latency of about 10ms., because of the larger size of the human limbs. Along with the main finding in the Woigt and coworkers[37] experiments, was the inhibitory characteristic of the responses when the muscles were voluntarily activated (Table 1). Poulsen and Krogsgaard[32], presented similar results in experiments with knee joints, however, they were response-dependent on the stimuli. The testers implanted stimulus electrodes directly into the ACL during knee arthroscopy in eight patients with suspected meniscus lesions. The EMG activities from the medial head of the quadriceps femoris, rectus femoris, long head of biceps femuris, semitendinosus, and medial head of the gastrocnemius muscles were registered while electrical stimulations were given to the afferent nerve fibers. The changes in EMG activities were taken during rest and during isometric muscle contractions in knee flexors and extensors. Under relaxed conditions, a series of electrical stimuli given to the ACL produced visible contraction in the hamstrings in seven patients with a latency of 95m.. In contrast, when the knee flexors were voluntarily isometrically activated, the response changed to total inhibition of the active hamstring, and in gastrocnemius muscles with a latency of 65ms. In a similar way, with a latency of 100ms., there was a strong inhihibition of the rectus femuris and medial quadriceps when the patients performed knee extensor contractions.

Although these studies have demonstrated that the activities in the muscles around the joints (shoulder and knee) are influenced by sensory input from mechanoreceptors, most of them differ from the cat experiments, which have shown significant shorter latencies, similar to the flexor reflex afferent (FRA) responses (Figura 1A). In addition, they found inhibitory responses with voluntary movements, which was influenced by the type of activity performed by the subjects (relaxed, flexed and extended isometric contractions), with different latencies. In this case, direct muscle reflexes from capsule and ligament afferents, as a protective function, appear to not be used by humans.

The results found in human experiments suggest that the relationship between mechanoreceptors and the muscular responses are more complex than those proposed previously in cat studies, from the latencies and the type of responses, other pathways must be taken in consideration. Gamma mediated control has been proposed by Johansson and colleagues[17] (Figura 1B). They performed graded electrical stimulation in the posterior articular nerve of knee joint on the population of static and dynamic gamma motoneuron in anesthetized cats. The stimulation on these nerves was very effective in eliciting reflex responses in almost all cells investigated ($\cong$ 92%). All types of reflex responses were observed: i.e., excitatory and inhibitory, as well as the combination of excitation with inhibition.

Reflex mechanisms through Golgi tendon organs (Ib afferents) present in the musculo-tendinous junction are another inhibitory pathway that should be considered. These receptors are located usually near or within the articular capsule. Priori and coworkers[33] demonstrated that stimulation in these structures provoked a dysfacilitation of the a - motorneurones supposedly through pre-synaptic inhibition of IA fibers (Figure 1C).

Finally, inputs from joint afferents can directly reach the primary motor cortex through relatively simple transcortical pathways. This transcortical pathway provides a degree of flexibility to rapid responses that are unavailable in spinal reflexes[34]. This type of reflex is characterized by the long latency response (long loop - 40ms. for arms and 100ms. for legs) compared to spinal reflexes (short loop - 10/20ms. for arms and 60ms for legs). Experiments with monkeys have demonstrated that spindle input to the motor cortex is powerful enough to change the firing patters of pyramidal tract cells (cortical pathway) during the course of movement, and this activity can influence spinal motorneurone discharge. The best example of this was the experiment where a monkey held a constant position of the wrist by contracting the flexor muscle against a constant load. If the load was suddenly removed, thereby unloading the active (flexor) muscle, the activity of the pyramidal cells was followed by corresponding changes in EMG activity of the flexor muscles with a latency appropriate for the known conduction times from the motor cortex (long loop response)[7]. Another example of the long loop latency is the group of experiments on grip force[18,19], which from the time of response showed that cutaneous afferent discharge could exert powerful and appropriate reflex changes to the commands involved in a coordinated grip. Future experiments to investigate long-loop responses from afferents in joints (mechanoreceptors) should be developed (Figure 1D).

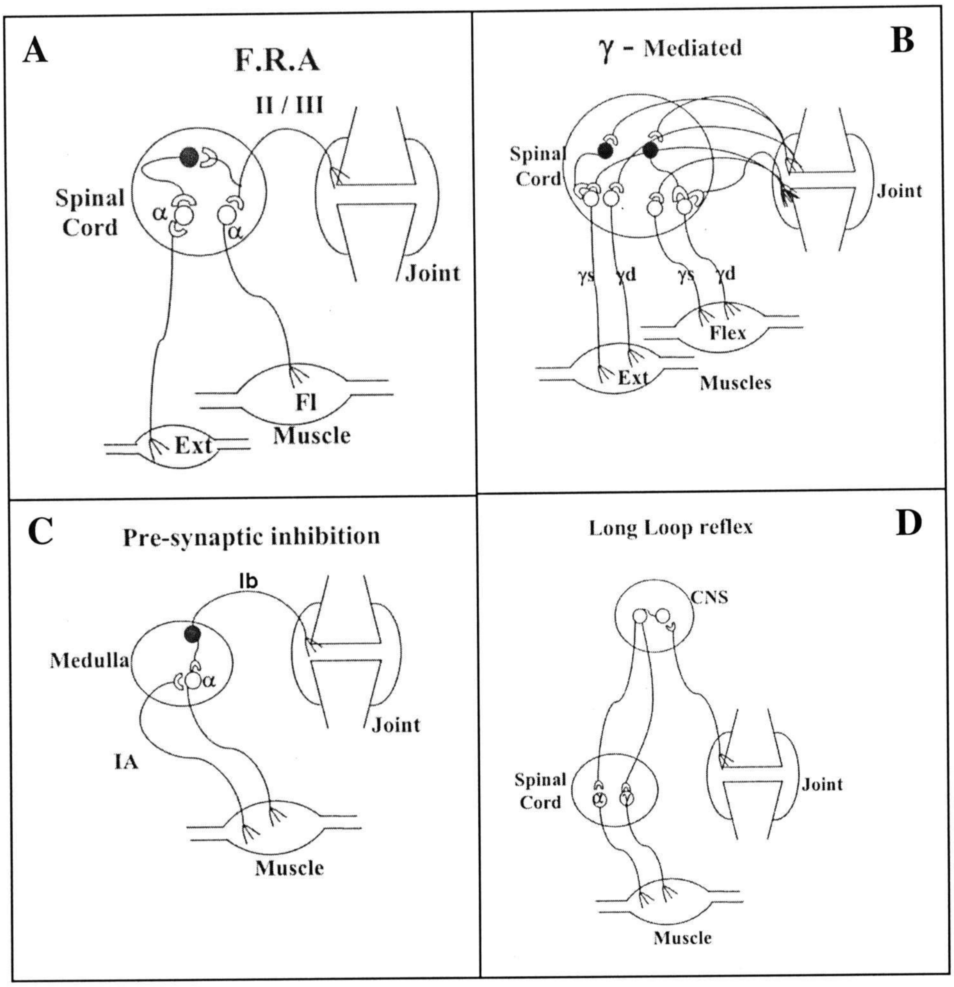

FIGURE 1 – Representative schema showing the possible pathways utilized by the CNS from peripheric stimuli (joints). A) flexor reflex afferent (FRA); B) gamma mediated; c) pre-synaptic inhibition of IA from Ib; d) long loop reflex.

Clinical investigations

Several studies have associated the frequent problems of glenohumeral joint instability with kinesthetic (sense position) and neuromuscular control deficits in subjects with recurrent glenohumeral instability (traumatic and nontraumatic)[9,35]. However, Zukerman et al.[39] demonstrated no differences in healthy subject kinesthesia to perform passive shoulder movements under the effect of lidocaine injections. The authors concluded that if the receptors of the joint capsule and glenohumeral ligaments are responsible for proprioception, then there is adequate compensation from extracapsular receptors, such as the muscle spindles. Assembling these studies, and beyond this last explanation, we can speculate that, in unstable shoulders not only the capsule and ligaments were affected but also mechanical and neural structures surrounding the joint, disrupting neural conduction pathways that make intricate interconnections among peripheral and central structures. Additionally, although the joint mechanoreceptors can divide the kinesthetic sense with muscular spindles, they also can play a crucial role in the coordination of movements (not tested in this experiment), in which the joint nerves have demonstrated more responsiveness than the muscle afferents in the Johansson and et al.[17] experiments.

Glousman et al.[11] measured shoulder muscle activities during pitching using fine wire electromyography in subjects with anterior glenohumeral instability. The authors showed an increase in the biceps and supraspinatus muscle activities, combined with a decrease in the pectoralis major, subscapularis, latissimus dorsi and serratus anterior. Imbalances in muscles activities also have been reported in the middle and anterior deltoid during flexion and abduction of the shoulder, which decreased their activity. In contrast, the subscapular muscle showed an increase of activity during internal rotation. This experiment compared patients suffering from recurrent anterior shoulder dislocations and generalized joint laxity with normal subjects[22].

Functional significance

The present review has shown clearly that the presence of differentiated types of receptors (capsule and ligaments) in the shoulder joints shows convincing relationships with muscles involved in the control, stabilization and execution of movements. The latencies obtained between stimuli and muscular responses leads one to consider the actions of other possible mechanisms used by the nervous system to control movements. According to mechanoreceptors, they not only contribute to detection of movement direction and joint position sense, but are also involved in the control of movements and coordination. Disruptions in these pathways can modify muscular coordination, and compromising shoulder stability. In addition, this instability can lead to excessive superior and anterior humeral head translations predisposing the shoulder's structures to micro traumas, thus leading to recurrent inflammations, such as the well known impingement syndrome.

In view of the previous findings, rehabilitation programs for altered movement patterns using proprioceptives techniques are absolutely justifiable. Normally, these techniques deal with position sensibility activities, muscular co-activation, and reflexive activities, such as plyometric shoulder exercises[23]. Also, in order to enhance the proprioceptive techniques, more attention could be attained in shoulder exercises that use sequence and coordination in their execution, once alpha motorneurons and long loop responses are involved in these types of tasks[17,18,19]. Finally, additional experimental and clinical investigations should be done to elucidate both: the proprioceptive deficits involved in shoulder instability and the effective functions of the joint mechanoreceptors. Once these responses are obtained, treatment approaches for joint instability can be optimized.

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