Influence of static wrist orthosis on muscle activity and shoulder and elbow range of motion during a functional task: a biomechanical study

Influência da órtese estática de punho na atividade muscular e amplitude de movimento de ombro e cotovelo durante uma tarefa funcional: estudo biomecânico

Influencia de la ortesis estática de puño en la actividad muscular y la amplitud de movimiento de hombro y codo durante una tarea funcional: el estudio biomecánico

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ABSTRACT | Orthoses are therapeutic resources that are appropriate to protect and remedy deformities or to help in the performance of certain functions; however, its use may lead to proximal compensations in the shoulder. Thus, this study aims to evaluate the influence of dorsal static 30° extension orthoses on the shoulder and elbow biomechanics in 25 asymptomatic individuals during a functional task. The range of motion and muscle activation was collected by simultaneous and synchronized analysis during the Elui functional test related to feeding, under the conditions with and without the orthosis. In order to allow a comparison of the different subjects and muscles, the data were analyzed by EMG signal of each muscle and, for kinematic analysis, pre-defined marker coordinate systems were constructed. The captured signals were filtered and processed by custom software, and the t-test for paired samples, SPSS® software, p<0.05, was used. We found significant increase in activation of the anterior deltoid and pectoralis major muscle in the reach phase and upper trapezius, anterior and posterior deltoid in the release phase with the orthosis. The kinematic analysis showed a significant increase in the range of motion of shoulder abduction movements, elbow flexion and pronation in the displacement phase and shoulder extension and elbow flexion movements in the release phase. Our findings suggest that the use of static wrist orthosis while performing a task can lead to compensations, with predominant activation of more proximal muscles of the upper limb.

Keywords | Activities of Daily Living; Electromyography; Biomechanical Phenomena; Upper Extremity; Orthotic Devices.

RESUMO | As órteses são recursos terapêuticos indicados para proteger, corrigir deformidades ou auxiliar em certas funções; porém, seu uso pode acarretar compensações proximais no ombro. O objetivo deste estudo é avaliar a influência da órtese estática dorsal do punho, em 30° de extensão na biomecânica do ombro e cotovelo, em 25 voluntários assintomáticos durante uma tarefa funcional. Os dados da amplitude de movimento e ativação muscular foram adquiridos de forma sincronizada e simultânea durante parte do teste funcional Elui, que simula alimentação, dividida em alcance, deslocamento e liberação, de uma jarra, nas condições sem e com órtese. Para possibilitar a comparação entre os diferentes sujeitos e músculos, os dados foram analisados pela integral do sinal EMG de cada músculo e, para análise cinemática, foram construídos sistemas de coordenadas de marcadores pré-definidos. Os sinais captados foram filtrados e processados por um software personalizado, e utilizou-se o teste t para amostras pareadas – software SPSS, p<0,05. Notou-se um aumento significativo da ativação dos músculos deltóide anterior e peitoral maior na fase de alcance, e trapézio superior, while performing a task can lead to compensations, with predominant activation of more proximal muscles of the upper limb.

Keywords | Activities of Daily Living; Electromyography; Biomechanical Phenomena; Upper Extremity; Orthotic Devices.

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INTRODUCTION

The upper limb is an important segment for contact with the external environment, and the joint sensorimotor system and the peripheral sensory nerve fibers are essential for proper movement skills, enabling to perform the activities of daily living (ADLs)\textsuperscript{1-3} such as grasping and handling of objects, feeding or dressing, directly depending on the proper stability of the wrist\textsuperscript{4}, mainly represented by the synergistic action of the extensor and flexor muscles of the wrist and fingers\textsuperscript{5,6}. While performing a functional task with the fingers, the stabilizers of the wrist, elbow and shoulder help prevent compensatory movements and, therefore, are closely related\textsuperscript{2}.

Biomechanical studies using surface electromyography and kinematics have been used for objective and quantitative assessments of the upper limb\textsuperscript{8,9}. Electromyography evaluates the muscular activity of the musculoskeletal system and the kinematic analysis evaluates the movement performed without taking its causes into account\textsuperscript{10}.

Orthoses are therapeutic devices to stabilize or immobilize, prevent or correct joint deformity, protect and assist the healing process or facilitate the functioning, and may have more than one purpose\textsuperscript{11,12}. Orthoses are therapeutic resources and, as such, they should be prescribed considering anatomo-physiological principles related to the disease or dysfunction, after an individual evaluation in a rehabilitation process of the patient with a specific functional deficiency or pain issue, and they can be prefabricated or tailor made, produced from various thermoplastic materials of high or low temperature, involving a segment or one or more volar, dorsal or semi-circular joints\textsuperscript{13,14}. Studies have shown that their use while performing functional tasks may lead to changes in the quality and pattern of movement across the upper limb, with compensations in terms of overload on the proximal muscles, when compared to the same movement without the device\textsuperscript{15-18}, increasing the risk of compensatory proximal lesions in the shoulder\textsuperscript{19}. They have also shown that static wrist extension orthoses inhibit the activation of wrist extensors during finger gripping tasks, thus being indicated in specific pain cases\textsuperscript{17}. However, no study has performed the simultaneous analysis of changes in joint kinematics and electromyographic activity in the upper limb in people with a wrist orthosis. Such findings can help rehabilitation professionals anticipate the effects.
and properly guide patients on the use of these devices while performing functional tasks. Then, this study aimed to analyze and compare the electromyographic activity and simultaneous kinematics of the shoulder and elbow while performing a functional task with and without a dorsal wrist extension static orthosis.

METHODOLOGY

This study was approved by the Research Ethics Committee of the Hospital das Clínicas da Faculdade de Medicina de Ribeirão Preto da Universidade de São Paulo, protocol nº 777.193. All study participants signed an informed consent form. The sample was calculated with GraphPad StatMate®, using the standard deviation of the values (µV) for the electromyographic activity of the extensor carpi radialis muscle while performing a gripping task. Data were obtained from a pilot study with 16 participants. The sample of 25 volunteers and 90% power was obtained.

Participants

Twenty-five healthy subjects, aged 18-35 years, male and female, with right hand dominance confirmed by Edinburgh inventory were invited to participate in the study. Individuals with prior history of trauma or musculoskeletal dysfunction in the upper limbs and individuals diagnosed with cognitive impairment were not included.

Surface electromyography

A Delsys® (Trigno Wireless System) electromyography machine, set to the acquisition frequency of 2,000 Hz, was used to capture the activation of the studied muscles. The skin site where the sensors were placed had its hair removed and cleaned with 70% alcohol. The sensors were fixed in place by means of double-sided adhesive tapes supplied by the equipment manufacturer. The position of the sensors followed the recommendations of the SENIAM (Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles) project, so that the parallel bars of the sensors were perpendicular to the muscle fibers.

Kinematic analysis

For the kinematic analysis, a 3D image capture system (Nexus, Vicon Motion Systems Ltd) comprised of eight infrared cameras that captured the movement by tracking seven passive reflective markers, which were fixed to the skin with double-sided adhesive tape (Figure 1). The positioning protocol of the markers was defined from a previous pilot study and the location of the markers on the trunk, shoulder and elbow was based on a protocol pre-established by the software. To ensure proper tracking of the markers while performing the movement, the cameras were arranged around the entire collection field. Then, all markers were tracked regardless of the utensils used to perform the dynamic functional test of the upper limb, or any change of limb position in the different planes of movement during the analyzed task.

Figure 1. Position of reflective markers
A: side view; B: back view; CLAV: jugular notch of the sternum; AACE: Left acromioclavicular joint; AACD: Right acromioclavicular joint; ELD: Right lateral epicondyle; EMD: Right medial epicondyle; PEU: Midline of the forearm in the direction of the ulnar styloid process; PER: Midline of the forearm in the direction of the radial styloid process.
The kinematic analysis allowed to obtain the range of joint motion of flexion, extension, abduction and internal rotation of the shoulder, flexion, extension of the elbow and pronation and supination.

Signal processing

Trigno® Wireless is a system that allows the integration with Vicon Motion Capture System®, so that both electromyographic and kinematic data were acquired synchronously and simultaneously with Vicon Nexus Software®. After a pre-processing performed in the same software to adapt the exported data format, signal processing was performed offline in custom programs in Matlab® software (The MathWorks, Inc.).

The raw signal passed through a 4th-order bandpass Butterworth filter, with a cutoff frequency between 10 and 500 Hz. To obtain the linear envelopes (iEMG), the filtered signal was rectified and then filtered again using a 4th-order 15 Hz lowpass Butterworth filter. Then, iEMG corresponded to the mean integral of each muscle in the analysis window of interest, allowing subsequent comparisons.

In the kinematic analysis, data were filtered using a 4th-order lowpass Butterworth filter with a cutoff frequency of 5 Hz. Subsequently, local coordinate systems of the trunk, arm and forearm were built from seven predefined markers and following the recommendations of the International Society of Biomechanics. Euler angles were used to obtain the joint angles. The movements were described from the distal segment in relation to the proximal segment following the Y-X-Y rotation sequence.

The task

A functional task was selected that simulates a feeding ADL that belongs to the Elui Functional Test for the Superior Member, or the Elui Test. This is an easy-to-apply and reliable functional test that evaluates the functionality of the hand and upper limb, recording the time in seconds it takes to independently perform each of the seven tasks. The ‘Pour Water’ task was chosen because it involves gripping fingers with stabilization of the wrist extension, associated with the displacement of a load, which consisting of moving a jug with one liter of water from one place on the table and pouring its content into another jug away from it. To perform the task, a volunteer was placed sitting with his hand to be tested on the table at the indicated place, and the other hand remained all the time on the left thigh. After the ‘go’ command, he performed the following sequence of movements: pick up the plastic jug with water, go around the table, return, and pour the water into the other jug, and finally returning the empty jug to its original place (Figure 2). In addition to the markers on the volunteer, three markers were also placed on the first jar to track its displacement while performing the task, subdividing it into phases called reach, displacement, and release of the jug for data processing.
The dorsal wrist orthosis (Figure 3) was made of Taylor 3.2 mm low-temperature thermoplastic material for molding purposes and it was individually adapted to each volunteer by means of three adjustable Velcro straps, the first on the volar face of the hand and the other two on the forearm. The volunteers were evaluated while performing the functional task in two conditions in random order, with 2-minute interval: without the orthosis and with dorsal wrist orthosis at 30° extension. This angle was defined in previous electromyographic studies as the one of the greatest muscular inhibition of wrist extensors, but allowing the grip of the fingers. The use of the orthosis on the dorsal side of the hand and forearm was selected to release the palmar face of the hand, for easy grasping of the fingers during the functional task.

Figure 2. Start position and the phases of the task performed in the Elui test – ‘Pour water’: reach, displacement, and release

Orthosis

Figure 3. Static orthosis at 30° extension of the dorsal wrist in thermoplastic material
Data analysis

Data processing and graphic representations were developed offline using Matlab® software (The MathWorks, Natick, MA). Both muscle activity and range of motion were compared in different conditions. The kinematic analysis evaluated the average of the maximum values of each movement in each phase. The analysis of the electromyographic data used the mean value for the integral (iEMG) from the linear envelope of each muscle in each phase and each condition. The statistical analysis used the t-test for paired samples, after confirming data normality by the Shapiro-Wilk test, using the SPSS® software. The level of significance was p < 0.05.

RESULTS

The time to perform the ‘Pour Water’ task of the Elui Test was on average 13.3±2.4 seconds. The reach phase corresponded to 11.31%, the displacement phase 77.43%, and the release phase 11.23% of the total cycle of the task. With the orthosis, the mean time to perform the task was 14.6±3.1 s; the reach phase corresponded to 11.95%, the displacement phase 77.15%, and the release phase 10.89% of the total cycle of the task. No significant difference was observed between the conditions with and without the orthosis.

In the reach phase, a significant difference was observed in the mean value of the integral for the activation of the anterior deltoid muscle (AD) (87.93±17.22 µV) in the condition without the orthosis when compared to the AD (99.23±27.00 µV) with the orthosis, and the pectoralis major (PM) muscle (74.88±14.63 µV) without the orthosis when compared to the PM (85.27±25.44 µV) with the orthosis. During the analysis of the displacement phase, no significant difference was observed for any of the muscles analyzed. In the release phase, significant differences were observed for the activation of the upper trapezius (UT) (65.08±27.47 µV) without the orthosis, when compared to the same muscle with the orthosis UT (77.75±26.68 µV), AD (55.72±22.05 µV) without the orthosis when compared to the AD (66.85±21.21 µV) with the orthosis, and the posterior deltoid (PD) (55.89±19.01 µV) without the orthosis when compared to the PD (71.67±19.01 µV) with the orthosis (Graph 1).

Graph 1. Mean of the iEMG integral of each muscle, in each phase, in both conditions with and without the orthosis.

*Muscles with significant difference between the conditions (p≤0.05). Ts: Upper trapezius; DA: anterior deltoid; DM: medial deltoid; DP: posterior deltoid; BCP: biceps brachii; TCP: triceps brachii; PM: pectoralis major.
In the kinematic analysis, the average of the maximum values was obtained for each movement in each phase. During the reach phase, no significant difference was observed in the movements analyzed. However, in the displacement phase, significant differences were observed for shoulder abduction movements without the orthosis (0.12±10.90°) when compared to the use of the orthosis (-4.46±10.69°), flexion of the elbow without the orthosis (110.58±7.94°) when compared to the use of the orthosis (102.23±8.31°), and elbow pronation without the orthosis (12.41±5.21°) when compared to the use of the orthosis (10.33±5.68°). In the release phase, a significant difference was observed for the movements of shoulder extension without the orthosis (2.79±16.68°) when compared to the use of the orthosis (8.45±14.51°), and elbow flexion without the orthosis (98.11±8.70°) when compared to the use of the orthosis (90.97±8.72°) (Table 1).

Table 1. Movements analyzed in each phase of the task

| Movement       | Reach          | Displacement | Release       |
|----------------|----------------|--------------|---------------|
|                | FO  | EC  | AO* | RIO | FC* | PC* | EO* | FC* |
| Mean           | SD  | Mean | SD  | Mean | SD  | Mean | SD  | Mean | SD  |
| Without the orthosis | 66.08 | 14.88 | 53.24 | 9.93 | 0.12 | 10.9 | 42.91 | 10.44 | 110.58 | 7.94 | 12.41 | 5.21 | 2.79 | 16.68 | 98.11 | 8.7 |
| With the orthosis at 30° | 65.09 | 14.62 | 52.05 | 33.85 | -4.46 | 10.69 | 43.05 | 8.51 | 102.23 | 8.31 | 10.33 | 5.68 | 8.45 | 14.51 | 90.97 | 8.72 |

FO: shoulder flexion; EC: elbow extension; AO: shoulder abduction; RIO: internal rotation of the shoulder; FC: elbow flexion; PC: elbow pronation; EO: elbow extension. *Movements with statistically significant difference.

**DISCUSSION**

This study aimed to evaluate the influence of static wrist orthosis at a 30° extension on the biomechanics of the shoulder and elbow in asymptomatic individuals while performing a functional task. For this study, we considered the hypothesis that the standardized static wrist orthosis could alter the activation of the muscles and the range of motion of the upper limb. The selection of this orthosis was based on the studies conducted by Jansen et al.\(^25\) and Marcolino et al.\(^26\), who analyzed the influence of these orthoses at several wrist angles through electromyography of the wrist extensor muscles and observed reduced extensor muscle activation with orthoses at 30° extension, while performing a functional task of isometric grip.

Distal stabilization of the upper limb by means of an external device promotes a rearrangement of the entire proximal muscle and joint chain, so that the overall function is not impaired, with loss of fine and more specific movements. According to the electromyographic data obtained in this study, during the reach phase there was a greater interaction of the anterior deltoid and pectoralis major muscles, which would be explained by a probable proximal muscle compensation due to the distal restriction on the wrist caused by the orthosis while performing the task functional. In contrast, Ricci et al.\(^23\) did not observe a greater activation of the pectoralis major during the same phase, when the patterns of movement and muscular activation were analyzed while performing the same functional task, but without orthoses.

The displacement phase was characterized mainly by the transport of the jar with water and the displacement of the arm in the space. A relation of similarity of the muscular activation pattern can be observed in the displacement phase in the two conditions (with and without the orthosis), since there was no significant difference of activation in any of the muscles in that phase when comparing both conditions. It is due to the fact that during this phase, the wrist stabilization occurs not only because of the presence of the orthosis, but also because of the synergism of the forearm musculature required for any transport activity, allowing an isometric and stable contraction\(^27\). Therefore, the displacement phase is less influenced by the presence or absence of the orthosis, and it is a probable justification for the data obtained.

The release phase predominantly comprises movements supported by gravity; therefore, they require less muscular effort. The result obtained in the release phase shows that the co-contraction of the anterior deltoid and posterior deltoid muscles keeps the proximal stability of the limb to the detriment of wrist immobilization. Yoo et al.\(^28\) obtained similar results as they also demonstrated a significant increase in upper trapezius activation while performing an assembly task that required shoulder movement in space, when comparing the condition with and without the orthosis. Another study\(^29\) also demonstrated that
during a manufacturing task in which volunteers had to move objects and place them into a box, there was a significant increase in the activation of the upper trapezius, anterior deltoid, and posterior deltoid. With an electromyographic analysis, Ferrigno et al. reported that the use of a static wrist orthosis during a typing and computer mouse handling task also influenced the higher recruitment of the upper trapezius muscle, in agreement with the findings of this study.

During the reach phase, the main movements observed were shoulder flexion and elbow extension, which did not present significant difference when comparing the two conditions. Our findings differ from another study involving the use of a static wrist orthosis for the comparison of the effect of immobilization versus non immobilization when performing the movements of flexion, abduction, and shoulder rotation while feeding, in which a significant difference was found for the flexion and abduction movements, leading to a greater muscular activation of the shoulder with the orthosis in the feeding movement. A hypothesis for this difference in results may be the type of task selected, since the functional task of carrying a jar is a gross motor activity when compared to the feeding movement.

Shu and Mirka suggested, in a kinematic study that used an occupational task, a significant increase in shoulder abduction and trunk posture when the task was performed with the orthosis in the neutral position of the wrist when compared to the task without the orthosis. In this study, in the displacement phase, the presence of abduction movements and internal rotation of the shoulder, flexion and pronation of the elbow were observed. The negative value obtained in our results of this movement confirmed that during the displacement phase no abduction of the shoulder was observed in relation to its starting point. The use of the wrist orthosis limited mainly the movements originated at the proximal joints of immobilization. Therefore, due to wrist immobilization with the orthosis, significant differences were also observed in elbow flexion and pronation movements, since this task required a greater movement of excursion.

The predominant movements in the release phase were shoulder extension and elbow flexion, which can be considered the opposite pattern of the reach phase. A significant difference was observed for these movements when performed with and without the wrist orthosis, with great variability in the movement pattern among the volunteers.

Chang and Jung proposed that the use of volar wrist orthosis when performing skilled activities significantly reduced the generation of force and the time to perform the analyzed activities. Therefore, the authors explain the importance of the theoretical knowledge and a good evaluation when prescribing an orthosis.

The study limitations include the use of volunteers without injury in the upper limb, when simulating activities without prior training. Further studies are required to analyze biomechanical changes in clinical situations and while performing different functional tasks.

CONCLUSION

This study demonstrated that the use of a wrist orthosis at 30° extension altered the biomechanics of the shoulder and elbow when performing the selected task, with emphasis on greater muscular activation of the proximal muscles of the upper limb. A proper evaluation of the patient is required to prescribe the use of an orthosis, due to the effects that this device can produce in terms of biomechanical compensations while performing a task.

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