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Stabilization effectiveness and functionality of different thumb orthoses in female patients with first carpometacarpal joint osteoarthritis

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ABSTRACT

Background: Thumb orthoses have to reconcile and satisfy competing goals: stability and mobility. The purpose of the study was to characterize the stabilization effectiveness and functionality of different thumb carpometacarpal osteoarthritis orthoses.

Methods: Eighteen female carpometacarpal osteoarthritis subjects were included. Four orthoses were compared: BSN medical (BSN); Push braces (PUSH); Sporlastic (SPOR); and medi (MEDI). Three-dimensional thumb kinematics during active opposition–reposition with and without orthosis was quantified. Ranges-of-motion of the carpometacarpal and metacarpophalangeal joint in x- (flexion–extension), y- (adduction–abduction) and z-direction (pronation–supination) were determined. Hand functionality was examined by Sollerman test.

Findings: All orthoses restricted carpometacarpal range-of-motion in all directions. In x-direction carpometacarpal range-of-motion was smallest with MEDI and BSN, in y-direction largest with PUSH compared to all other orthoses, in z-direction smaller with BSN and MEDI compared to PUSH, but similar to SPOR. All orthoses restricted metacarpophalangeal range-of-motion in x-direction, except PUSH. In x-direction metacarpophalangeal range-of-motion was smallest with MEDI compared to all other orthoses. In y-direction and z-direction only BSN and MEDI restricted metacarpophalangeal range-of-motion. Sollerman score was highest with PUSH, lowest with MEDI and both differed from other orthoses. Values for BSN and SPOR were similar and lay between PUSH and MEDI.

Interpretation: Stabilization is borne by functionality. The high stabilization effectiveness provided by MEDI resulted in lowest hand functionality. PUSH, which partially stabilized the CMC joint and allowed large motions in the MCP joint, afforded largest hand functionality. Best compromise of stability and functionality could be reached with BSN. Long-term studies are needed to monitor clinical efficacy.

1. Introduction

Osteoarthritis (OA) of the thumb carpometacarpal (CMC) joint, also called the thumb trapeziometacarpal (TMC) joint, is a disorder that often causes pain and motion loss affecting typically postmenopausal women in their fifth to sixth decade of life (Fitzgerald and Hofmeister, 2008; Ghavami and Oishi, 2006). Although the exact etiology is unknown, genetic, gender, environmental and physiological factors all appear to play a role (Estes et al., 2000).

The CMC joint is considered the most important joint of the thumb; in turn, the thumb is the most important digit of the hand, as it greatly magnifies the complexity of human prehension (Neumann and Bielefeld, 2003). When individuals with symptomatic hand OA were compared with asymptomatic individuals, they reported two to three times as many functional limitations with dressing, eating and carrying a 10-pound load (Dillon et al., 2007).

In accordance to Eaton and Littler (1973) CMC OA can be classified into four stages that are discernible on X-rays. It is interesting to note that the degree of pain and associated functional problems varies considerably among patients with different stages of the disease; patients with minimal disease can experience severe pain, whereas those with advanced disease may be symptom free (Glickel, 2001).

The mainstay of conservative treatment of thumb CMC OA has been stabilization by orthotic devices (Barron et al., 2000), which has been fairly shown to relieve pain in patients (Bani et al., 2013a, 2013b; Becker et al., 2013; Berggren et al., 2001; Boustedt et al., 2009; Egan and Brousseau, 2007; Gomes Carreira et al., 2010; Valdes and Marik, 2010; Wajon and Ada, 2005; Weiss et al., 2004). The focus of splinting the thumb CMC joint is to decrease inflammation by providing rest and immobilization and to decrease pain by providing stability during activities that load the joint as well as to prevent or correct subluxation and deformity of the thumb (Zhang et al., 2007). A variety of thumb

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Fig. 1. Thumb orthoses to be tested. (A) Rhizo Forte V/2013, BSN medical (BSN); (B) Ortho CMC, push braces (PUSH); (C) Rhizo Hit, Sporlastic (SPOR); (D) Rhizomed, medi (MEDI).

orthoses are available (prefabricated and custom-made) in different types of material. However, since 40% to 50% of the hand's overall usefulness results from the action of the thumb and its irreplaceable role in accomplishing everyday tasks (Ateshian et al., 1995; Lin et al., 2011; Swanson et al., 1987), orthoses should optimally support the thumb CMC joint while leaving other joints of the thumb and hand completely free so that thumb and hand function is maintained (Weiss et al., 2004). This builds the basis for patient compliance and therefore treatment success.

Although immobilization of the thumb by orthotic devices in CMC OA is common practice, there are no guidelines specifying the type of orthosis suitable for CMC OA treatment. Research evidence is missing to support one specific orthotic type or design that best meets pain relief, comfort and function. This is likely due to the lack of supporting kinematic data demonstrating the effectiveness of thumb stabilization by wearing orthoses. The studies presented investigating the effectiveness of different orthotics focused only on clinical parameters such as pain improvement and function, while none of them analyzed thumb motion restricted by the orthotics. However, thumb kinematics describing the stabilization effectiveness of thumb orthoses combined with evaluations of hand functionality are mandatory in order to define an orthotic design that best meets the competing demands of mobility and stability. Therefore, the purpose of our study was to characterize the stabilization effectiveness and functionality of different thumb CMC OA orthoses.

2. Methods

2.1. Subjects

Eighteen female subjects (mean age 63 (3)) with stage II/III CMC OA of the thumb (according to the classification by Eaton and Littler (1973)) participated in the study. Patients were excluded from the study if they had previous thumb surgery or concomitant neurological diagnoses. In the case of patients with bilateral CMC OA the most symptomatic hand on subjective report of pain was studied. Ethics approval was obtained from the local ethics committee and all patients provided written informed consent before enrollment.

2.2. Orthoses

Four thumb orthoses will be tested and compared in this study: (A) Rhizo Forte V/2013, BSN medical (BSN); (B) Ortho CMC, Push braces (PUSH); (C) Rhizo-Hit, Sporlastic (SPOR); and (D) Rhizomed, medi (MEDI) (Fig. 1). The Rhizo Forte by BSN medical is based in the palm and includes the thumb CMC and MCP, but excludes the wrist. Its rigid, multi-curved, contoured aluminum insert is covered by thermoplastic polyurethane (TPU). The Ortho CMC by Push braces is based on a minimalistic design, as it only supports the CMC and excludes other adjacent joints such as the MCP or wrist. It is made of TPU into which a multi-curved contoured aluminum insert was positioned around the thenar eminence. The Rhizo Hit by Sporlastic includes the wrist and the MCP joint of the thumb in addition to the CMC joint. It is a semi-stable textile splint into which an aluminum spaceframe is incorporated. The Rhizomed by medi is made from rigid aluminum covered by textile soft padding. Like the Rhizo-Hit, the Rhizomed also includes the wrist and the MCP. With variances in individual thumb segment (bone) lengths both the Rhizo-Hit and Rhizomed also covered the interphalangeal joint of the thumb. All orthoses can be custom-fitted since the aluminum inserts are manually compressible in order to fit best individual hands and thumbs.

2.3. Thumb kinematics

A six infrared camera system (VICON Motion Systems, Oxford, UK) was employed to quantify three-dimensional (3-D) thumb kinematics with and without the orthoses. Retro-reflective marker arrays consisting of three retro-reflective markers were attached to the skin on the Os metacarpale (Metacarpale I) and phalanx proximalis of the thumb, as well as on the Os metacarpale (Metacarpale II) of the index finger (Fig. 2A). Using a retro-reflective markers pointer, the anatomical landmarks at the MCP and CMC joint of the thumb and MCP and CMC joint of the index finger were correlated with the respective marker arrays. Over the anatomical landmarks, segment coordinate systems were formed, whose origins were in the respective middle of the Os metacarpale and phalanx proximales of the thumb, as well as on the Os metacarpale of the index finger. 3-D angular kinematics was determined from the coordinate frames established by the markers.

The in vivo kinematics of the thumb CMC and MCP joints in relation to the index finger during maximum active opposition–reposition in the five different test conditions (without orthosis and while wearing four different orthoses) were analyzed. Therefore, hands were fixed in a custom-made test bench (Fig. 2B). Patients sat with the respective shoulder abducted approximately 0° in the frontal plane, flexed approximately 0° in the sagittal plane and had their elbow flexed at about 90°. The wrist joint and the forearm were placed in a neutral position with the palm perpendicular to the horizontal plane. The four fingers were stabilized at full extension. The forearm and wrist were strapped and kept stable during the experiment. Each subject performed maximal active opposition–reposition as defined by Li and Tang (2007). During opposition–reposition, each subject started with the thumb at a natural/relaxed position and then moved the thumb tip to the distal palmar site of the little finger (opposition). Then, the subject moved along a circular path away from the little finger until the thumb was in the plane of the palm and maximally extended (reposition) (Fig. 2B). Three opposition–reposition cycles were performed for each trial at a self-selected velocity and patients were asked to stop maximum active opposition–reposition when their individual pain threshold was reached. The execution of the movements was supported by verbal commands and patients were allowed to practice maximal thumb opposition–reposition with the marker arrays attached before data recording. In order to avoid interference of the marker positions through contact with the orthoses, marginal material modifications were conducted without to influence the mechanical properties of the orthoses. In addition, if needed, reflecting parts of the orthoses were covered. The order of the orthoses was randomized.

The motion analysis system sampled the coordinates of the markers at a rate of 100 Hz. After recording, the data were exported and further analysis was carried out with a custom-made MatLab program (Version R2013b, MathWorks, Natick, MA, USA). Angles at the CMC and MCP joints were calculated using Cardan angles of x–y'–z'' rotation sequence. For both the CMC and MCP joints, the first rotation about the x-axis represented flexion–extension, the second rotation about the y-axis represented abduction–adduction and the last rotation about the z-axis represented pronation–supination (axial rotation). Based on that, we determined the angular motion capability of the CMC and MCP joints in three motion directions, i.e., x, y and z. Outcome measures were the RoM of the thumb CMC and MCP.

In order to evaluate the thumb motion reproducibility of the CMC and MCP joints during the opposition–reposition task, three patients performed three maximum RoM in x, y and z without orthosis and while wearing the four orthoses.

2.4. Hand function

Hand function while using the different orthoses was assessed by using a test box in accordance to the hand function test by Sollerman and Ejeskar (1995) (Fig. 3). The Sollerman test includes 20 standardized activities of daily living including opening jars, turning keys, handwriting, using a knife and fork and pouring liquids from various containers. The purpose of this test is to produce a true picture of grip function in activities of daily living and to reflect the most common main grips

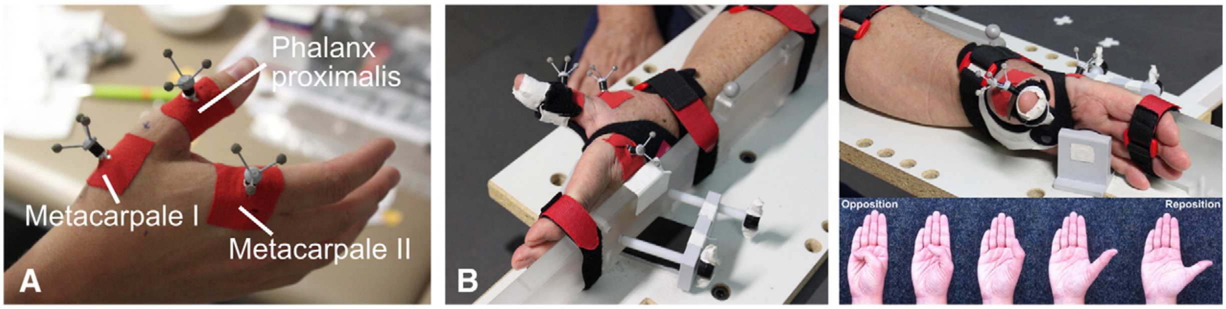

Fig. 2. (A) Marker arrays positioned on thumb and index finger. (B) Forearm and hand of a subject positioned and fixed in custom made test bench during maximum active opposition–reposition. Description of thumb opposition–reposition motion made by subjects. Subjects started with the thumb at a natural/relaxed position, and then they moved the thumb tip to the distal palmar site of the little finger (opposition). Then, the subject moved along a circular path away from the little finger until the thumb was in the plane of the palm and was maximally extended (reposition).

used in daily life. During testing, subjects were seated in front of the box, which was placed on a table. The instructions to the subjects were that the tasks should be done with no hurry, that they should be seated throughout the test, but were permitted to stand if they had to (yields a lower test score) and that a free choice of grip is allowed. Each of the 20 tasks were measured on a four-point scale, providing a maximum score of 80 for a participant who could complete each task with the correct hand-grip in less than 20 s without any disability. The randomized order of the orthotics has been retained unchanged.

2.5. Statistics

All data were checked for normal distributions by Kolmogorov–Smirnov test. Results are presented as mean values and standard error. A one-way ANOVA repeated measures was used to examine the effect of the different orthoses on thumb kinematics and hand function. A Bonferroni post hoc comparison was performed when a significant main effect was detected. Interrelations between thumb joint kinematics and hand function were analyzed using Pearson's bivariate correlation analysis. A *P*-value less than 0.05 was regarded as statistically significant. All statistical analyses were performed with Statistica for Windows (Version 7.1, StatSoft GmbH, Hamburg, Germany).

Fig. 3. Test box in accordance to Sollerman test of hand function (Sollerman and Ejeskar, 1995).

3. Results

3.1. Motion reproducibility

Motion reproducibility of the CMC and MCP joint RoM in x, y and z direction are summarized in Table 1. The mean absolute RoM differences between the three repetitions of maximum opposition–reposition performed each by three subjects without orthosis and while wearing the four orthoses are presented. In all directions, motions with and without orthosis showed good reproducibility with mean differences ranging from −1.5° to +3.8°.

3.2. Thumb kinematics

Without orthosis, the average RoM of the CMC joint was 44.2° in x direction, 25.8° in y direction and 37.3° in z direction (Fig. 4). All orthoses significantly ($P < 0.05$) restricted CMC RoM in x direction (39–64%), y direction (37–68%) and z direction (29–61%) (Fig. 4). The mean CMC RoM in x direction was significantly ($P < 0.05$) smallest with MEDI and BSN compared to PUSH and SPOR. The mean CMC RoM in y direction was significantly ($P < 0.05$) largest with PUSH compared to all other orthoses. The mean CMC RoM in z direction was significantly ($P < 0.05$) smaller with BSN and MEDI compared to PUSH, but similar to SPOR.

Without orthosis, the average RoM of the MCP joint was 61.5° in x direction, 16.4° in y direction and 19.6° in z direction (Fig. 5). BSN, SPOR and MEDI significantly ($P < 0.05$) restricted MCP RoM in x direction (37–78%), while PUSH was the only one that did not (Fig. 5). The mean MCP RoM in x direction was significantly ($P < 0.05$) smallest with MEDI compared to all other orthoses, followed by BSN and SPOR. Only BSN and MEDI significantly ($P < 0.05$) restricted MCP RoM in y direction (44–56%) and z direction (33–67%). The mean RoM in y direction was significantly ($P < 0.05$) smallest with BSN and MEDI and both did not differ from each other. The mean MCP RoM in z direction was significantly ($P < 0.05$) smallest with MEDI compared to all other orthoses.

3.3. Hand function

The average Sollerman sum score was highest with PUSH (78), lowest with MEDI (46) and both differed significantly ($P < 0.05$) from the other orthoses (Fig. 6). The average sum scores with BSN (72) and SPOR (75) were between the values of PUSH and MEDI and showed no statistical difference.

Table 1
Motion reproducibility of the CMC and MCP joint during opposition–reposition with and without orthosis. The mean absolute RoM differences are presented.

	Without		BSN		PUSH		SPOR		MEDI	
	CMC	MCP	CMC	MCP	CMC	MCP	CMC	MCP	CMC	MCP
X direction (°)	−1.9	+0.4	+2.8	+2.1	+0.1	−0.9	−0.7	+0.1	+0.2	+1.2
Y direction (°)	+1.3	−1.8	+0.6	+1.5	−1.5	−1.5	−1.2	+0.6	+0.1	+0.4
Z direction (°)	−1.5	−1.5	+3.8	−0.4	−0.8	+0.5	−0.1	−0.7	+0.1	+0.7

3.4. Interrelations between thumb joint kinematics and hand function

In order to investigate how the motion capability of the thumb affected the functionality of the hand, the kinematics of the CMC and MCP joints were correlated with the Sollerman sum score of hand function. Linear correlation coefficients as well as *P*-values summarized in Table 2, demonstrate that hand function score is strong positively correlated with the RoMs of the CMC and MCP joints.

4. Discussion

Immobilization of the thumb by orthotic devices is a common practice in the conservative treatment of CMC OA. Kinematic data demonstrating the effectiveness of thumb stabilization by wearing orthoses are missing in order to support one specific orthotic design that best meets pain relief and function. We therefore aimed to investigate the stabilization effectiveness and functionality of different thumb CMC OA orthoses by considering objective kinematic and subjective functional outcomes.

A variety of thumb orthotics are available in order to treat CMC OA, mainly based on two types of designs: the long opponens-type splint that includes the wrist and the MCP joint of the thumb in addition to the CMC joint and the short opponens-type that is based in the palm and includes the CMC joint only or both the CMC and MCP joints (Neumann and Bielefeld, 2003). Stabilization by orthotic devices aims to prevent or correct subluxation and deformity of the thumb, to decrease inflammation by providing rest and, therefore, to decrease pain in the affected joint. Accordingly, previous studies investigating the effectiveness of different CMC OA orthoses focused only on clinical parameters, such as pain improvement and function, while none of them analyzed thumb motion permitted by the orthoses (Bani et al., 2013a; Becker et al., 2013; Berggren et al., 2001; Boustedt et al., 2009; Gomes Carreira et al., 2010; Wajon and Ada, 2005; Weiss et al., 2004; Wilder et al., 2006). Further, Kjeken et al. (2011), who carried out a systematic review of studies addressing the effect of orthotics summarized that none of the studies included a definition of the primary kinematic function of the orthoses or a hypothesis of why and how the design of the orthoses would be effective to reduce symptoms. This might explain some inconsistencies reported by other authors regarding the effectiveness of improving pain by this intervention (Rannou et al., 2009; Sillem et al., 2011; Wajon, 2009; Weiss et al., 2000).

Since the thumb enables unique kinematic motion patterns not seen in any other joints of the hand, it is the most important and functional digit of the hand (Colditz, 2000; Kuo et al., 2004). Therefore, all orthotic designs have to reconcile and satisfy the competing goals of providing stability and mobility. The priority for symptomatic CMC OA patients is pain relief, which needs to be provided through stabilization by the orthosis. On the other hand, if motion is so heavily restricted by an orthosis that daily activities cannot be performed, tolerance and compliance are often questioned (Pai et al., 2006). Since CMC OA is a chronic condition and longer periods of orthotic wear decrease pain (Boustedt et al., 2009; Gomes Carreira et al., 2010; Swigart et al., 1999), we believe that orthoses should optimally be designed in a way that they support the thumb CMC joint while leaving other joints of the thumb and hand completely free so that daily activities are not impeded (Weiss et al., 2004).

The results of our study clearly demonstrate that the stabilization of the CMC and MCP joints varies considerably with the different orthoses. In the CMC joint, MEDI and BSN afforded the largest stabilization, while with PUSH minimal stabilization was achieved. Similarly, the largest motion restriction in the MCP joint was induced by MEDI, followed by BSN, whereas with PUSH and SPOR the MCP joint motion was minorly constrained. However, this is likely due to design differences between the four orthoses. Among the CMC joint, both MEDI and BSN also include the MCP joint. Both orthoses are made of aluminum giving support to the thumb from the palmar side of the hand. In contrast, PUSH only supports the CMC joint and excludes all adjacent joints. This explains why, with PUSH similar RoMs in all directions were found compared to the condition without orthosis. Even though SPOR also included the MCP joint in addition to the CMC joint, this orthosis was inferior to BSN and MEDI, enabling higher RoMs not only in the CMC but also in the MCP joint. This might be a consequence of its semi-stable textile design.

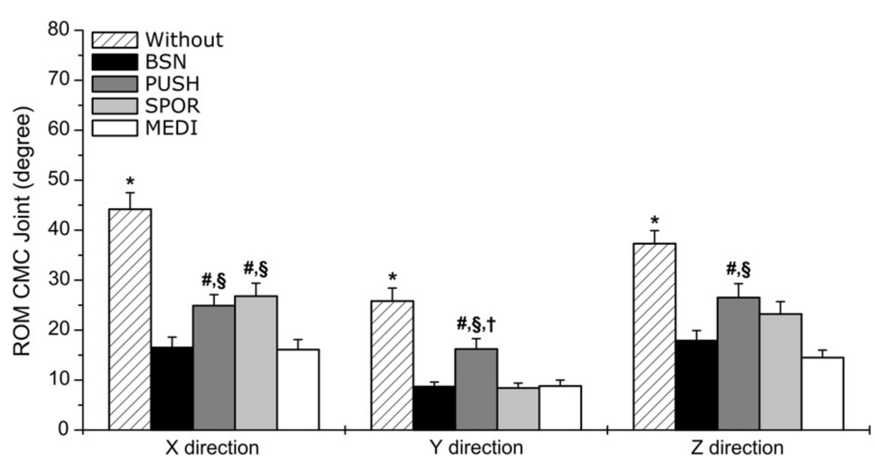

Fig. 4. Range of motion of the thumb CMC joint during opposition–reposition with and without orthosis. Mean and SE. *Significantly different from all orthoses $P < 0.05$, #significantly different from BSN $P < 0.05$, §significantly different from MEDI $P < 0.05$, †significantly different from SPOR $P < 0.05$.

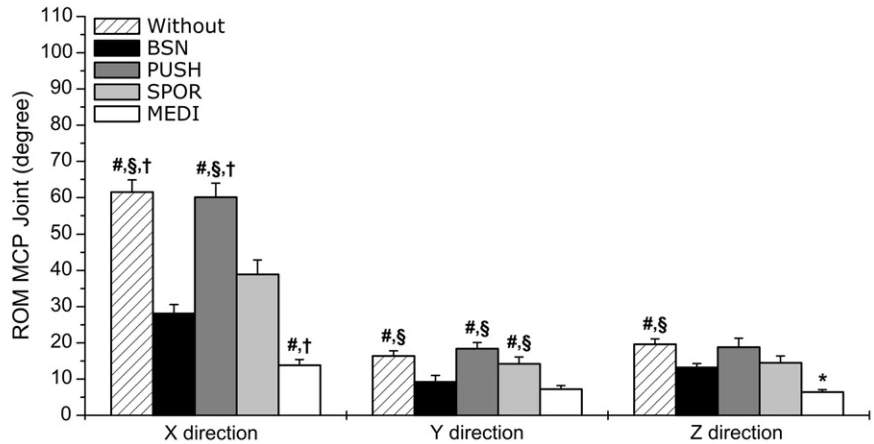

Fig. 5. Range of motion of the thumb MCP joint during opposition–reposition with and without orthosis. Mean and SE. *Significantly different from all other orthoses $P < 0.05$, #significantly different from BSN $P < 0.05$, §significantly different from MEDI $P < 0.05$, †significantly different from SPOR $P < 0.05$.

With regard to functionality, PUSH allowed the largest functionality of the hand. This was not unexpected, as this orthosis enabled full motion capabilities of the MCP joint which, as mentioned above, is an essential joint for grasp maneuvers. This is also demonstrated by our correlation analysis showing that hand functionality score is highly positively correlated with the RoMs of the MCP joint. In contrast, with MEDI the lowest hand functionality could be achieved, which is probably related to the fact that it massively restricted the motion of both the CMC and MCP joints. Further, MEDI also includes the wrist, a feature that has been observed limiting patients' hand functionality while performing the Sollerman test. In turn, BSN and SPOR both provided larger functionally compared to MEDI, which perhaps is due to the lower motion restriction in the MCP joint. As neither orthoses impeded the motion capabilities of the MCP joint as much as MEDI did hand functionality was preserved. Especially in the BSN, the thumb is placed in a natural, flexed position making pinch maneuvers easy, because the other fingers can easily reach the thumb tip. This is in accordance with Chaisson et al. (1997) who recommended stabilizing the thumb in slight adduction in order to allow palmar pinch without movement; thus, providing pain relief. However, compared to BSN, SPOR was less sufficient to stabilize the CMC joint, a characteristic that might be at the cost of effectiveness to relief pain. Since this study focused on kinematic and functional effects only, it is unclear how pain levels develop by wearing such orthoses. Moreover, it has to keep in mind that, depending on subluxation and deformity of the thumb as well as disease stage, CMC OA patients might suffer from pain at different thumb positions or directions, meaning that an individual/customized application of orthoses needs to be considered in order to gain the best pain reduction with minimum loss of function.

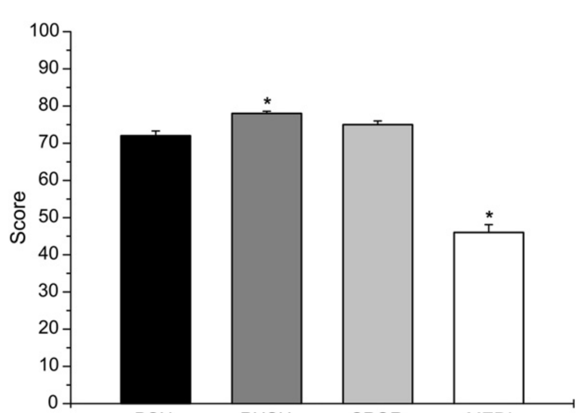

Fig. 6. Average Sollerman sum score of hand function while using the orthoses. Mean ± SE. *Significantly different from all other orthoses $P < 0.05$.

There are a few limitations in the study that should be discussed here. First, it cannot be excluded that increasing pain during the measurements might have influenced the outcomes in RoM. However, in order to avoid any systematic orthosis effect, the order of orthoses has been randomized. Moreover, we presented good reproducibility in both the CMC and MCP joint in all directions with and without orthosis. Second, we only analyzed kinematic effects of the orthoses. In order to complete our results, a long-term study is needed to monitor patient compliance and if pain relief can be achieved by the orthoses. Third, the results of the present study are limited to a female population since we did not include any male subject affected by CMC OA. Fourth, as CMC OA patients are also frequently affected by OA of the distal and/or proximal joints of the second to fifth digit, and this was not assessed in the included subjects, it cannot be excluded that affection of these joints has influenced subjects' hand function as measured by the Sollerman test. However, since patients wearing the PUSH reached almost maximum hand functionality score (78 of 80), and all orthoses tested did not cover/support any of the other digits of the hand, we rather believe that the differences in functionality scores are related to the motion restriction of the thumb caused by the different orthoses.

5. Conclusion

This study is the first to characterize the stabilization effectiveness and functionality of different thumb CMC OA orthoses. The data presented show that stabilization is at the expense of functionality. The high stabilization effectiveness provided by MEDI, as demonstrated by low motion capabilities of the CMC and MCP joint, resulted in the lowest hand functionality score. PUSH, which partially stabilized the CMC joint and allowed large motion capability of the MCP joint, in turn, afforded the largest hand functionality. However, taking into account that orthoses should optimally support the thumb CMC joint while leaving other joints of the thumb and hand completely free so

Table 2
Linear correlations between thumb joint kinematics (RoM) and hand function (Sollerman sum score). Significant correlations are indicated bold lettering.

	X direction (°)		Y direction (°)		Z direction (°)	
	r	*P*-value	r	*P*-value	r	*P*-value
CMC joint						
Sollerman sum score	**0.337**	**0.004**	**0.265**	**0.024**	**0.378**	**0.001**
MCP joint						
Sollerman sum score	**0.674**	**<0.001**	**0.412**	**<0.001**	**0.488**	**<0.001**

that thumb and hand function is maintained, a good compromise of stability and functionality was achieved with SPOR and BSN, with BSN providing larger stabilization at similar functionality compared to SPOR. Perhaps, it is the interaction between the rigid aluminum frame and the multi-curved, natural hand posture-fitted design at BSN that, on the one hand, provides sufficient support/stabilization to the CMC joint, and, on the other hand, enables essential motion in the MCP joint so that hand functionality can be maintained. However, long-term studies are needed in order to monitor comfort, patient compliance and if pain relief can be achieved by the orthoses.

Conflict of interest

None of the authors has anything to disclose for this manuscript and there are no conflicts of interest.

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