

A New Splint Design for the Thumb CMC Joint

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NOTE TO THE READER:

In this paper the terms: 1) splint 2) orthosis and 3) brace are used interchangeably since common usage varies throughout the world.

THUMB CMC JOINT & OSTEOARTHRITIS

The thumb trapeziometacarpal joint, also called the thumb carpometacarpal (CMC) or basal joint, is the most common site of upper extremity surgery due to disabling osteoarthritis.¹⁻⁴ The articulation of the first metacarpal bone with one surface of the trapezium is the locus of this common pathology. The incongruous contours of these two shallow saddle-shaped joint surfaces provide no intrinsic osseous stability, requiring the ligaments and muscles to assume responsibility for stability to prevent translation during loading.¹ Additionally, the base of the first metacarpal is approximately 34% larger than that of the trapezium which concentrates pressure on the trapezium surface.⁵⁻⁹

To allow the normally large range of motion of the thumb CMC joint, a loose but strong joint capsule is required. The inherent joint mobility diminishes the joint stability.^{10,11} Of the seven ligaments that maintain the

relationship between the base of the first metacarpal and the trapezium, the deep anterior oblique ligament (also commonly called the beak ligament) is considered the most important stabilizing ligament. It is primarily responsible for preventing dorsal translation of the metacarpal on the trapezium. With osteoarthritis, the beak ligament becomes insufficient and the metacarpal base moves dorsally in relationship to the trapezium.

Osteoarthritis, also called degenerative joint disease, is a noninflammatory type of arthritis marked by degeneration of the articular cartilage, overgrowth of bone at the margins, and changes in the synovial membrane. Usually not as severe as rheumatoid arthritis, osteoarthritis is considered part of the normal aging

The insufficient beak ligament allows the metacarpal base to move dorsally in relationship to the trapezium.

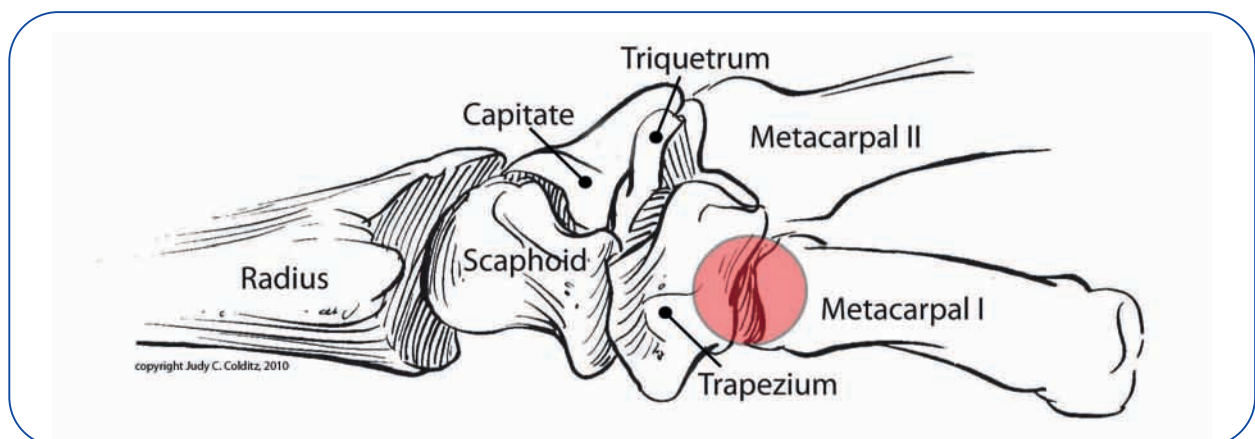


Figure 1; Radial view of the hand illustrating the carpometacarpal joint (highlighted).

Osteoarthritis is part of the normal aging process, involving joints that receive the most stress.

process, and is most likely to involve the joints that receive the most use or stress over the years.¹²

Symptoms of osteoarthritis may include joint pain, tenderness, stiffness or in-

stability. CMC osteoarthritis causes increased laxity of the joint capsule, creating the common clinical complaint of pain with resisted thumb motion, particularly forceful pinching. Movement of one bone end against the opposing joint surface creates pain.¹³



Figure 2: Photo of the thumb CMC joint surfaces

Thumb CMC joint osteoarthritis is believed to result from chronic stress to this incongruent joint. Strong association exists between excessive basal joint laxity and the development of premature degenerative changes.⁴ With minimal inherent bony stability, the CMC joint is dependent upon a force couple of muscle tension and passive ligament tension for stability. Of the eight muscles which influence thumb CMC joint motion three of

The common deformity is flexion and adduction of the first metacarpal.

the extrinsic muscles (abductor pollicis longus, extensor pollicis brevis and extensor pollicis longus) are relatively inefficient extensors and abductors at

the CMC joint. In contrast, three of the four thenar muscles pull the first metacarpal head toward the palm (into flexion), and thus the balance of motion is loaded toward flexion. This muscle force inequality explains the most common direction of deformity of the first metacarpal: flexion and adduction.

DIAGNOSIS / EARLY RECOGNITION

Individuals with thumb CMC osteoarthritis experience pain within the joint, tenderness to palpation, and/or excessive laxity of the joint or joint stiffness, and have

difficulty accomplishing tasks which require forces that load the joint. Both repetitive and resistive home and work activities may exacerbate symptoms. Common complaints are pain with tasks such as twisting open a jar lid, turning a key in a lock or turning doorknobs, sustained pinching or writing, picking up a large book, holding a cup of tea/coffee, doing needlework, carrying an object that weighs more than 4.5 kg (10 lbs.), and using scissors.^{1, 2, 14, 15} Grip strength is diminished in those with symptomatic hand osteoarthritis.¹⁴

The diagnosis of CMC joint osteoarthritis is made based on pain complaints consistent with CMC osteoarthritis, positive clinical examination, and radiographic findings. Clinical examinations commonly used may include CMC joint palpation which indicates joint inflammation, the grind test which evaluates the quality of the articular surfaces, the crank test which both evaluates the joint quality and translational laxity, the distraction test where a pain response indicates joint inflammation and volar compression of the first metacarpal base which also indicates joint inflammation.^{4, 6, 16} In addition

to a positive response to some or all of these tests, it must be ruled out that pain is coming from compression of the median nerve or inflammation of the tendons in the first dorsal compartment (De Quervain's tenosynovitis) or another cause. Although x-ray findings confirm the diagnosis when clinical exam is positive, radiographic evidence may be present without accompanying symptoms.^{1, 17} Since there is poor correlation between radiographic severity and clinical symptoms, non-surgical treatment must be based on functional/pain complaints rather than radiographic findings.

Non-surgical treatment must be based on functional/pain complaints, not radiographic findings.

INCIDENCE

Osteoarthritis (OA) of the thumb CMC joint is particularly prevalent in postmenopausal women,^{18, 19} many of whom already have normal laxity of this joint.⁴ From 25-40% of individuals over the age of 55 have radiographic evidence of CMC osteoarthritis.^{2, 3, 20} Contact forces are greater in females due to fact that male joint surfaces are more congruent,²¹ creating an approximate ratio of 1 in 4 women and 1 in 12 men in older age groups.^{1, 15, 17, 18, 22, 23}

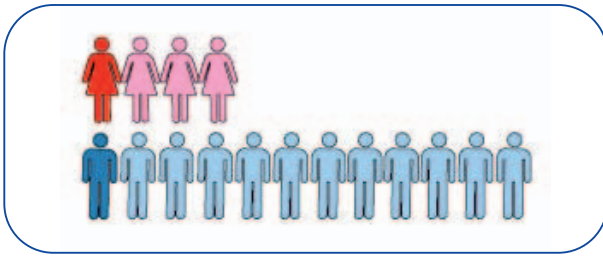


Figure 3: One in four women and one in 12 men over age 70 have osteoarthritis of the thumb CMC joint.

Pain and disability are strongly associated with osteoarthritis of the thumb CMC joint.

As age increases, both the frequency and severity of hand OA increases up to 80% of those over 70+.²⁴⁻²⁶ Obesity also appears to be a strong correlation with symptoms.^{20, 23} Although

epidemiological studies of hand osteoarthritis are few, one study identified those with symptomatic osteoarthritis as 17% of women and 9% of men. Of the joint sites where osteoarthritis is seen in the hand, pain and disability is strongly associated with presence of osteoarthritis at the thumb base joint.²²

BIOMECHANICS

As osteoarthritis develops, the already slack capsule of the thumb CMC joint becomes excessively lax as the beak ligament loses its ability to checkrein dorsal translation of the metacarpal on the trapezium.⁴ When the



Figure 4: X-ray of classic CMC joint deformity: the distal end of the first metacarpal moves toward the palm and the proximal end shifts dorsally.

thenar muscles contract during pinch, the first metacarpal tilts; i.e. the distal end moves toward the palm and the proximal end shifts dorsally. It is this shift of motion, even though perhaps slight, which creates pain. A progressive deformity of the thumb CMC joint ultimately modifies the pull on the thumb MP joint, creating secondary problems of imbalance at this joint.^{19, 27} If one imagines the thumb as a tent pole to be stabilized, three evenly spaced guy wires with identical tension are needed. During pinch, the thumb muscles must provide this precarious balanced posture to transmit the force of pinch evenly to the base joint.

Pellegrini describes the challenge of treating thumb CMC joint osteoarthritis: "To reconcile and satisfy

the competing goals of providing stability and mobility to the trapeziometacarpal articulation."²⁸ This goal is the challenge of any splinting of the thumb CMC joint that allows continued functional use of the thumb.

Mobility and stability are competing goals.

SPLINTING/BRACING

Splinting/bracing of the osteoarthritic thumb CMC joint is considered "the mainstay of conservative care,"¹ and relieves pain in patients with osteoarthritis of the first CMC joint.^{1-3, 15, 17, 24, 29-40} When splinting is combined with activity modification and non-steroid anti-inflammatory medication, Berggren, et al showed that 70% of patients at 7 months no longer required surgical intervention.^{2, 31} At 1 year follow-up Boustedt, et al found the group given splints/braces (worn day and night), joint protection instruction, heat, and home exercise significantly decreased pain and stiffness and improved in daily activities compared to a control group given only joint protection instruction. Hand grip strength also increased 27% as compared to 17% increase in control group.³⁰ Both the National Collaborating Centre for Chronic Conditions in the United Kingdom and the evidence-based European League Against Rheumatism (EULAR) recommends splints/braces as part of thumb CMC osteoarthritis treatment.^{13, 29}

The focus of splinting/bracing the thumb CMC joint may be to:

- Decrease inflammation by providing rest and immobilization

- Decrease pain by providing stability during activities that load the joint.

In some cases splints/braces can achieve both purposes.

Immobilization

Immobilization splinting that is used to decrease inflammation rarely allows functional use of the thumb. These splints incorporate the wrist and/or the MP joint of the thumb in addition to the CMC joint.^{1,2, 15, 17, 30, 32, 39} Tolerance and compliance are often questioned since individuals cannot accomplish daily tasks with these splints.² Additionally, prolonged use of the splint is not

desirable due to the likely disuse atrophy of the thenar muscles.^{36, 39} Because of the functional limitations such splints impose, these splints/braces are

often worn only at night, although this may follow a relatively short initial period of full time wear.³⁶

Immobilization splinting rarely allows functional use of the thumb.



Figure 5: An immobilization splint prevents functional use of thumb and/or the wrist.

Designs which incorporate adjacent joints are deemed necessary by many because the common three-point pressure design is not possible at the thumb CMC joint. The small size of the trapezium coupled with the inability to surround the thumb CMC joint makes it impossible to apply a stable three point splint. Thus motion of the thumb CMC joint is commonly limited by capturing other adjacent joints.

Dynamic Stability

Inflammation results from excessive motion that occurs at the CMC joint. If motion is minimized, both pain and inflammation are diminished. In contrast to an immobilization splint, a dynamic stability splint focuses on



Figure 6: A small custom molded splint/orthosis that only includes the thumb CMC joint.

preventing excessive motion during load which also serves to check the progressive deformity of dorsal translation. The splint is designed to provide stability by applying an external substitute for the inadequate beak ligament.

A smaller splint design that includes only the thumb CMC joint can provide dynamic stability. Individuals prefer a short splint.³⁴ Since greater periods of splint wear decrease pain,^{30, 32, 38, 39} splints/braces that do not impede daily activities allow longer periods of wear.

A thumb CMC splint/orthosis that only includes the first CMC joint provides dynamic stability by use of a *pseudo-hydraulic environment* principle.⁴¹ This principle (identified by Sarmiento who first applied it to fracture bracing of long bone fractures) provides stability to a bone via the pressure created by contained contracting muscles. As contracting muscles become larger in circumference an external containment device limits muscle expansion and the expansion force is directed inward, increasing the pressure which stabilizes the bone within the contained space.

In the thumb CMC joint, stability is accomplished by conformed molding around the thenar eminence when the muscles are relaxed. During hand use when the muscles contract and attempt to increase in bulk, the pressure is directed inward to stabilize the first metacarpal, maximizing the immobilization effect of

When the thumb muscles increase in bulk within the splint, they stabilize the first metacarpal.

the splint during active use. Since pain at the CMC joint is primarily present during active loading, this splint immobilizes the CMC joint during active pinch/grasp, because it depends on active thenar muscle

contraction. Since symptom severity is influenced by loading of the joint during use,⁴² a splint which limits translation of the metacarpal when the joint is loaded will be more effective than a splint that immobilizes but prevents use of the thumb. Since wrist motion does not create pain with thumb CMC joint osteoarthritis,² wrist immobilization is not necessary.

Activities requiring pinch are the primary cause of thumb CMC joint symptoms.⁴ Since the smaller splint design leaves the critical digital sensory area free, it does not impede pinching, fingering, handling or gripping activities. Since the thenar muscles are active while in this splint, concerns about disuse atrophy of the thenar muscles is eliminated.

Unlike most splints applied to joint/s, this CMC splint cannot be worn too long or too much. The problem at

the thumb CMC joint is one of excessive motion. It would be ideal if the splint was worn enough for the joint to "stiffen" and have greater stability. Inclusion of the wrist has been common practice in the past and therefore many contend that any splint for the thumb CMC joint must cross the wrist for adequate stabilization. Others report pain control with this smaller splint design that excludes all joints but the thumb CMC.^{33, 34, 43, 44}

Disuse atrophy of the thenar muscles does not occur in the dynamic stability splint: the muscles are active in the splint.

Following the initial period of post-operative immobilization, a small dynamic stabilization splint such as described above may also be appropriately used after surgical procedures to the CMC joint. The splint maintains the ideal posture of the first metacarpal while allowing increasing strength of the thenar muscles in the ideal position during functional use, preparing the individual for effective weaning from external support. Additionally, this small splint design allows continuing use of the hand while protecting the healing capsule following a sprain/strain injury to the thumb CMC joint.

DEVELOPING A SPLINT/ORTHOSIS TO SOLVE THE PROBLEM

Having identified the widespread need for an effective splint/brace to reduce pain at the thumb CMC joint with osteoarthritis, Nea International bv / Push Braces

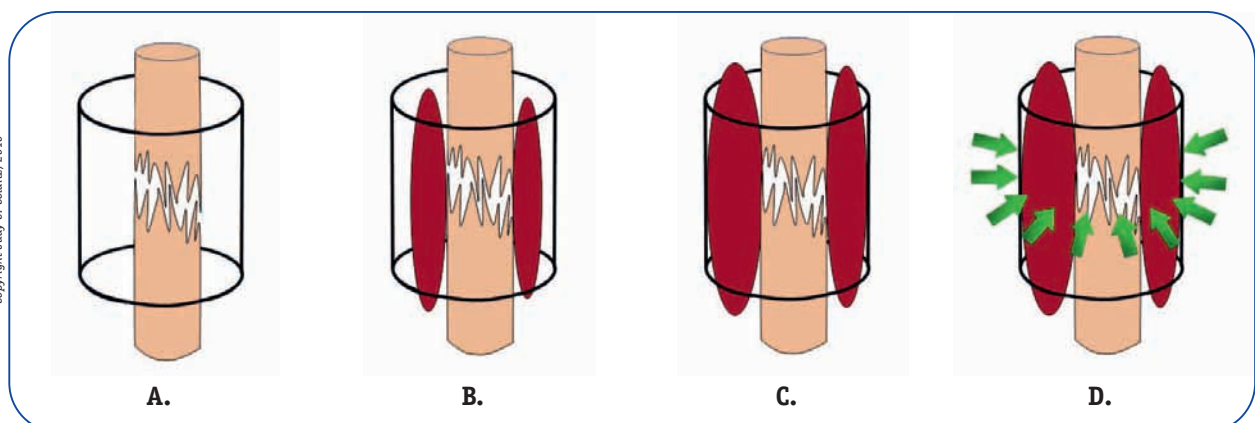


Figure 7: The dynamic stabilization splint creates a pseudo-hydraulic environment which was originally used to stabilize long bone fractures: A. A cylinder contains the area to be stabilized. B. The relaxed muscles almost fill the space C: The contracted (expanded) muscles completely fill the space within the cylinder and D: The expanded muscles create internal pressure which prevents the bone ends from moving.

[Maastricht, the Netherlands] began development of a unique splint design. Previously intimately fitted braces were possible only by application of a custom molded device.^{43, 44} Because of the varying skill of those applying custom molded splints, often frequent adjustments of custom molded splints are necessary for maximum comfort.³⁶ Low temperature thermoplastic materials used for these splints are relatively rigid when molded. A successful splint mandates precise fit, long-term durability, a surface which does not easily abrade or become unsightly, and tolerance to high temperatures such as being left in an automobile in hot weather.

The challenge in designing a splint/brace is to meet the goal of allowing maximum mobility while providing precise stability for a variety of hand sizes. To develop the ideal splint design for this problem, Push consulted with recognized experts. Following input from the experts on important requirements of the design, the Push design team developed prototypes which were sent to the experts for critical evaluation and scoring.

Criteria for the Push Brace Design Process

The following criteria were required by Push Brace:

Made of materials that:

- Are durable and will not break or crack
- Are relatively flexible to minimize edge pressure but also relatively stiff when in a curved contour
- Minimize surface abrasion
- Tolerate heat
- Are easily cleaned
- Are antimicrobial.

Designed so the brace:

- Is adjustable to individual thenar eminence contour and size
- Is easily applied and removed with one hand without applying torque to the thumb CMC joint
- Provides support to the thumb CMC joint but does not impede any other joint movement
- Minimizes pressure areas regardless of underlying contour.

Meets the criteria of:

- Effectively controlling thumb CMC joint pain
- Being well tolerated when worn for long periods
- Being preferable to custom molded design/s or other commercial designs for this problem
- Being cost-effective for individuals with this problem.

Final Design

The Push design evolved to a molded base design made of thermoplastic polyurethane (TPU) into which a multi-curved contoured aluminum insert was specifically positioned around the thenar eminence. After the splint is applied to the hand with the thumb metacarpal bone positioned with a slight open angle relative to the second metacarpal, the aluminum insert is manually



Figure 8: The Push CMC brace showing the adjustable metal insert that stabilizes the first metacarpal but leaves all other joints free to move.

The aluminum insert is fitted to the thenar area while the muscles are relaxed.

compressed to fit the thenar eminence *while the muscles are relaxed*. This snug fitting creates the pseudo-hydraulic environment which stabilizes the thumb during active pinch/grip. The shape of the molded base covers a minimal amount of the palmar surface and does not impede motion of the thumb MP joint or the wrist joint. The edges of the material are flexible, preventing sharp edge pressure seen in many custom molded splints. The double straps run through a slot in the base material, allowing easy application/removal and application of snug tension upon closure. The criteria list was fully met by the final design.

FIELD TESTING OF FINAL PUSH CMC BRACE DESIGN

Field Test

A field test was conducted with the final Push CMC prototype by Nettie Koekebakker at 4hands, a private outpatient hand therapy clinic in Amsterdam, the Netherlands. The study included 13 patients with a mean age of 52.8 years who were diagnosed with thumb CMC osteoarthritis and already being treated in the clinic. Nine patients had a diagnosis of thumb CMC osteoarthritis, three had recently undergone thumb CMC arthroplasty surgery and one had thumb CMC instability/laxity. These patients were already wearing a previously fitted custom molded thermoplastic splint, which supported the thumb CMC joint and also included the thumb MP joint. The patients had been advised to wear the splint during daily repetitive and resisted home or work activities that would increase pain without wearing a splint but not wear the splint at night. All patients received joint protection instruction, advice on how to use their hand optimally during daily activities, and instruction for home exercises. Home exercises were performed 2-3 times a day and included strengthening of the intrinsic thumb muscles and active isometric pinch grip exercises with a balanced arch.

At the beginning of the field test the Push CMC prototype was fitted and all patients were asked to wear the prototype for 6 weeks using the same wearing protocol as the splint they had been using previously. At the

time the splint was fitted, the following information was recorded:

- Visual Analogue Scale (VAS) Score for pain (score range 0 -10) ⁴⁵
- Thumb opposition (according to the 0-10 Kapandji opposition score) ⁴⁶
- Maximal voluntary isometric grip strength without brace (Jamar hand held dynamometer) ⁴⁷⁻⁴⁸
- Maximal voluntary isometric two-point, tripod and key pinch strength without brace (pinch gauge) ⁴⁸
- Self-report questionnaire that records physical function and symptoms.

In addition, during the field test the patients were asked to maintain a written diary in which they noted their daily experiences with the brace.

Results of Field Test

After wearing the Push CMC prototype for 6 weeks all assessments were repeated. Grip and pinch strength were measured while wearing the brace. Comfort level and user friendliness of the thumb splint were evaluated with a questionnaire specifically designed for this study (Table 1) and the participants were asked to assign a final score of the brace on a visual analogue scale (0-10). (Table 2) For all participants the wearing schedule was different. A dentist and a photographer wore the splint mostly all day at work. Other patients used the splint from thirty minutes to two hours depending on daily activities, such as computer work.

According to the post wear assessments no significant changes of thumb opposition, VAS for pain, or grip and pinch strength were noted. The self-report questionnaire that records physical function and symptoms showed significant improvement, indicating the patients were able to function at a higher level with this splint. Eleven participants answered the questionnaire on comfort level and user friendliness of the thumb splint, stating they found the brace always or often pleasant to wear. The functional use of the splint

Patients scored functional use of the splint good to excellent.

scored from very good to excellent. All patients would recommend this brace to patients with a similar problem (Table 1). The brace was scored on the visual analogue scale (range 0-10, 10 is excellent) with a mean score of 8.16 (SD 0.59). In the diary notes, patients mentioned

that the brace gave good support, significant freedom of movement, was usable under a glove, could be used during wet activities and was handy to take with them because of its small size.

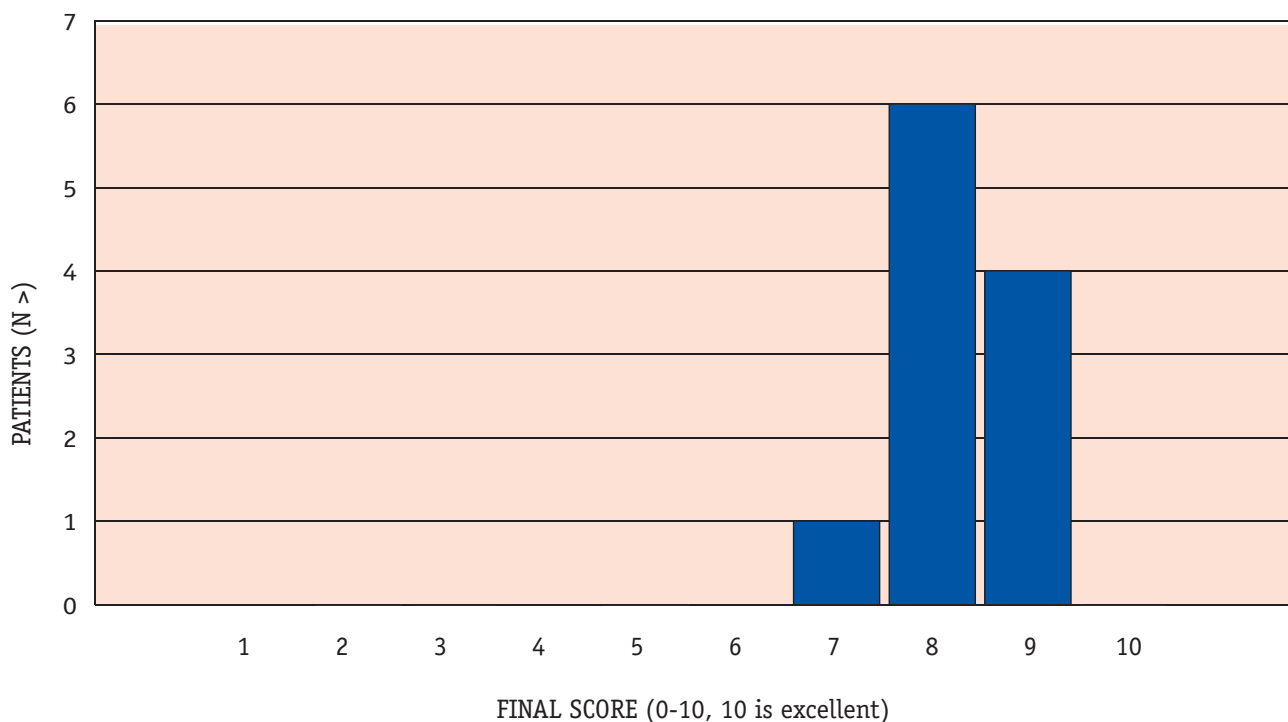
Results of the field test as well as patients' recommen-

dations were taken into consideration in finalizing the Push CMC brace design. In addition, the final splint design was subjected to inhouse testing to assure the splint met acceptable standards for the criteria such as durability and heat tolerance.

Table 1: Patient's response to questions about splint comfort and user friendliness (n=11)

Questions	Scores (%)				
	Always	Often	Sometimes	Never	
The splint was comfortable to wear	32%	68%	0%	0%	
The splint allowed function of my hand/thumb	Perfect 55%	Good 45%	Fair 0%	Moderate 0%	Poor 0%
While wearing the splint my thumb feels	Stable 95%	Unstable 5%			
I would recommend the splint to others	Yes 100%	No 0%			

Table 2: Patients final score (10 = excellent, n=11)



CONCLUSIONS AND RECOMMENDATIONS

The authors find the final Push brace design highly desirable. Ms. Koekebakker feels the Push CMC brace is a

The Push brace meets the criteria of providing precise stability while allowing maximum mobility of the surrounding joints.

break-through in the treatment of thumb CMC joint pathology, optimally supporting the thumb CMC joint while leaving other joints completely free. She was impressed by the ability of the splint to be comfortably worn by her

patients while maintaining thumb function. One participant, a dentist, was able to fully execute all activities in his dental practice while wearing the splint and using gloves.

Ms. Colditz, having designed the small custom-fitted design discussed above, finds the Push splint to be an exceptional design. It is the only manufactured splint that can be custom fitted around the thenar muscles to precisely stabilize the thumb CMC joint while also allowing full mobility of the surrounding joints. She feels this design will change the current splinting approach to thumb CMC osteoarthritis.

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About the Authors

Judy Colditz is an internationally recognized expert on hand therapy who has written numerous articles, chapters and given papers and workshops in more than 24 countries. Currently Ms. Colditz develops educational DVD/CD modules for hand therapists. In her 38 years of experience she has focused on the problems of the CMC thumb joint. Ms. Colditz is past president of both the American Society of Hand Therapists and the International Federation of Societies for Hand Therapy.

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