Plaster of Paris:

The Forgotten Hand Splinting Material

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ABSTRACT: This article examines the concept of tissue adaptation in response to the application of plaster of Paris splints and casts. A review of the history of plaster of Paris and its composition, its working properties, and precautions for its use introduces the reader to this oft-forgotten material. Four designs are described for plaster of Paris application—circumferential padded casts, digital unpadded casts, plaster slabs, and contour molds. The discussion of clinical application of plaster of Paris covers joint tightness, arthritis, contracted joints due to spasticity, muscle-tendon tightness, skin tightness, skin and joint tightness, and edema reduction. In addition, a new application called casting motion to mobilize stiffness (CMMS), developed by the author, is discussed. The use of plaster of Paris to improve postoperative flexor tendon glide is also discussed. This review article intends to stimulate the reader to use plaster of Paris splinting or casting more frequently to solve clinical problems.

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WHY PLASTER OF PARIS?

Plaster of Paris, a highly compliant material, is often overlooked in the splinting of hand patients. This article enumerates the advantages of plaster of Paris and illustrates its application in specific clinical situations. This information is intended to encourage therapists to introduce plaster of Paris more readily into their treatment armamentarium as a means of accomplishing tissue change.

The current primary treatment to mobilize stiff joints and adherent soft tissue is the application of intermittent force via mobilization splinting. The sustained positioning of joints and soft tissue with plaster of Paris provides a gentler and more precise means of tissue remodeling than does dynamic or static progressive splinting. The only possible response to continual positioning in a plaster of Paris cast is plastic deformation, a permanent change in tissue length due to the realignment of collagen fibers.

Removable splints create an elastic response in the tissues such that, on removal of the splint, the tissue returns to the previous position. The idea of mobilizing tissue by immobilizing it seems contradictory. One must grasp the concept of positioning tissue and waiting until it has time to adapt to a new length and shape. Bell[1] agrees that we must abandon the traditional concept of applying force, and think instead of the ability to position joints to positively influence the dynamic remodeling properties of soft tissue.

Because we know that prolonged periods of immobility have negative effects,[2–14] many clinicians assume that short-term immobilization of joints and soft tissue is to be avoided. The risk of losing motion (even temporarily) is so intolerable that plaster of Paris casting is avoided unless it is the last resort for gaining motion. Immobilization of uninjured joints must be prolonged, and the extremity kept immobile for the negative effects of immobilization to stiffen uninjured joints. A loss of motion in one direction usually occurs with plaster of Paris splinting or casting, but clinical experience has proved this to be temporary. The unspoken assumption—that all joints should be allowed to move in all directions when regaining motion in the hand—must be abandoned if efficiency and precision in joint and soft tissue mobilization are to occur.

If joint tightness or tissue adherence is present in a recently injured hand, tissue elongation can be regained and motion restored by a brief period of casting. The clinical goal is quickly converted from gaining motion to maintaining motion. Thereafter, intermittent splinting can maintain the gains. In contrast, if intermittent splinting and manual mobilization techniques are the first choice, many hours of tissue elongation are needed to effect permanent tissue change.

Joint stiffness and tissue adherence that are mature and resistant to intermittent mobilization splinting and manual mobilization also respond to positioning with plaster of Paris casting. In some chronically stiff

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hands, constrained motion in a cast can direct active motion to the stiff joints, so that they regain both soft tissue glide and joint motion. Because the cast is not removable and all motion is directed repeatedly to the same tissue, dramatic change occurs without the application of external force.

Kolumban[15] offers the only study to date that compares the effectiveness of serial plaster of Paris casting with the the effectiveness of mobilization splinting. In his study with leprosy patients, casting was clearly superior to dynamic splinting and resulted in fewer pressure areas.[16] Unfortunately, no comparative studies of patients with joint stiffness due to trauma are available. Since the primary benefit of plaster of Paris is a more rapid change in the quality of the soft tissue, photographs do not adequately convey this progress. No objective means of quantifying these changes currently exist. Direct palpation is the only means of demonstrating the quality of change in soft tissue.

Since plaster of Paris casting is frequently used as a means of mobilization "splinting," the words *splint* and *cast* become confusing in this context. In this article, *splint* is used when the piece is removable (regardless of the material from which it is made) and *cast* is used when the design (usually made of plaster of Paris) cannot be removed by the patient.

HISTORY

Archives provide numerous reports of various substances being applied to splinted body parts to stiffen the part for fracture immobilization. It was not until 1852 that a technique was developed for applying plaster of Paris directly to an extremity. (It is called plaster of Paris because it was first prepared from the gypsum mined in Paris, France.) In 1852, a Dutch army surgeon, Antonius Mathysen, treated battle wounds in the Crimean War with cotton bandages filled with dry plaster of Paris.[17]

This somewhat awkward means of plaster application continued until 1927, when binder ingredients (starches, gums, and resins) were added to improve the adherence of the plaster to the gauze. These additives made the application of a cast less messy and more consistent. Later, other additives were incorporated to change the physical properties of plaster of Paris, such as the setting time, which allowed standardized production.[18,19]

In the first half of the 1900s, plaster of Paris was the most readily available material both for immobilization of acute injuries and intermittent immobilization or mobilization splinting. Serial plaster splinting or casting was used to mobilize stiffened joints due to trauma[20] and contractures due to arthritis.[19] Bunnell[20–22] incorporated outriggers into plaster of Paris splints to provide dynamic mobilization. Brand's work[23] in India with leprosy patients introduced the use of plaster of Paris for serial positioning of joints, especially the small interphalangeal (IP) joints.

In the 1970s, low-temperature thermoplastic materials became available. These materials, which could be quickly molded on the patient and easily altered, revolutionized mobilization splinting of the hand. At about the same time, lighter-weight and water-resistant synthetic casting materials replaced the traditional plaster of Paris casting materials used for acute injuries. As a result of these two developments, plaster of Paris came to be used less frequently by both physicians and therapists. The infrequency with which plaster of Paris is currently used in hand therapy is reflected by the very brief mention of its use in recent hand splinting texts.[24–27]

COMPOSITION

Plaster of Paris is derived from gypsum (calcium sulfate dihydrate), a naturally occurring rocklike substance found in rock salts. When gypsum is heated to 128° C, most of the water is driven off, resulting in a powdery substance commonly known as plaster of Paris. When water is added to the dry plaster of Paris, the water molecules incorporate themselves into the crystalline lattice of the calcium sulfate dihydrate, thus giving up most of their kinetic energy in the form of heat. This hydration process converts the weak and powdery plaster of Paris into a homogeneous, rock-hard mass.[18,19,28]

The time required for the plaster to set up varies, depending on the additives.[29] Manufacturers clearly label their products with the set-up time. Plaster of Paris with minimal additives is called gypsona. When plaster of Paris is used for hand mobilization, gypsona impregnated into leno-weave gauze (a nonraveling, closely woven gauze) is highly recommended (Gypsona Gauze Type-Leno, Smith & Nephew, Inc., Germantown, Wisconsin).

Gypsona has a creamier consistency than the plaster of Paris with additives, although the latter is more durable and water-resistant.[29] For removal, a cast made of gypsona may first be softened by soaking.

ADVANTAGES AND DISADVANTAGES

The advantages of plaster of Paris as a splinting material are 1) its ability to intimately conform[1,23,30]; 2) the decreased possibility of pressure areas, because of the increased conformity[16,23]; 3) the lesser sheerforce (the movement of the splint or cast on the skin)[1]; 4) its porosity, which allows absorption of perspiration and prevents skin maceration[23,30]; 5) its retention of body heat, which provides a gentle, neutral warmth[31–34]; 6) its reasonable cost[23,30,35]; and 7) its use in the construction of comfortable, nonremovable casts to facilitate tissue response.

No thermoplastic material, regardless of its molding properties, can mimic the ability of plaster of Paris to conform. Synthetic casting materials are much stiffer than plaster of Paris,[36–38] although they are stronger.[37,38] Strength is a consideration only in weight-bearing casts and large casts over joints influenced by spastic muscles.

Thermoplastic splints and plaster of Paris casts are estimated by the author to have similar material costs per application, but the time cost for construction of a mobilization splint is much greater than for a plaster of Paris cast. Synthetic casting materials are about 2 to 2.5 times more costly than plaster of Paris.[36–38]

Disadvantages of plaster of Paris are 1) the skill required for precise application and safe removal of casts made from it; 2) the sensitivity of hardened plaster of Paris to water exposure, which may cause inconvenience in the performance of activities of daily living; and 3) its heavier weight in comparison with thermoplastic splinting materials. Because the period when a cast is worn full time is relatively brief, the weight of the cast is rarely a problem. Besides, the cast will not be unnecessarily heavy if it is skillfully constructed and applied.

PRECAUTIONS

Care must be taken in the application of plaster of Paris to prevent inaccurate positioning or stabilization, with inappropriately displaced pressure. Pressure areas and circulatory constriction are possible, although these complications are far more common when plaster of Paris is applied to an acutely injured hand. Patients with asensate areas are most vulnerable to complications from inappropriate pressure.

The primary concern in the application of plaster of Paris is avoidance of excessive heat from the exothermic process, which can cause second- or third-degree burns.[18,39–41] Therapists should be fully aware of the multiple factors that influence the exothermic process in plaster of Paris.

The greatest influence on the exothermic process is the speed of the setting time: The faster the setting time, the greater the exothermic process.[17,40,42] The second most important influence is the thickness of the plaster of Paris, with a thicker cast or splint generating more heat.[17,40,42] Third, increased temperature of the dipping water also increases the heat generated.[19,40,42]

Wrapping material over the setting plaster of Paris or covering the cast or splint with pillows prevents the heat from dissipating and significantly increases the internal temperature.[40–42] As the cast or splint is setting, the patient should be instructed to avoid covering it until it is completely cool and dry.

Other factors that affect the heat generated by the exothermic process are the humidity and temperature of the room[40] and whether the immersion water has had previous plaster of Paris dipped in it.[40,42]

The thickness of the padding is an insignificant factor in temperature alteration.[40] Recommended temperatures for the dipping water vary greatly in the literature.[19,28,40,42,43] For each type of plaster of Paris used, therapists should follow the manufacturer's written recommendation for immersion water temperature.

During cast removal, vibration from the oscillating saw blade generates heat. If the cast saw blade is held in one position, the heat generated by it may burn the patient. To prevent this, the saw technique must incorporate an up-and-down movement of the blade.[17,44,45]

If pressure on the blade is maintained after it has cut through the plaster, a friction burn or abrasion to the skin will result. Practice is required to develop skill in cast removal, so that saw movements are kept securely in control and the pressure is released as soon as the blade pierces through the plaster.

As discussed later, plaster of Paris can be applied directly to the skin. Contact dermatitis, although rare, should be considered whenever an unpadded cast or splint is applied.[43,46,47]

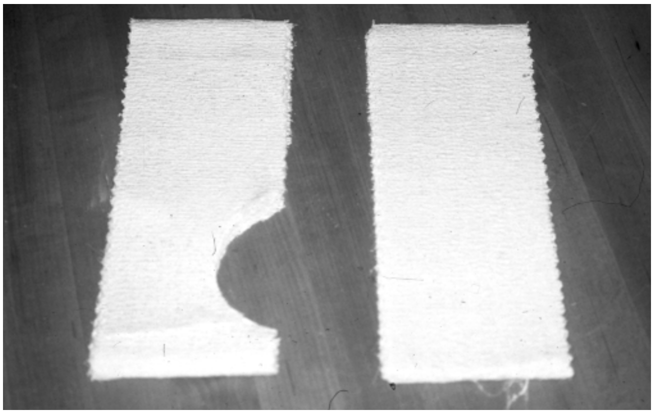
SPLINT AND CAST DESIGNS

Plaster application to the hand has three basic designs—circumferential casts (padded over the hand, unpadded over the digit), padded slabs, and isolated contour molds.

Circumferential Padded Cast

Padded casts have a layer of tubular stockinette applied directly to the skin, over which cast padding is applied prior to the application of plaster of Paris. The use of cotton cast padding (Webril undercast padding, North Coast Medical, Inc., Morgan Hill, California) rather than synthetic padding is recommended. Synthetic padding will narrow as tension is applied, whereas the cotton will shred apart before excessive tension is applied, preventing the possibility of excessively tight application. Synthetic padding also usually has more cushion, making the application of intimately molded plaster of Paris over the padding more difficult.

A wet roll of plaster of Paris is quickly wrapped around the padded part, overlapping by 25% to 50%, with four to six layers applied for a non-weight-bearing circumferential cast.[18,44] As soon as a complete roll of plaster of Paris has been applied, the layers are smoothed together until it becomes one mass. Once the set point is reached, joints cannot be repositioned or the contour changed. Any attempted remolding will hinder the interlocking of calcium sulfate crystals and weaken the cast or splint.[28]



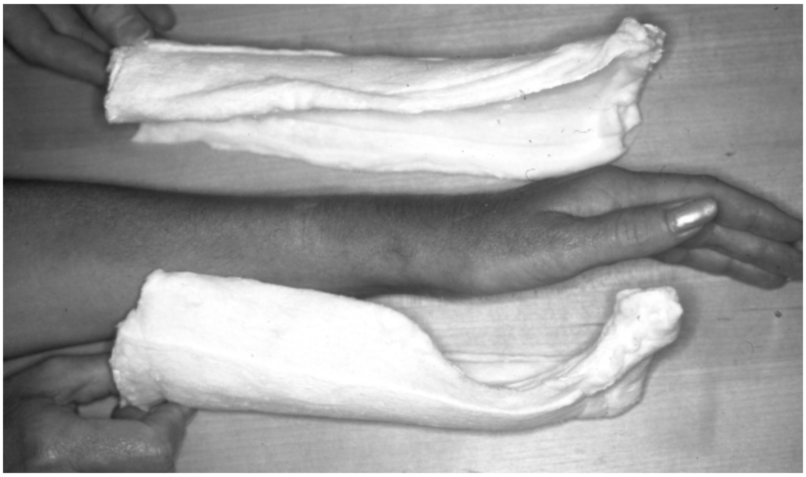



FIGURE 1. *Plaster of Paris slabs are used to serially position the wrist.* Top left, *Multiple layers of plaster of Paris are prepared.* Top right, *Slabs are immersed in water and then smoothed out over layers of cast padding.* Left, *A volar slab is applied and wrapped in place, and the wrist is held in extension while the plaster of Paris hardens.* Above, *After identical application of a dorsal slab, both slabs can be removed and reapplied.*

Circumferential casts require removal by cutting down two sides with an oscillating cast saw. If the padding and stockinette are cut on one side only, the circumferential cast becomes a hinged removable cast (called a bivalved cast). The addition of circumferential hook-and-loop straps allows periodic reapplication of the cast during weaning periods.

Digital Unpadded Casts

Because of the tubular shape of the digits, digital casts can be applied directly to the skin and easily removed by soaking in water or cutting with scissors. (Cast saws are never used on unpadded casts.) The plaster of Paris adheres slightly to the underlying skin, forming perfect contact for pressure distribution. Multiple layers of 1-inch-wide plaster of Paris strips are wrapped around the digit and smoothed together while the joints are gently positioned. Bell-Krotoski provides detailed descriptions of this technique.[1,16]

Plaster Slabs

Plaster slabs are lengths of multiple layers of plaster of Paris applied to one or both sides of the extremity. Prior to application, a wet slab is placed on strips of padding material and smoothed out so that the plaster of Paris layers meld together and adhere to the padding. The slab is then held in place on the extremity with an elastic bandage or gauze wrap. When two slabs are used, one may be applied and allowed to harden slightly before the second is applied. The slabs can be removed and reapplied by the patient (Figure 1).

Contour Molds

Contoured plaster of Paris molds are used to apply positive pressure to scars and, secondarily, to assist in repositioning joints. Since the plaster of Paris contours well and does not cause maceration, it is the ideal material for application directly over scars, especially if the skin needs to be held at length while the positive pressure is applied. The plaster of Paris may be applied directly to the skin, or one layer of padding may be applied underneath. One layer of wet plaster of Paris is applied at a time and is smoothed in place, until the desired size and shape are achieved. To prevent friction of the mold on the hand, the mold is applied with an elastic or self-adherent elastic wrap rather than with straps.

Regardless of the design, the most important aspect of successful use of plaster of Paris is the melding of the layers together, to make a strong and well-molded contour.

CLINICAL APPLICATIONS

Joint Tightness

The periarticular structures of the human joint adaptively shorten under any circumstance in which the joint is not carried through the full range of motion. If trauma creates scar within the periarticular structures, the resistance to full motion becomes even greater. Joint tightness is currently the most common clinical problem treated with plaster of Paris casting or splinting.

Serial Digital Casting

Serial digital casts are frequently used to decrease IP flexion contractures. This technique was developed by Brand[23] and Kolumban[48] in work with leprosy patients in India, and it is detailed by Bell-Krotoski[1,16] and others.[49] Kolumban's work[48] has validated the superiority of serial casting for increasing joint motion in patients with leprosy, compared with both traditional physical therapy techniques and dynamic splinting.

Both recently injured joints and chronically stiff joints respond to serial casting. Those who hesitate to apply serial casting for a brief period early in the treatment of proximal interphalangeal (PIP) joint problems are missing a valuable opportunity. A few days of serial casting will significantly decrease joint edema while enabling the joint to regain the weaker motion of extension.

In many cases, reducing joint edema is as crucial to the resumption of normal joint motion as is decreasing the resistance of the periarticular structures. A bulbous, somewhat fluctuant PIP joint with inflammation localized to one or more collateral ligaments is an ideal candidate for a short period of serial casting early in rehabilitation.

Concerns are often expressed that the circumferential pressure of the cast on a digit may cause ischemia due to increased swelling. Since the cast is never applied in the acute inflammatory stage and since the pressure of the hardened cast is static, the common response of the digit is decreased edema. The rest that the cast provides to the joint contributes to diminished inflammation, which also reduces edema.

Both edematous PIP joints and contracted PIP joints may gain greater flexion as a result of the extension mobilization casting. In an edematous joint, greater flexion results from increased room to move into a closed pack position. In a contracted joint, the elongation of scar impeding volar plate movement allows the volar plate to more readily fold out of the way during flexion.

An additional advantage of plaster of Paris digital casting is the ability to mobilize adjacent joints in opposite directions. In a fixed boutonniere deformity, the DIP joint can be mobilized into flexion and the cast allowed to harden. The PIP joint is then cast toward extension with the application of additional plaster of Paris. Conversely, fixed swan neck deformities can be gently altered by first mobilizing the DIP joint into extension and then the PIP joint into flexion.[1] Digital casts may also be used to mobilize an isolated tight joint while a thermoplastic splint with outriggers is applied to elongate a tight muscle–tendon unit.[1]

Serial Plaster of Paris Slabs

Plaster of Paris slabs are particularly useful for regaining wrist extension after distal radius fracture.[43] Immediately following mobilization of the wrist in therapy, the wrist is positioned in easy maximum extension and a volar slab is applied. A dorsal plaster of Paris slab is then applied to hold the wrist securely against the volar mold. When applied together, these two molds sandwich the wrist and hold it in maximum extension (Figure 1). The patient wears this for prolonged sessions during the day, and sleeps in it. After waking, the patient starts with the wrist at its maximum extension, rather than working to regain the maximum achieved the previous day. When the patient can actively lift the wrist out of the volar slab, a new one is molded.

Arthritis

Prior to the development of anti-inflammatory drugs, plaster of Paris immobilization splints or casts were used to decrease synovial inflammation and reduce pain in patients with inflammatory arthritis. When inflammation subsided, serial plaster of Paris splints or casts were then applied to regain motion in the stiffened joints.[19] Since the advent of anti-inflammatory drugs, immobilization splinting for control of synovial inflammation is rarely used in the United States. The use of night resting splints[19] has continued, but these splints are now made from thermoplastic materials for ease of construction and greater durability.

There remains a large realm of appropriate application of plaster of Paris to minimize and in some cases reduce hand joint deformities resulting from arthritis and other connective tissue disorders. As joint deformities or instability begins, the balance of the forces crossing the joints of the hand is altered. Deformities are likely to progress if there is no external influence in the opposite direction. Gentle, slow repositioning of the joints via serial plaster of Paris splinting or casting allows the soft tissues to resume their previous length. This is the ideal way to mobilize such joints comfortably.

It is only when forceful serial casting is applied that concern for cartilage neurosis via sustained pressure is a consideration. Since rheumatoid arthritis is a collagen disorder that increases the laxity of the supporting structures of the joints, fear of stiffness from a reasonable period of immobilization from serial splinting or casting is unfounded.

Serial casting to reduce digital deformities, such as boutonniere and swan neck deformities, may be approached as in the hand with trauma, so long as x-rays show an absence of a fused joint. Even an obstinate joint with a pseudarthrosis can sometimes be slightly repositioned so that the deformed position is more functional. Therapists will do no harm if they discard any idea of force application in their approach to patients with such deformities, and apply plaster of Paris to gently reposition the tissue.

In a patient with severe contractures due to scleroderma, the possibility of regaining joint motion is obliterated by the nature of the disease. Patients with severely contracted PIP joints have ischemia of the taut dorsal skin, and dorsal ulcers are frequently present. These ulcers are hard to heal, because the position of the severely contracted joint places continual tension on the dorsal skin, and the prominent apex of the flexed PIP joint is prone to abrasion. A carefully applied serial digital cast (with a thin layer of cast padding over the PIP prominence) will protect an ulcer from pressure or fiction and can slowly relieve some of the tension on the dorsal skin, allowing the ulcer to heal. Care must be taken that the cast is not tight enough to constrict even further the already diminished blood flow of the finger.

Contracted Joints Due to Spasticity

Inhibitive casting is used as a treatment technique in patients with cerebral palsy and head injuries, to decrease spasticity and improve joint contractures.[31–34,50–53] Although reports of the use of plaster of Paris inhibitive casting are limited to single case studies or general observation, a significant change in quality of movement and amount of joint motion is consistently reported.[31,33,34] The extremity is cast in a functional tone-inhibiting posture that theoretically reduces cutaneous input and spasticity by providing neutral warmth and even cutaneous pressure.[31–34] The prolonged positioning also results in muscle lengthening.[31] After initial progress has been noted, the cast is bivalved and worn for limited periods during day. As one would expect, these patients need long-term casting to retain the gains that have been made.[31,33]

Most casting of these patients is used to mobilize large joints such as the elbow or knee. Both circumferential serial casts and drop-out casts are used. Drop-out casts are circumferential around either the proximal or the distal bone, but the other bone is allowed to move only in the direction away from the contracted position. This allows active muscle contraction of the desired (and weaker) muscle into a greater range of joint motion, but it prevents the joint and muscle from resting in the fully contracted position.[32,54,55]

This concept of controlling the direction and extent of joint motion has been used by the author to develop a new approach to mobilization of the stiff hand—casting motion to mobilize stiffness (CMMS)—which is discussed below.

Muscle–Tendon Tightness

Tightness of the muscle–tendon unit of either the extrinsic flexors or the extensors is remedied by serial positioning of all the joints crossed by the muscle, to regain maximum length.[43] Since each joint being positioned requires three points of pressure to be accurately immobilized,[56] the multiple joints of the hand and wrist can best be serially positioned using volar and dorsal plaster of Paris slabs. If only one component is used, stability of the splint on the hand is dependent on the strapping or wrapping, which over time allows movement of the hand joints in the splint.[57] When plaster of Paris slabs are used both dorsally and volarly, only one position is available for all the joints, and this position is sustained.

This slab technique also provides a safe means of repositioning an acutely injured hand while providing gentle compression to minimize edema. The volar slab is molded to position the wrist and hand in the desired position. When the volar slab starts to harden, the dorsal slab is molded. An additional smaller slab is molded to hold the thumb (Figure 2).

Skin Tightness

Because both burns and skin grafts provide a large bed of contractile scar, maintenance of skin length in all directions is needed to avert loss of joint motion. Plaster of Paris conformed over an area can comfortably position numerous joints accurately and also provide perfectly distributed pressure with a breathable material.

Plaster of Paris seems to be the ideal material in such circumstances, rather than being used only for patients who are noncompliant, as advocated by some.[58,59] The tissue response with plaster of Paris—the reduction of subtle edema, the flattening and softening of the tissue, and its increased mobility in response to gentle pres-

FIGURE 2. Dorsal and volar plaster of Paris slabs with a small thumb slab can slowly and safely reposition joints in the acutely injured hand while providing conformed compression to reduce edema.

sure[59]—is always superior to the tissue response with thermoplastic splints. The straps of thermoplastic splints can never stabilize a splint as accurately as can circumferential application of plaster of Paris or contour molds held in place with wraps.

The prolonged splinting or casting needed by patients with extensive burn or skin injuries is a challenge. The immobilization imposed by any type of splint or cast, whether made of thermoplastic material or of plaster of Paris, is difficult to balance with the need for joint movement. Plaster of Paris can easily be applied in a design that allows for splint removal. Bivalved casts, splints, or molded supports wrapped in place with self-adherent wrap or overlapping molded plaster of Paris slabs can provide well-distributed pressure but also can be removed for skin hygiene and exercise.

Because skin scars can cover any plane of motion and any number of joints, multiple joints often need to be positioned. When thermoplastic materials are used, all joints must be simultaneously positioned while the thermoplastic material is cooling. With plaster of Paris, one joint can be precisely positioned and the plaster of Paris allowed to harden. Then additional plaster of Paris can be added for careful positioning of the adjacent joint. By use of plaster of Paris, a contracted hand can be slowly coaxed into a more functional position.[59] If motion is lacking in both directions, Rivers[59] suggests using alternating flexion and extension casts to prevent significant loss of motion in either direction.

Plaster of Paris is well tolerated over open wounds. One study of split thickness skin grafts to the lower extremity showed that in patients who received casts immediately after surgery, wound closure was more rapid, graft acceptance was better (72% vs. 100%), and fewer therapy treatments were required than in an uncasted group.[35] Since plaster of Paris decreases friction of the splint or cast on the wound and absorbs wound drainage, it allows unimpeded wound healing. Wounds with unhealed areas and immature scars intolerant of friction (such as burn wounds that easily blister) are ideal candidates for the gentle pressure that plaster of Paris provides. Such wounds are tolerant of plaster of Paris also because collection of perspiration and moisture–a negative aspect of thermoplastic splinting material—is avoided.

Skin and Joint Tightness

If joint tightness accompanies skin shortness due to scarring, plaster of Paris provides direct pressure to the scar while joints are mobilized with repeated repositioning. In the author's opinion, the concurrent presence of skin and joint tightness is an absolute indication for the use of serial casting. This is espe-

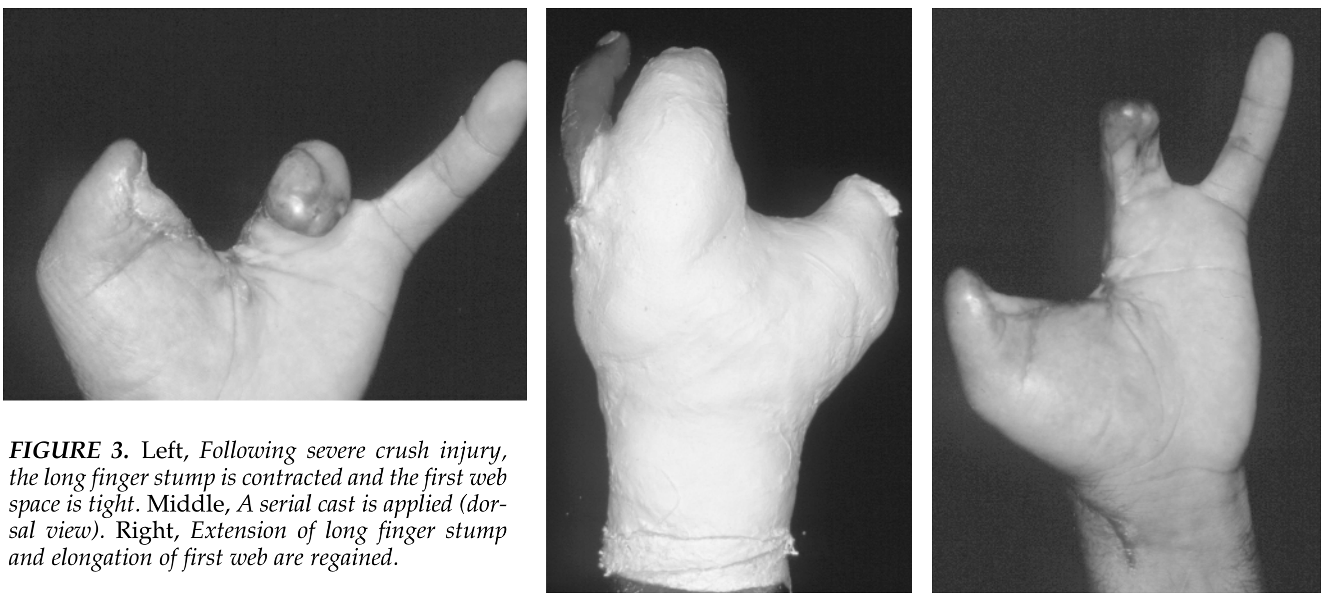


FIGURE 3. Left, *Following severe crush injury, the long finger stump is contracted and the first web space is tight.* Middle, *A serial cast is applied (dorsal view).* Right, *Extension of long finger stump and elongation of first web are regained.*

cially true in the thumb, where the many directions of motion and planes of skin movement make mobilization difficult. In multiple tissue injuries with skin injury—such as explosion injuries to the palm, skin loss in the first web, and severe crush injuries to the palm—plaster of Paris is likely to be more useful than thermoplastic materials (Figure 3).

Edema Reduction

Traditional hand therapy techniques for edema reduction are elevation, active motion, and compression with either elastic gloves or wraps or the application of massage. Recent increased awareness of the anatomy and physiology of the lymphatic system has caused many hand therapists to adopt gentler approaches when using these techniques, since we have learned that excessive pressure can prevent lymph fluid from entering the initial lymphatics.[60,61] Active finger movement while in a wrist cast causes the skin on the palmar and dorsal surface of the hand to move. The soft constraint of the padded plaster of Paris around the metacarpal area provides a light massage to the skin that facilitates lymphatic flow. Since the cast retains its original size and shape, there is no danger of a constrictive force, such as that seen with proximal compressive wraps.

This response was highlighted by a dramatic reduction in edema in a patient with a severe crush injury. A small cast was applied around the amputated thumb stump to contour the palmar scar and provide maximum abduction of the first metacarpal. The presence of the thin padded cast over the metacarpal area resulted in a dramatic reduction of edema (Figure 4). Use of such a thin cast over the metacarpal area and around the base of the thumb may in some cases be a preferable edema reduction technique in the severely injured hand.

Joint Tightness, Soft Tissue Adherence, Chronic Edema, and Altered Pattern of Motion in the Chronically Stiff Hand

Casting motion to mobilize stiffness (CMMS) is a technique developed by the author that uses plaster of Paris casting to selectively immobilize proximal joints in an ideal position while constraining distal joints so that they move in a desired direction and range.[62,63] Only active motion is used to gain both active and passive joint motion. No passive force is applied to any joint during the casting. The hand is simply positioned so that the muscle and joint movement needed is the only motion that can occur repeatedly over a long period of time (Figure 5).

In the chronically stiff hand, generalized joint stiffness results in joint tightness with a hard end-feel and constraint of soft tissue movement. Since the cast redirects the muscle–tendon excursion constantly to the joints where it is most needed, cyclic active motion mobilizes the tissue in both directions.[64] The active motion re-establishes the normal collagen cross-linking.[65–67] Mobilization splinting, on the other hand, moves the tissues in only one direction. Additional negative effects of mobilization splinting are constriction that contributes to edema, immobilization that prevents pumping of the venous and lymphatic system, and the possibility of excessive force, all of which prolong the inflammatory response.[68,69] These factors and the intermittent nature of mobilization splinting often make mobilization splinting ineffective in the chronically stiff hand.

The advantages of using active motion to mobilize stiffness in the CMMS technique far outweighs any negative effects of temporary immobilization of proximal joints. The movement of the stiffest joints maintains lubrication within the collagen cell matrix, prevents abnormal cross-link formation, facilitates lym-

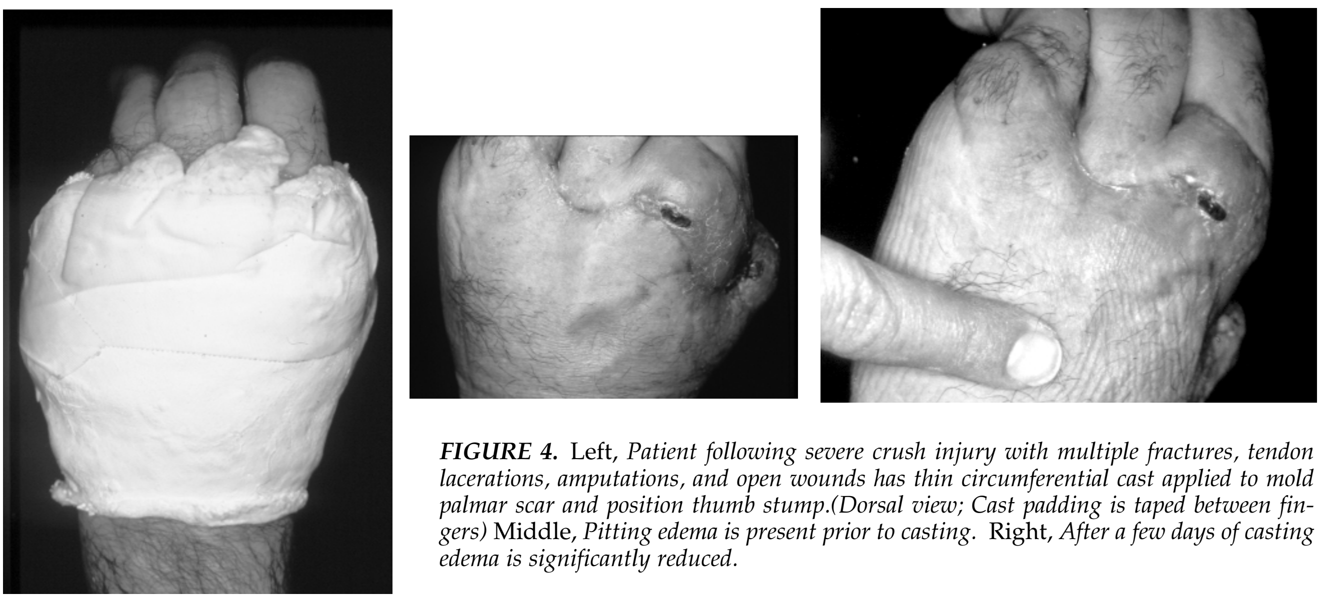


FIGURE 4. Left, *Patient following severe crush injury with multiple fractures, tendon lacerations, amputations, and open wounds has thin circumferential cast applied to mold palmar scar and position thumb stump.(Dorsal view; Cast padding is taped between fingers)* Middle, *Pitting edema is present prior to casting.* Right, *After a few days of casting edema is significantly reduced.*

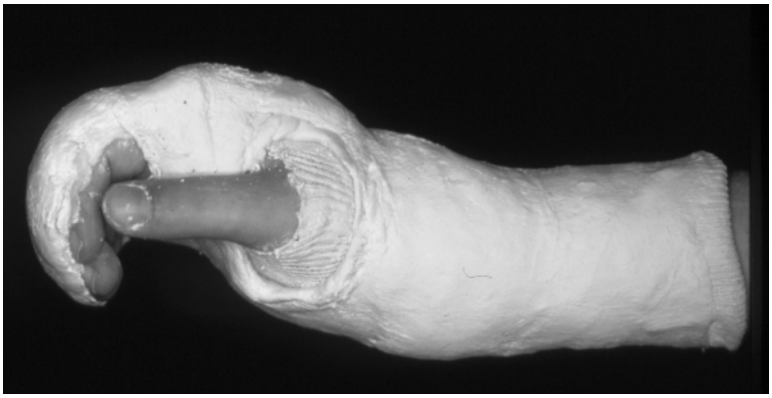


FIGURE 5. *Child with severe lawn mower injury at the wrist is fitted with a cast to support the wrist and position the fingers in slight flexion to facilitate maximum tendon glide after flexor tenolysis.*

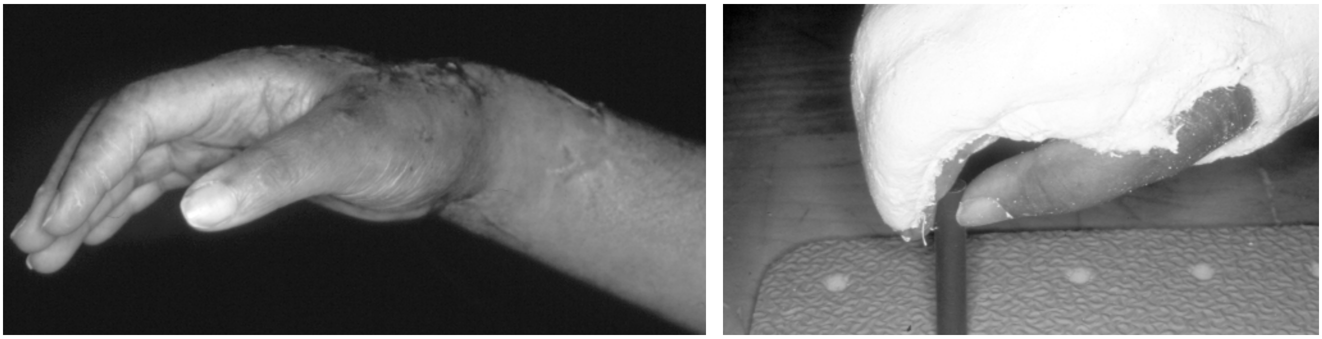


FIGURE 6. Left, *Active finger flexion of patient with multiple wrist injuries and 4-month chronic open wound shows abnormal posture and limited motion.* Right, *Cast with dorsal hood over the fingers immediately re-establishes pinch.*

phatic flow, strengthens muscles, and re-establishes independent glide of tissue layers. Although continuous passive motion has proved to be effective in the treatment of acute joint injuries,[70–72] neither laboratory nor clinical studies have demonstrated its usefulness for reducing stiffness once it is present.[71,73]

Abnormal patterns of motion are established as a result of the lack of tissue mobility (Figure 6, *left*). The patient repeatedly moves the loosest joints, which encourages the somatosensory cortex to memorize this aberrant pattern. Therefore, regaining motion in the stiff hand is both a complex mechanical and cerebral issue.

The mechanical problems are shown by the presence of deviate patterns of motion. The most common patterns are the dominant intrinsic flexion pattern, in which the metacarpophalangeal (MCP) joints flex before the IP joints, reinforcing the stiffness in the IP joints; and the dominant extrinsic flexion pattern with stiff MCP joints, in which the IP joints flex fully before MCP joints. Almost all patterns of motion will cause a loss of the normal reciprocal balance of tenodesis, in which finger flexion occurs concurrent to wrist extension. A vicious cycle is established because the tissue stiffness prevents the normal pattern of motion, and without the normal pattern of motion the stiffness cannot be resolved.

FIGURE 7. *Patient with diminished finger flexion following distal radius fracture is fitted with a cast with the MCP joints in extension to allow active IP flexion to mobilize the interosseous muscles.*

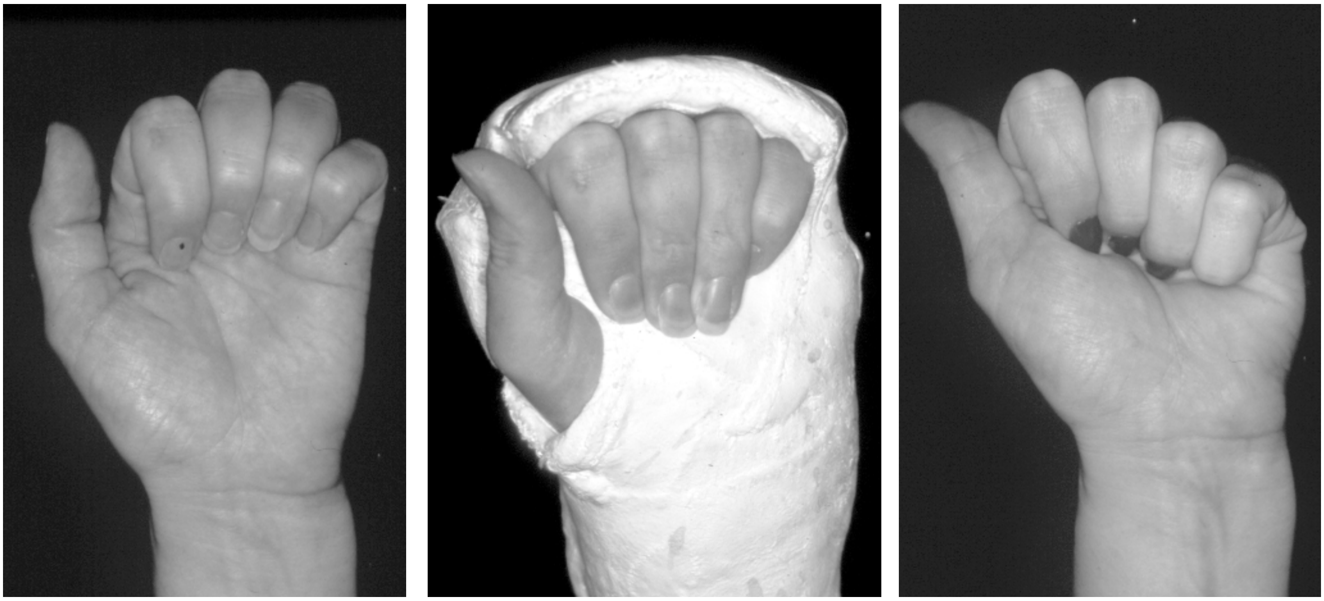


FIGURE 8. Patient with hard end-feel stiffness of MCP joints following MCP joint dislocations:. Left, *Limited active MCP flexion.* Middle, *Cast that dictates active MCP flexion in end range.* Right, *Active flexion after casting.*

Depending on the dominant pattern of motion, the CMMS cast blocks and stabilizes the proximal joints. For example, a hand with the dominant intrinsic flexion pattern is cast with MCP flexion blocked. If profundus glide is poor, a dorsal hood is added to position the distal interphalangeal (DIP) joints in relatively greater flexion than the PIP joints, ensuring that the most likely muscle movement will be that of the the flexor digitorum profundus. In hands with extremely limited motion, supporting the wrist in extension and placing a hood over the fingers immediately positions the fingers so that pinch is possible (Figure 6, *right*). This quickly converts a nonfunctional hand to an assisting hand while digital motion is being regained.

Arbuckle and McGrouther[74] validated the use of the dorsal hood to position the IP joints in greater flexion than the MCP joints. They showed that the normal pattern of digital flexion is initiated with IP flexion prior to any significant MCP flexion (hook position). One must be cautioned against blocking the MCP joints in full extension in the very stiff hand, since tight interosseous muscles may provide too much resistance to active IP flexion in the initial stages of mobilization. When reasonable profundus glide is regained, the cast position is changed to full MCP extension so that IP flexion can mobilize the tight interosseous muscles (Figure 7).

A second example is the hand with stiff MCP joints but flexible IP joints. The dorsal hood extends only over the proximal phalanges (Figure 8). The patient works on pulling the proximal phalanx away from the dorsal hood using primarily intrinsic muscles (minimal IP flexion) (Figure 8, *middle*). When a greater range of MCP flexion is gained, a new dorsal hood is applied to allow this active motion to occur in a greater range of flexion.

Although casting or other immobilization of the IP joints might be considered to transmit all flexor force to the resistant MCP joints, the author has not found this necessary, even with joints with a significant hard end-feel. At no time is any force applied to any joint with the plaster of Paris cast, nor are joints held at the absolute end-range of motion. The joints are simply positioned within the cast to optimize active motion.

Third, if isolated joints are stiff, the cast restrains all proximal (or other) joint movement. Movement occurs only at the site of the greatest stiffness (Figure 9). This is particularly helpful with PIP joint stiffness in which both flexion and extension are lacking. This is the only mobilization technique by which motion can be gained in both directions at the same time.

The neurologic consequences resulting from the altered pattern of motion create an additional consideration in the rehabilitation process. Since stiffness produces an abnormal pattern of motion, the motor cortex learns this pattern of motion as the new "normal." Neuroscience research shows that animals and human beings trained in movement combinations magnify the cortical representations of the motor areas used predominantly and that lack of use decreases the corresponding cortical area.[75–77]

For motor cortex repatterning to occur, repeated motion in the desired pattern is needed over a period of time.[78,79] With removable splints, a patient reverts to the aberrant pattern of motion each time the splint is removed, and repatterning of the cortex is defeated. This explains why mobilization splinting so often fails to reduce resistance in the very stiff hand or

FIGURE 9. Left, *13-year-old patient with unusual pattern of hyperflexion of both the metacarpophalangeal and distal interphalangeal joints with limited proximal interphalangeal (PIP) joint flexion following proximal phalanx fracture.* Middle, *Cast to prevent motion at all joints but the PIP joint.* Right, *Final flexion.*

joint. For progress to occur and be maintained, the patient must wear the CMMS cast for a significant period of time and wean slowly. Since original cortical connection patterns persist and can easily be reactivated,[78] a few weeks in a cast can convert the pattern of motion even if the stiffness has been of long duration.

In the chronically stiff hand, mild pitting edema accompanies atrophic, shiny skin and diminished or absent joint creases. The tissues are firm to palpation and have decreased mobility. The excess fibrosis from the prolonged immobility and the presence of high-protein edema impede the flow of lymphatic fluid.[60,80,81] Because of the limited active motion, the lymphatic system becomes stagnant. Since the single most effective stimulator of the lymphatic system is active motion,[12,60,61,80,82,83] CMMS casting effectively facilitates lymphatic pumping by encouraging active motion. No other mobilization technique provides this stimulus so consistently.

Since the initial lymphatics in the skin are easily collapsed by excessive pressure,[61,84] light pressure is required to facilitate lymphatic flow. The cast provides light pressure to the hand, while movement of the hand within the padded casts provides a facilitatory pseudo-massage to the skin. There is also a direct relationship between ambient temperature and the permeability of the initial lymphatics.[85,86] The insulation of the cast provides neutral warmth, retaining the body heat. In addition to effecting lymphatic flow, the neutral warmth may assist in general tissue relaxation and facilitate tissue elongation.[31,32]

Dramatic results have been seen in numerous patients with chronically stiff hands due to a wide variety of conditions. Each case is unique, and the cast design must be specific to the altered pattern of motion. The cast must be precisely applied with accurate molding to ensure well-distributed pressure. Most therapists are uncomfortable with the temporary loss of motion in some joints and are likely to wean a patient out of the cast too early, so that a period of recasting is often required. Therapists must let go of previous assumptions that motion must be gained in all directions simultaneously.

The CMMS technique should not be used on patients who are claustrophobic or have acute injuries or in a patient whose anatomy is so altered that a balance of motion cannot be regained when the CMMS casting is discontinued.

Postoperative Mobilization of Flexor Tendon Glide

In unusual circumstances, following flexor tenolysis or flexor tendon repair, the application of a plaster of Paris cast to stabilize the wrist and allow only finger flexion may be the optimal postoperative approach. If a patient has had limited flexor tendon glide for a period of time, the unimpeded intrinsic muscles will always be dominant. Placing the hand in a cast in which only flexor glide is possible assists the patient with accurate muscle pull-through. In flexor tenolysis, the cast may be applied early after surgery.

Limited proximal excursion of the flexor tendons means that the muscles have never been allowed to maximally contract. Placing the hand in a cast with a dorsal hood over the fingers allows the patient to work in the end range of active finger flexion, which also allows effective muscle strengthening. When this motion is regained, extension can be incorporated into the exercise program. Stretching and intermittent splinting can help the patient regain the extension, since it was dominant prior to the tenolysis. This treatment approach has been particularly useful with children and with mentally retarded adults who have difficulty appreciating the correct motion.

In patients who have had flexor tendon repairs and are in unusual circumstances (such as incarceration) and in patients who have limited comprehension, the hand is placed in a cast with a dorsal hood after 3 weeks of immobilization. The dorsal hood protects the hand from forced extension but allows active flexion while stabilizing the wrist. At 6 weeks, when the tendon can withstand passive extension, the cast is removed and the patient works on regaining extension while maintaining flexion.

Some therapists have expressed concern that the dorsal hood would create IP flexion contractures. Since the joints are moving actively and edema is minimal, this concern has appears to be unfounded.

This type of cast application allows simplification of the postoperative regimen. The motion with the greatest deficit is the primary focus. Until adequate gains are made in that direction of motion, motion in the other direction is ignored. Casting can be thought of as a jump-start for the greatest deficiency. The few weeks of casting are, realistically, a very short period relative to the maturation process of the healing scar.

CONCLUSION

This article reviews the characteristics of plaster of Paris and re-introduces the concept of tissue adaptation in response to the application of plaster of Paris splints and casts. Clinical examples of the use of plaster of Paris are discussed, and a variety of applications in cases with specific diagnoses are described.

It is hoped that the reader will question previous assumptions about temporary immobilization of uninjured joints, concurrent goals of gaining motion in all directions, and methods of edema reduction. Such questions should lead the reader to use plaster of Paris splinting or casting more often to solve clinical problems. Therapists who lack plaster of Paris handling skills should seek the assistance of a skilled practitioner and should apply and remove numerous casts before using these treatment techniques with patients.

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