A History of Splinting:
To Understand the Present, View the Past

Elaine Ewing Fess, MS, OTR, FAOTA, CHT
Hand Research
Zionsville, Indiana

ABSTRACT: The purpose of this study was to identify, using an intensive literature review, the primary historical factors and events that shaped the evolution of current splinting technique and practice. Publication dates determine the chronological order of events, and splints are defined according to the ASHT Splint Classification System. Purposes of splinting are analyzed and listed according to frequency of citation in splint manuals and books, and a historical review of splinting practice describes splints, events, and persons who influenced the evolution of splinting from the time of Hippocrates through the 20th century. Factors influencing splint development include disease, political conflict, advancements in medicine and technology, agency and organizational decision making, centers of practice, and availability of information. Infection, polio, war, technology, plastics, surgical advances, soft tissue remodeling, anatomy, biomechanics, government agencies, hand centers, seminars, professional organizations, publications, and a classification system have all played important roles in 20th century splinting practice.
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The splinting of extremities rendered dysfunctional by injury or disease is not a new concept, and yet clinicians often are not aware of splinting history beyond their own experiences. Delving into the past strengthens the foundation of clinical practice by identifying themes that have persisted over time and by expanding crucial knowledge of the field. It also imparts a heightened appreciation for current methods by providing new insights into the pivotal events that contributed to the development of modern splinting theory and technique.

Those who ignore the past inevitably recreate it.* Both novice and experienced clinicians alike have "invented" revolutionary new splint designs, only to discover later that their highly touted creations have been in use for years! Knowledge of history promotes perspective, wisdom, and humility. Historical information also diminishes the odds of recurring mistakes being made by each new generation of clinicians. With experience comes the realization that little is truly new in the world. Ideas beget ideas, eventually creating a wall of knowledge to which many have contributed. Splinting concepts and practices have a rich and, for the most part, undocumented history. In an age abounding in historical treatises, the lack of historical analysis of splinting theory and practice is both surprising and perplexing.

The purpose of this study, which is based on an intensive literature review, is to identify the primary historical factors that shaped the evolution of current splinting technique and practice. With more than 900 references specific to splint design, technique, and application available in the medical literature, individual mention and review of each article is not in the scope of this paper. Instead, published papers, manuals, and books are grouped according to their content and purpose, allowing identification of chronological trends both internal and external to the field.

To more efficiently manage the sheer volume of references, chapters in books are not included in this study, unless omission of the work would create a serious deficit in the information base. Publication dates determine the chronological order of events. While a material or technique may have been used several years prior to, or after, its published report, the date of the report is the defining criterion in this study, allowing uniform management of documented events and exclusion of unconfirmed accounts. Splints illustrated in this study are defined according to the ASHT Splint Classification System.[1] This

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Correspondence and reprint requests to Elaine Fess, MS, OTR, FAOTA, CHT, Hand Research, 635 Eagle Creek Court, Zionsville, IN 46077; e-mail: <e2indy@aol.com>.

*Cf. "Those who cannot remember the past are condemned to repeat it."—GEORGE SANTAYANA (1863–1952) allows more accurate description, analysis, and comparison of splints. For the sake of brevity and ease of reading, and because many of the persons mentioned in this article are well known, only the surnames of 20th century contributors to splinting practice are used in this text. Their full names and credentials are listed in the Appendix.

DEFINITION AND PURPOSES OF SPLINTING

The definition of terms provides a foundation from which to work. It also offers insight into past language usage from which contemporary usage has evolved.

Splint, *brace*, and *orthosis* are often used interchangeably, and *support* is a synonym for all three terms. Webster's *Third International Dictionary* defines *splint* as "a rigid or flexible material (as wood, metal, plaster, fabric, or adhesive tape) used to protect, immobilize, or restrict motion in a part." Demonstrating the close relationship between noun and verb, *to splint* is "to immobilize (as a broken bone) with a splint; to support or brace with or as if with a splint; to protect against pain by reducing motion."

Stemming from an archaic form meaning "arm" or "armor," *brace* refers to "an appliance that gives support to movable parts (as a joint or a fractured bone), to weak muscles (as in paralysis), or to strained ligaments (as of the lower back)." The verb form of *brace* means, "to prop up or support with braces."

With origins from the Greek *orthōsis*, meaning "straightening," an *orthotic device* is "designed for the support of weak or ineffective joints or muscles," and *orthotics* is "a branch of mechanical and medical science dealing with the support and bracing of weak or ineffective joints or muscles."[2]

Despite subtle differences, it is apparent that considerable overlap exists in these definitions and that the definitional criterion focuses on immobilization, support, or restriction purposes. A weak case may be made for the assertion that "support" includes mobilization splints for supple joints but, interestingly, none of these definitions addresses the important concept of splinting to mobilize stiff joints or contracted soft tissues.

Analysis of the reasons cited for splint application in published splinting manuals and books reveals a different scenario, which is more comprehensive in scope. According to noted authors in the field, splints immobilize, mobilize, or restrict motion.[1] Listed according to frequency of citation, the purposes of splints are to increase function,[3–27] prevent deformity,[*] correct deformity,[†] substitute for lost motion,[‡] protect healing structures,[§] maintain range of motion,[#] stabilize joints,[**] restrict motion,[††] allow tissue growth/remodeling,[‡‡] improve muscle balance,[§§] control inflammation,[##] protect normal structures,[***] allow early motion,[†††] aid in fracture alignment,[‡‡‡] decrease pain,[§§§] aid in wound healing,[14–16,18,20] transmit muscular forces,[18,32,37,38] rest joints,[15,16,21,34] strengthen weak muscles,[13,14,21] influence spasticity,[6,18,23] resolve tendon tightness,[34,35] decrease scar,[33,35] keep paralyzed muscles relaxed,[3,20] encourage predetermined functional stiffness,[3,32] treat infection,[3,18] increase patient independence,[39] and continuously move joints.[23]

From this comprehensive list, six of the cited reasons for splint application each have from 9 to 25 references spanning more than 50 years, indicating lasting affirmation and verification over time. These six rationales include 1) increase function, 2) prevent deformity, 3) correct deformity, 4) protect healing structures, 5) restrict motion, and 6) allow tissue growth or remodeling. In contrast, three of the last five cited reasons for splinting—keep paralyzed muscles relaxed, encourage predetermined functional stiffness, and treat infection—although still appropriate, are more reflective of earlier practice, when polio was prevalent and before antibiotics were available. The final reason cited—continuously move joints—is an obvious newcomer to the list.

GENERAL HISTORICAL OVERVIEW

Physical discomfort evokes an instinctive response to immobilize the painful part, and use of extrinsic devices to accomplish the immobilization process is inherently intuitive. In early antiquity, splints were used primarily for treating fractures (Figure 1). Splints of leaves, reeds, bamboo, and bark padded with linen have been dated to ancient Egyptian times, and some mummified remains have been found wearing splints for fractures sustained either before or after death.[40,41]

Copper splints for treating burn injuries were described in 1500 B.C.[42] Hippocrates (460–377 B.C.) used splints, compresses, and bandaging to immobilize fractures. These splints were gutter-shaped split stalks of large plants, wrapped in wool or linen, that were put on separately.[43] Hippocrates also devised a distraction splint for reducing tibial fractures, which consisted of proximal and distal leather cuffs separat-

* References 3, 4, 6–8, 10, 12–16, 18, 20–23, 25, 26, 28–33.
† References 3–6, 8–18, 20, 21, 23, 28, 30, 32–35.
‡ References 5, 7, 8, 10, 12, 15–18, 20, 21, 23, 24, 28, 32, 34, 35.

§ References 3, 5, 8, 10, 12, 17, 18, 20–23, 32–35.
\# References 5, 10–16, 18, 30, 32–34.
** References 8–10, 12–14, 17, 18, 21–24, 32.
†† References 3, 8, 10, 12–14, 34–36.
‡‡ References 3, 8, 12, 18, 21, 22, 35, 37, 38.
§§ References 5, 6, 9, 13, 14, 18, 25, 28, 35.
\#\# References 10, 17, 18, 23, 32–35.
*** References 3, 5, 8, 12–14, 35.
††† References 8, 10, 12, 15, 16, 35.
‡‡‡ References 14–16, 18, 19, 35.
§§§ References 6, 10, 18, 20, 31, 34.

ed by multiple pairs of too-long, springy, narrow wooden slats. When in place on the lower leg, this splint distracted the fracture and brought the bones back into alignment.

In medieval times (1000 A.D.), use of palm-branch ribs and cane halves for splinting continued. Plaster-like substances were made from flour dust and egg whites, and vegetable concoctions were made of gum-mastic, clay, pulped fig, and poppy leaves. The Aztecs (1400 A.D.) made use of wooden splints and large leaves held in place by leather straps or resin paste.[40] Although most ancient splints were applied to immobilize, Hippocrates' tibial distraction device is a clear example of a mobilization splint.

Moving forward in time, with the introduction of gunpowder in combat, European armor makers were forced to seek other avenues for their armor fabricating skills. Brace fabrication was a clear alternative for these experts, with their knowledge of metalwork, exterior anatomy, and technicalities of joint alignment. By 1517, joint contractures were treated with turnbuckle and screw-driven metal splints appropriately dubbed "appliances for crooked arms" (Figure 2).

The first one-page splint manual may have been written in 1592, by Hieronymus Fabricius, a surgeon, who devised an illustrated compilation of armor-based splints to treat contractures of all parts of the body (Figure 3). In France and England, from the 1750s to the 1850s, surgeons worked closely with their favorite appliance makers, or "mechanics," to design and build custom braces and splints. A. M. Delacroix, a highly regarded French appliance maker, used thin metal strips as mobilization assists in his braces.

FIGURE 1. Extension immobilization splint, type 0 (1). *This ancient Egyptian splint for a fracture dates from 2750–2625 B.C. (From British Medical Journal, March 1908. Reprinted from American Academy of Orthopaedic Surgeons:* Orthopaedic Appliances Atlas, vol. 1. *Ann Arbor, Mich.: J.W. Edwards, 1952.)*

NOTE: *The splint names shown in bold italics in the legends are the official names assigned by the ASHT Splint Classification System[1] and may include the following abbreviations: CMC, carpometacarpal joint; DIP, distal interphalangeal joint; IP, interphalangeal joint; MP, metacarpophalangeal joint; PIP, proximal interphalangeal joint.*

FIGURE 2. Elbow extension mobilization splint, type 0 (1). *A turnbuckle provides incremental adjustments in this 1517 splint. (Reprinted from LeVay D:* The History of Orthopaedics. *Park Ridge, NJ: Parthenon, 1990.)*

Although plaster of Paris was used in 970 in Persia, it was not accepted until the mid-1800s in Europe or slightly later in America, where it was viewed with disfavor by influential surgeons. Early disadvantages included prolonged set-up time and lack of a suitable latticing fabric.

By 1883, surgeons and appliance makers had become fiercely competitive, with surgeons feeling that appliance makers were only "useful if kept in their place." The surgeon/appliance-maker schism deepened and the two parties diverged, becoming independent factions for brace fabrication. Both disciplines had talented devotees.

In 1888, F. Gustav Ernst, an appliance maker, published a book[44] describing and illustrating sophisticated splints for treating upper extremity problems. These included a splint to support a paralyzed arm using a combination of gun-lock and centrifugal springs; a supination splint with ball-and-socket shoulder movement, with a set screw to prevent rotation, rack-and-pinion elbow extension, and a two-piece forearm trough with rotation ratchet movement for supination; a rack-and-pinion elbow and wrist flexion contraction splint with ratchet movement wrist rotation; a spring-driven wrist splint for wrist paralysis. It also included, for Dupuytren's disease, a rack-and-pinion finger extension splint, a single finger extension flat spring splint, a palmar retention splint, and a pistol-shaped splint for slight cases.

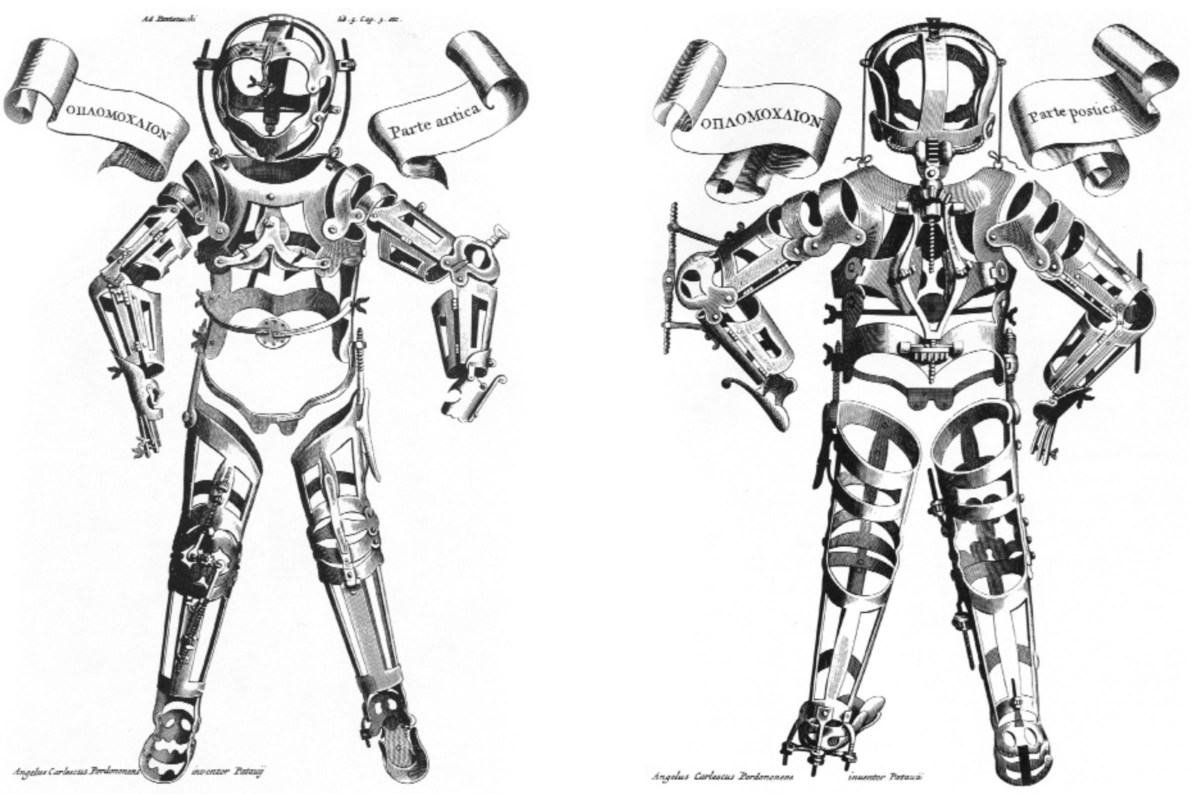


FIGURE 3. Fabricius' 1592 illustration depicts front (left) *and back* (right) *of armor-based splints for multiple parts of the body. (From Hieronymus Fabricius:* Opera Chirurgica. *Patavii, Italy: Bolzetti, 1641, in the collection of the Army Institute of Pathology. Reprinted from American Academy of Orthopaedic Surgeons:* Orthopaedic Appliances Atlas, vol. 1. *Ann Arbor, Mich.: J.W. Edwards, 1952.)*

At the same time, Hugh Owen Thomas, a British surgeon, identified principles of treatment and devised, among others, an inexpensive femoral splint and an ambulatory hip splint that allowed rest and outpatient treatment. Sir Robert Jones wrote of Thomas's splint workshop,

> There was a blacksmith at work in a smithy, a saddler finishing off the various splints, and duties of others were the making of adhesive plasters and bandages and the preparation of dressings. There were splints of every size to suit any possible deformity that might appear or for any fracture that might have occurred.[45]

Thomas's successful splinting endeavors spurred on the rapidly developing era of surgeon-fabricated splints and braces. In 1899, Alessandro Codivilla, an orthopedic surgeon in Italy, identified the importance of eliminating contractures prior to rebalancing with tendon transfers, foreshadowing the important contemporary partnership between surgical procedures and splinting.

In America, surgical methods were expanding, and surgeons were moving beyond being just "bone setters," "sprain rubbers," and "bandagists." By the 1880s, the importance of rehabilitation after treatment was beginning to be recognized and orthopedics, as a specialty arena, was gradually assuming autonomy from general surgery. By the early 1900s, plaster of Paris had widespread acceptance as medium for immobilizing fractures.

THE DEVELOPMENT OF SPLINTING PRACTICE IN THE 20TH CENTURY

Many factors combined to shape evolving theory and practice. These included, but are not limited to, disease, political conflict, advancements in medicine and technology, agency and organizational decision making, centers of practice, and availability of information. Although these factors are discussed separately in the following review of 20th century events, many overlap and intertwine over time.

Disease and Epidemiology

Infection

Wound infection was a major problem during the first four decades of the 20th century. Seemingly inconsequential trauma to a hand could lead to serious infection, and without the assistance of antibiotics, treatment results were unpredictable. In his 1916 book, *Infections of the Hand,* Kanavel[46] grouped infections into two categories: simple, localized infections; and grave infections, including tenosynovitis and deep fascial-space abscesses in one subgroup and acute lymphangitis in another. This book of almost 500 pages was important in that Kanavel defined the critical associations between synovial sheaths and fascial spaces. Case studies illustrated the dire consequences of poorly treated hand injuries, including that of a man who died from palmar scratches sustained from rubbing meat; a man who bruised his thumb getting off a streetcar and died of staphylococcus/streptococcus-related pneumonia; and a woman with arthritis who died from undiagnosed wrist infection of unknown etiology. Each of these patients presented with extensive local swelling, redness, and pain; septicemia or toxemia developed; and death occurred within 4 to 5 weeks. Kanavel noted that the age of patients who died averaged 43.8 years.

Differentiating between non-lethal swellings, as with thrombophlebitis or arthritis, was difficult, and failure, by the patient or the physician, to comprehend the potential seriousness of a problem could lead to the patient's untimely death. Although little is mentioned about splinting in his 1916 book, by 1924 Kanavel strongly advocated splinting in the functional position as one of the most important factors in successful treatment of infected hands.[47,48] Because the sequela of extensive infection was substantial restrictive scar, he also employed elastic traction splints to correct soft tissue contractures after infection was resolved.

Poliomyelitis

Identifying the underlying symptomatology and etiology of poliomyelitis spanned nearly two centuries of study. Although they were described by Michael Underwood, a British physician, in 1774,[49] it was not until 1840 that Jacob Heine, a German physician, identified the inconsistent presenting symptoms of poliomyelitis as manifestations of a single disease process. Twenty years later, in 1860, Heine defined standards of treatment management for "spinal infantile paralysis" victims, which were based on his experience. He advocated splinting, baths, and tenotomies, if needed. He also differentiated polio from spastic paralysis.[40]

In 1890, Swedish pediatrician Oscar Medin confirmed that polio was infectious and described anterior horn cell inflammation and tract degeneration as the cause of the weakness and paralysis that accompanied it.

Although the first outbreak of polio in the United States occurred in Louisiana, in 1841, the first epidemic happened in 1894, in Vermont. The first polio pandemic began in Scandinavia in 1905, eventually spreading to New York City and Massachusetts in 1907. In 1916, the first major epidemic in the United States occurred, with 8,900 new polio cases and 2,400 deaths reported in New York City alone.[50] Epidemics were reported in 1909 and then in 1912, 1916, 1921, 1927, 1931, and 1935. By 1942, there were 170,000 polio victims in the United States. In the majority of these patients, onset occurred between 1906 and 1939.[49]

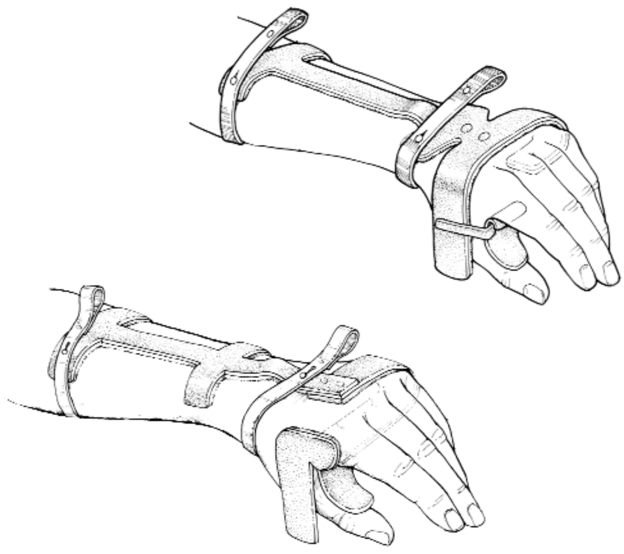


FIGURE 4. Thumb CMC palmar abduction, MP extension immobilization splint, type 1 (3). Top, *Rancho Los Amigos splint;* bottom, *Bennett splint (Warm Springs). Although they have different configurations, these two splints have the same Splint Classification System designation, because their functions are identical. (Reprinted, with permission, from Fess EE, Philips CA:* Hand Splinting Principles and Methods. *2nd ed. St. Louis, Mo.: Mosby, 1987.)*

Frighteningly, the magnitude of the epidemics increased as time passed. The 1933 epidemic resulted in 5,000 new polio cases. Ten years later, in the epidemic of 1943, new cases rose to 10,000. By 1948, 27,000 new cases were reported; and in the epidemic of 1950, the number of new cases was 33,000.[50] By the mid 1950s, with a peak of 57,879 new cases of poliomyelitis in the United States in 1952[51] and a 1955 baseline annual morbidity of 16,316,[52] polio had become the major focus of national rehabilitation and research resources.

Development of the iron lung[###] in 1928 increased polio survival rates and amplified demand for rehabilitative procedures. Large centers like those in Warm Springs, Georgia (1926), Gonzales, Texas, and Rancho Los Amigos, California (1949) became important hubs for research and treatment of poliomyelitis, and their developing orthotic departments were recognized for the splints and braces they created.[24,49,50,53] Some centers were so well known that splints made by these centers were identifiable solely by their configural characteristics (Figure 4). Advancements were also

[###]Webster's *Third International Dictionary* defines the iron lung as "a device for artificial respiration in which rhythmic alternations in the air pressure in a chamber surrounding a patient's chest force air into and out of the lungs, especially when the nerves governing the chest muscles fail to function."[2]

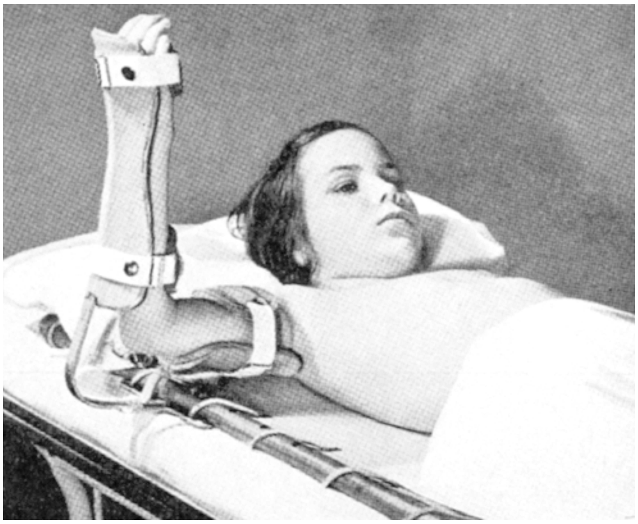


FIGURE 5. ***Shoulder abduction and neutral rotation, elbow flexion, forearm supination, wrist and index-small finger MP extension, thumb CMC palmar abduction and MP extension immobilization splint, type 0 (10).*** *This 1942 splint for a patient with polio immobilizes all the joints of the upper extremity except the finger and thumb interphalangeal joints, to provide neutral muscle balance. (Reprinted, with permission, from Lewin P:* Orthopedic Surgery for Nurses, Including Nursing Care. *Philadelphia, Pa.: Saunders, 1942.)*

made in tendon transfer theory and technique for rebalancing involved joints and restoring function to paralyzed extremities.

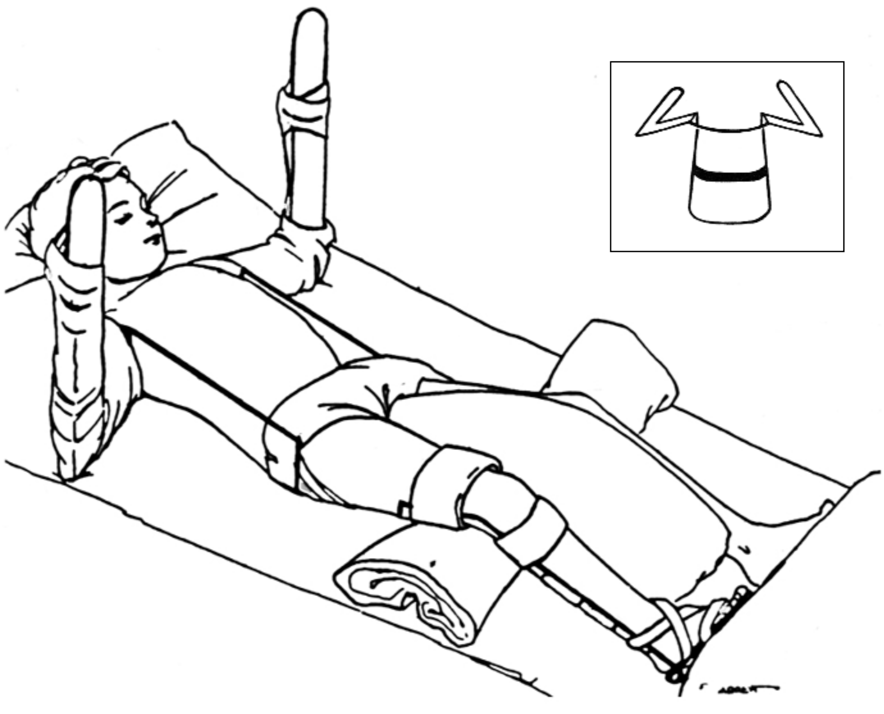
Early on, splinting was a critical factor in the treatment of poliomyelitis. Therapists who worked with patients with upper extremity polio needed in-depth knowledge of anatomy, kinesiology, and the deforming factors of pathology and substitution patterns, since these patients had widely varied patterns of muscle involvement.

During the preparalytic and paralytic stages of polio, splints were used to put muscles in neutral balance to prevent overstretching. Positions favoring maximal return of function were prescribed. For the upper extremity, to protect the deltoid muscles, shoulders were positioned with bed sheets, pillows, and sandbags in the "scarecrow" attitude, with 90° humeral abduction and external rotation and 90° elbow flexion. Splints were used to maintain forearms in 75% supination, wrists in dorsiflexion, fingers in slight flexion, and thumbs in opposition. Shoulder internal rotation and external rotation positions were alternated to prevent stiffness in either position. Metacarpophalangeal joints were splinted in extension so that the finger flexors would be used instead of the intrinsic muscles (Figure 5). If proximal interphalangeal (PIP) hyperextension occurred, elastic traction was applied, with attachment to the fingertips by thimbles or woven "Chinese finger-traps."[49,54]

Kendall advocated different shoulder, forearm, and finger metacarpophalangeal (MCP) joint positions, with 75° shoulder abduction (Figure 6), forearm neutral, fingers slightly flexed, and thumb in palmar abduction.[55] Prevention of deformity was so strongly emphasized that the extremities and torsos of some patients were encased in plaster to prevent over- stretching of critical muscle groups.

Sister Kenny, a controversial figure in Australia, promoted use of hot packs instead of splints for polio patients. Dismissing completely the traditionally held view that muscle imbalance was the cause of deformity in polio patients, she taught that deformi-

FIGURE 6. ***Shoulder abduction and neutral rotation, elbow flexion, forearm neutral, wrist extension, index-small finger MP-IP flexion, thumb CMC palmar abduction, and MP extension immobilization splint, type 0 (19).*** *These 1939 polio splints differ slightly in that they maintain the shoulders in 75° abduction, the forearms in neutral, and the fingers in flexion.* Inset, *wire frame for splints. (Reprinted from Kendall H, Kendall F.* Care During the Recovery Period in Paralytic Poliomyelitis. *Rev ed. Washington, DC: Public Health Service, 1939.)*



ty arose from muscle spasm. In 1935, a royal Australian commission found against Kenny's methods; so in 1940, she moved to the United States, where she found a more accepting climate. Although, it is now generally agreed that her methods had no effect on residual paralysis,[40] Sister Kenny was a major influence in polio treatment in the United States. Many polio treatment centers eventually assumed a middle-of-the-road approach, using both hot pack and splint interventions.

During the convalescent and chronic stages of polio, as weakness and loss of motion became apparent, splinting goals changed. Maintaining muscle balance and encouraging predetermined joint stiffness to enhance function became the primary focuses of splinting. Positioning was determined by individual patient requirements. If the extrinsic finger extensors were weak, the MP and interphalangeal (IP) joints were splinted in extension. Splints were fabricated from wire or plaster of Paris. Restricted passive range of motion slowed development of joint stiffness. Corrective splinting was used to increase range of motion of stiff joints in order to increase function and improve range of motion for tendon transfers. Therapy often lasted 2 to 4 years.[55]

Jonas Salk's inactivated-virus vaccine, in 1955, and Albert Sabin's oral vaccine, in 1961, resulted in the eventual eradication of poliomyelitis in the United States. By 1960, the incidence of polio had decreased by 90%, and after 1961, the incidence was less than 10%. The last case of polio in the United States from wild virus, not stemming from vaccination, occurred in 1979.[50,51]

Upper extremity splinting continued to play an important role in the treatment of the aftereffects of poliomyelitis:

> Advances in [orthotics] leading to greater functional capacity of the paralyzed upper extremities came after the discovery of the polio vaccine. This came, in part, from a lessening of the demands of acute and convalescent care and the fact that by this time the physician had learned to keep these very severely involved patients alive.[56]

Splints that aided hand and wrist function were often paired with overhead suspension slings, ball-bearing feeders, or walking feeders for shoulder, elbow, and forearm positioning, allowing functional movement of extremities against gravity (Figure 7).[39,50,57] Although leather hand-based splints were used for thumb or isolated finger positioning, most splints were fabricated in metal and had narrow bar configurations. Digital mobilization assists and wrist stop or spring mechanisms were incorporated as needed. Splints often served as bases for activities-of-daily-living (ADL) attachments, and as rehabilitation measures became more sophisticated, vocational activities were emphasized.[57] The intent was to make polio patients as independent as possible.[39]

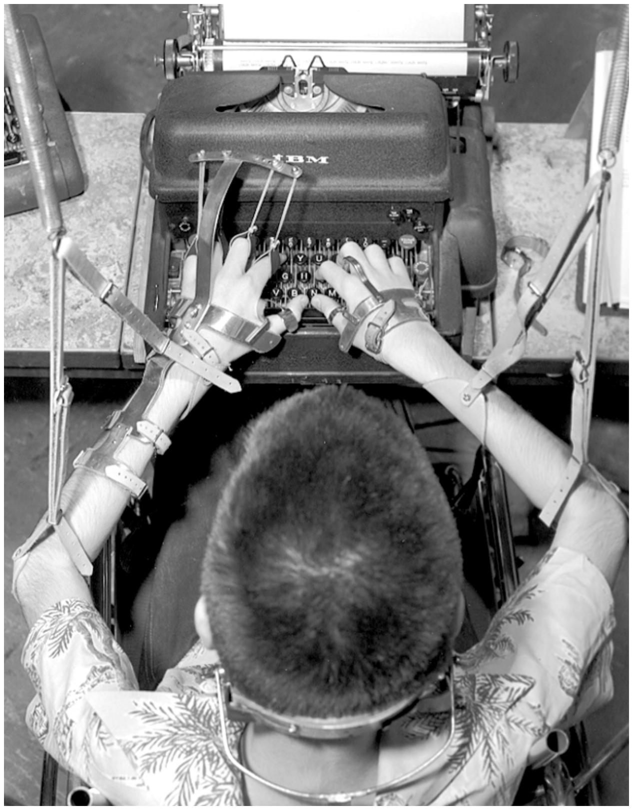


FIGURE 7.** Paralysis and weakness aftereffects of polio were often asymmetric, requiring different splints for upper extremity function.* Left side, ***Wrist extension, thumb CMC palmar abduction and MP extension immobilization / index-small finger MP-PIP mobilization splint, type 0 (11). Right side, ***Index-small finger MP flexion restriction / thumb CMC palmar abduction and MP extension immobilization splint, type 0 (6).*** *(From March of Dimes, archive no. G528; used with permission.)*

Political Conflict and War

It has long been acknowledged that declared armed hostile conflict between political states or nations has often accelerated advances in medicine and development of technology. As medical and technologic changes occur, splinting practice also changes.

Medical Advances Relating to Splinting

Despite the fact that one ninth of all wounds recorded by the Union Army involved the hand and wrist, little attention was given to surgical or rehabilitation procedures for the hand in the official medical and surgical documentation of the Civil War (1861–65). In the official record of surgical procedures for hand injuries in World War I (1917–18), mention was also notably sparse.[58] Gunpowder had forever changed the profile of war injuries, producing wounds that involved massive soft tissue loss and were contaminated with bone fragments and foreign particles. During the Civil War, fear of infection lead to the practice of amputating parts sustaining gunshot wounds that resulted in comminuted fractures.

Joseph Lister's concepts of antisepsis for surgical procedures did not gain universal acceptance until 1877. Infection and the lack of understanding of the need for thorough debridement also plagued wound treatment in WWI. Primary vs. secondary closure of wounds was just beginning to be understood by the end of the war, and penicillin would not become available until 1941. Hand injuries were considered minor in comparison with the morbidity-producing problems presented by rampant infection and gangrene.

During the period between WWI and WWII, general surgical practitioners who had no special knowledge of the hand were treating hand injuries. Flat splinting of fractures was prevalent, traction was often incorrectly applied, and burns were treated without asepsis despite groundbreaking contributions in the treatment of hand infections,[46] reconstructive surgery,[45] tendon repair and grafting,[59] and nerve repair.[60,61]

An important concept that would influence transfer of patients from battlefronts was reported by Trueta, in 1939—namely, that the pressure and immobilization provided by plaster casting promoted wound healing. He also observed that windows in casts caused swelling and edema that could lead to tissue necrosis and infection.[62]

During the early involvement of the United States in World War II, in contrast to previous war experience, the importance of treating hand and upper extremity trauma became apparent as casualties were assessed. Resulting data showed that 25% of all treated wounds involved the upper extremity, with 15% of these affecting the hand.

In 1943–44, at Letterman General Hospital (San Francisco, California), a major debarkation hospital from multiple theaters of operations, delayed wound healing and infection were associated with the long time it took to transport the injured from the Pacific and the China-Burma-India theaters:

> Many patients had been treated with the banjo splint or with flat, straight board splints applied to the hand and wrist in the position of nonfunction. Both methods are equally undesirable and were responsible for many disabled hands.[63]

These difficulties were exacerbated by tropical diseases and metabolic problems.

Since hand and upper extremity injuries required combined knowledge from the surgical fields of orthopedics, plastics, and neurosurgery, a plan was devised to treat patients with hand trauma as a distinct group, to allow focused care. Specialized hand centers in the United States and Europe were established to treat hand and upper extremity trauma.

Appointed special civilian consultant to the Secretary of War in late 1944, Bunnell was given the task of developing and coordinating the Army's hand surgery efforts. His already published book, *Surgery of the Hand,* became an official Army textbook.[64]

In an early report identifying problems of malunion, joint stiffness, inferior splinting, poor positioning, and ineffective wound coverage, Bunnell described commonly observed, incorrect ways of splinting the hand. He also defined the position of function as forearm neutral, wrist in 20° dorsiflexion and 10° ulnar deviation, fingers in slight flexion, with the index finger flexed the least and the small finger flexed the most, and the thumb in partial opposition with its joints partially flexed. Position of nonfunction was the opposite. He recommended splints for specific problems and emphasized the need for active, as opposed to passive, therapy and active use of the hand as a mainstay of good hand rehabilitation. Splints were constructed of wood, metal, wire, leather, plaster of Paris, and occasionally, plastic.

In his report, Bunnell opposed "rough manipulation of finger joints," stating that it was more harmful than good.[65] In addition to outlining surgical repair and reconstructive procedures, Bunnell discussed the importance of good splinting and cautioned that improper splinting is harmful, and he dedicated multiple pages to the characteristics of good splints, fitting splints, splinting precautions, immobilizing and mobilizing splints, and splinting for specific problems.[65]

Bricker (March 1945), in the European theater of operations, outlined principles for managing combat injuries of the hand, including:

> Splint purposefully, maintaining the palmar arch and flexion of the metacarpophalangeal joints; use traction only when it is urgently indicated, and then for a minimum length of time; concentrate on maintenance of function as remains; institute active motion as early as possible and supplement by occupational therapy... .[66]

In July 1945, Hammond listed nine concepts to improve hand care, with one of the nine being that "normal fingers should never be immobilized and should be moved for 10 minutes out of every hour, beginning immediately after the initial operation."[66]

In the United States, in the Zone of the Interior, Frackelton, at Beaumont General Hospital (El Paso, Texas), noted that "segregation [of hand patients] permitted the proper supervision of corrective splinting and institution of physical and occupational therapy both before and after operation"[67]; Hyroop, at Crile General Hospital (Cleveland, Ohio), reported that "special types of splints were used in contractures, nerve lesions, ankylosed joints, and as part of preoperative and postoperative therapy." He also noted that nerve repairs under tension were treated postoperatively with splints that allowed progressive motion.[68]

Littler, at Cushing General Hospital (Framingham, Massachusetts), described MP hyperextension contractures and collateral ligament shortening due to "secondary joint and tendon fixation" that severely hampered reconstructive procedures. These contractures required extensive surgical release "followed by elastic spring splinting with the wrist in extension, and early active exercise." Noting that "deformities of injured hands were common" and that "omission of splinting and improper splinting were very frequent causes," Littler went on to say,

> Corrective splinting was seldom necessary in hands on which protective splinting had been employed and for which persistent active and passive exercise had been undertaken. ... Appropriate protective splinting lessened functional disability and avoided the necessity for weeks of corrective splinting.[69]

Pratt, at Dibble General Hospital (Menlo Park, California), reported that "no difficulty was experienced in combining the two principles of immobilization of the injured part and mobilization of uninvolved joints." He continued with a review of splints frequently used at Dibble, ranging from simple web straps for flexion to wrist immobilization with finger MP flexion assists.[70]

Barsky, at Northington General Hospital (Tuscaloosa, Alabama), also noted the problem of immobilization with the MP joints in extension, which allowed the collateral ligaments to contract. He noted that, to avoid this, the splinting principles of "Koch and Mason were followed with good results, and in the future the universal Mason-Allen splint should be standard equipment for all hand work." He also stated, "Where there was no demonstrable roentgenographic change, elastic splinting accomplished a great deal."[71]

Phalen, at O'Reilly General Hospital (Springfield, Missouri), found Bunnell's splints "very satisfactory," noting that the "spring wrist cock-up splint was particularly effective in relieving flexion contractures of the wrist." An MP flexion, thumb abduction splint developed at O'Reilly was illustrated (Figure 8).[72]

Graham, at Valley Forge General Hospital (Phoenixville, Pennsylvania), reported that "it was the general rule to institute early motion and mobilization by activity and steady traction. Elaborate mechanical splints and appliances were not used for this purpose." Instead, Bunnell knuckle benders, traction gloves, flexion straps, and plaster casts with extension or flexion outriggers were applied. He noted that "traction alone was not adequate in contractures associated with adherent tendons; in these cases surgery was also necessary."[73]

Fowler, at Newton Baker General Hospital (Martinsburg, West Virginia), reported that "mobilization of stiff metacarpophalangeal joints was good" using traction applied by Bunnell knuckle benders or plaster casts with wire outriggers. "If traction succeeded, it was almost always successful within 3 weeks."[74]

Howard, at Wakeman General Hospital (Camp Atterbury, Indiana), stated that

> ... splinting was a very important procedure in the treatment of hand injuries. ... Splints had to be individualized or they would fail to embody the proper principles to obtain the desired correction. Temporary splints were often made by the ward surgeon with plaster of Paris as a foundation, the attachments consisting of embedded wires or other metallic appliances. The corrective type of splinting consisted of slow, steady traction in the proper direction, with care taken to avoid undue strain on joints not immediately involved.

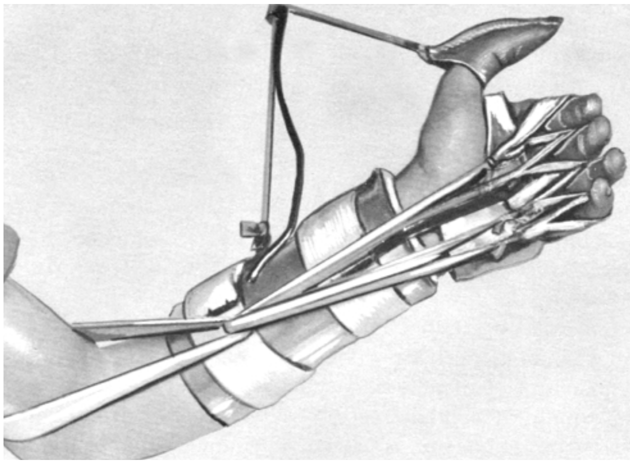


FIGURE 8. Index-small finger MP flexion, thumb CMC radial abduction and MP-IP extension mobilization splint, type 1 (8), *with triceps strap. A triceps strap keeps the MP flexion and thumb abduction/extension directed mobilization forces from pulling the forearm trough distally on the arm. (Reprinted from Bunnell S [ed]:* Surgery in World War II: Hand Surgery. *U.S. Medical Department. Washington DC: Office of the Surgeon General, 1955.)*

Howard also cautioned that "forceful manipulation of any small joint of the hand was contraindicated. Prolonged forceful elastic splinting could cause equal damage to small joints."[75]

There is no question that Bunnell set the standard for using hand splints in the treatment of hand trauma. His reports, bulletins, advice, and teaching, in conjunction with those of other dedicated early hand surgeons, forever changed how hand and upper extremity trauma was managed. Although the splints he advocated may seem antiquated when compared with contemporary ones, most of the principles Bunnell defined nearly 60 years ago continue to be applicable today.

In 1947, on the basis of their experiences in WWII, Allen and Mason described a "universal splint" that they had used with approximately 90% of the hand injuries they treated during the war.[76] Following Kanavel's earlier proposal,[47] this splint maintained the hand in the functional position and could be used for either extremity after initial surgery. They had subsequently employed this "universal splint" in civilian service, and advocated its use for all stages of transport, under pressure dressings, and for a wide range of hand injuries including phalangeal and metacarpal fractures, but excluding tendon and nerve injuries, which require different positioning.

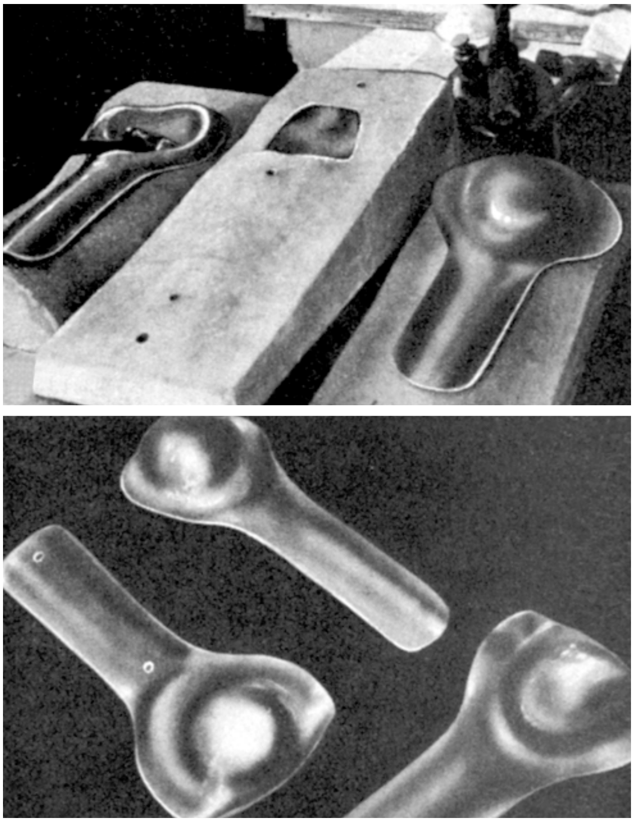


FIGURE 9. Index-small finger MP-IP flexion, index, ring-small finger MP abduction, thumb CMC palmar abduction and MP-IP extension immobilization splint, type 1 (16). Top, *Cement molds;* bottom, *aluminum splints. Allen and Mason's "universal splint" for immobilization of the hand maintained a functional position of the wrist, fingers, and thumb. The dome configuration of the finger pan held the finger MP joints in 30° to 40° flexion, and the slight abduction of the fingers helped maintain some extra MP collateral length of the index, ring, and small fingers but not of the centrally located long finger, which was not abducted. (Reprinted, with permission, from Allen HS, Mason M: A universal splint for immobilization of the hand in the position of function. Q Bull Northwest University Med School. 1947;21:220.)*

The fabrication of this universal splint was simple. Using a special concrete die, an aluminum sheet was hammered under "blow torch heat" into a molded cup configuration that supported the hand with a trough extension for the forearm. The dome shape was designed to support the arch of the hand, conform to the heel of the hand, and allow the thumb to rest in a "natural grasping position." Following industrial streamlining of fabrication processes, splints were made in two sizes (or three at most). Allen and Mason's "universal splint" became widely accepted as the preferred method for immobilizing the hand when a position of function was required (Figure 9).

A few years later, during the Korean conflict (1950–53), the amputation rate had dropped to 13% (from 49% in WWII) because of improvements in arterial suture technique. "Reconstruction . . . became the treatment of choice for arterial injuries, and these ceased to be a major indication for amputation."[40]

Although more upper extremities were saved, splinting practice did not mirror advances in vascular technique. Problems due to poor splinting methods, similar to those encountered in WWII, arose. In 1952, Peacock wrote:

> Unfortunately, the condition of some of the men from Korea with hand injuries arriving at this Hand Center has re-affirmed the lessons learned in World War II—namely, that improper splinting results in serious deformities which often require months of corrective splinting and operative intervention.[77]

His article on plaster technique for mobilization splinting detailed methods for constructing effective splints that were independent of the services of a brace maker, providing busy community surgeons with viable alternatives.

By the time the United States became involved in the Vietnam conflict (1960–71), vascular repair was routine. With better surgical skill, improvement in antibiotics, more rapid evacuation of the injured, and better equipment, the amputation rate after vascular repair dropped to 8.3%. Internal fixation came into greater use, considerably changing the philosophy of how fractures were treated.[40] Fewer amputations and better fixation of fractures meant that more combat injuries were candidates for rehabilitation. Although splinting concepts defined in WWII and reinforced in the Korean War remained for the most part unchanged, patients arrived in therapy departments in better condition, with fewer contractures from incorrect positioning.

The Brook Army Hospital Burn Unit contributed critical information on the treatment of burn patients, influencing all hand rehabilitation endeavors with their sophisticated understanding of antideformity position splinting and the importance of MP flexion and IP extension positioning. Progress in upper extremity tendon and nerve repair technique improved results of surgical reconstruction.

Technologic Advances Relating to Splinting

Technology advances, for the most part, involve improvements in materials used to fabricate splints. Military-generated, high-technology materials eventually found their way into the civilian milieu, enhancing daily life in many arenas, including medicine.

As noted previously, gunpowder prompted the armor makers' precipitous change of vocation from producing suits of armor to creating specialized "appliances," and metal splints came into common usage, a definite improvement over previous fiber-based materials. Plaster of Paris changed how war wounds were treated in WWI, and by WWII and the Korean War, plaster had become an important foundation material for splint fabrication. The use of a given material often overlapped in time that of oth-

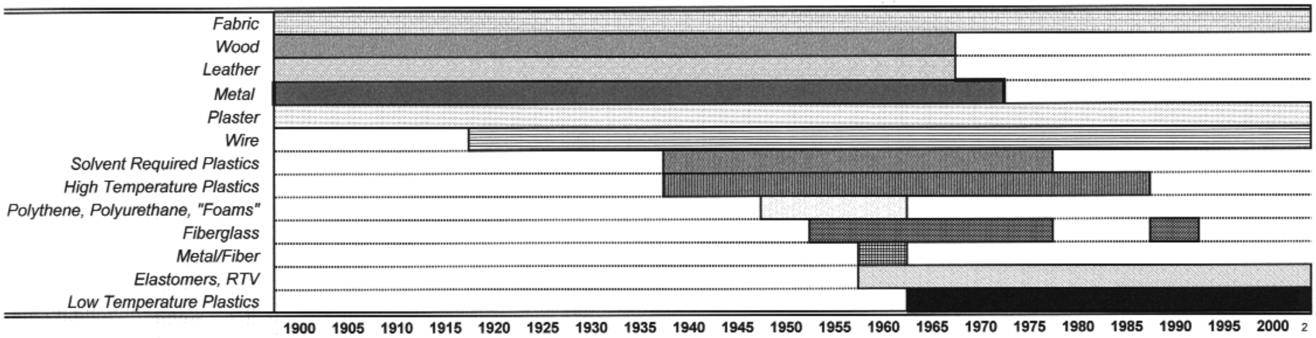
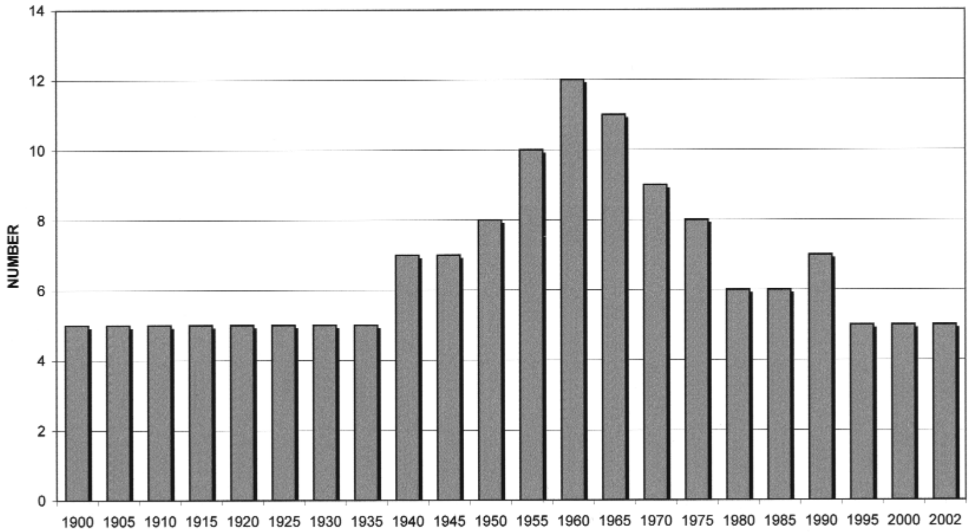


FIGURE 10. Above, *Splinting materials reported in use between 1900 and 2002, in 5-year increments. The graph shows overlaps in time, illustrating the multiple material options available in each 5-year period.* Right, *Number of splinting materials reported in use between 1900 and 2002. With the introduction of plastics and the continuing development of material science, the available types of materials increased markedly, beginning in 1940–45 and peaking in 1960–65. After this, a gradual decline of material types occurred as low-temperature thermoplastics prevailed.*



ers. From the 1900s to today, there was no time frame during which only one material was available for splinting purposes (Figure 10).

Beginning with WWI, the aeronautic field has been a major source of technologic development, with its ever-evolving pursuit of materials that reduce structural weight. The first all-metal, aluminum skin airplane flew in WWI. A few years later, in 1924, Kanavel described several aluminum hand splints,[47] introducing an innovative, durable, light-weight splinting material that would reign supreme for more than forty years.

By 1934, aluminum alloy planes were prevalent and aluminum was commercially available. The relative ease of making aluminum splints facilitated acceptance of the material. Koch and Mason described a wide range of aluminum splints in 1939. Interestingly, because of Koch and Mason's experiences with plaster and leather splints, their aluminum splint designs more closely resembled contemporary splints, with their wide area of applications, than the eventual narrow bar configurations with which aluminum is generally associated.

Later, near European battlefronts during WWII, the military connection literally came full circle when aluminum salvaged from downed planes provided a ready source of splinting material for frontline medical units. Aluminum allowed individual fitting and was easily sterilized[78]—both important factors in a war environment.

Aluminum and aluminum alloys were the materials of choice from the late 1940s through the 1960s,[3,26–28,65,79–84] playing a major role in the treatment of polio patients.[39,57] Although few therapists fabricate aluminum splints today, some commercially available components are made of aluminum alloys, and aluminum continues to be a staple for many orthotists.

The "plastics" revolution began in the late 1800s and early 1900s with the development of celluloid and Bakelite. The 1930s produced acetylene and ethylene polymers, and the 1950s brought urethanes and silicones.[40] Early plastics were important in the rapidly developing field of aeronautic technology, and a number of aircraft with primitive plastic–wood composite materials were introduced in the late 1930s and 1940s.[85] During WWII, plastics played a role not only in the reduction of airplane and vehicle weight but also in the creation of parachutes and body armor, in the form of nylon and fiberglass, respectively.

The use of plastics for splinting hand injuries began in the late 1930s and early 1940s. In 1941, Marble described a new plastic material, Thermex, that could be heated and formed and reheated, noting that the surgeon should select the material best suiting the need.[86] Celluloid, when heated, produced simple one-plane-curve splints, but two curves required that

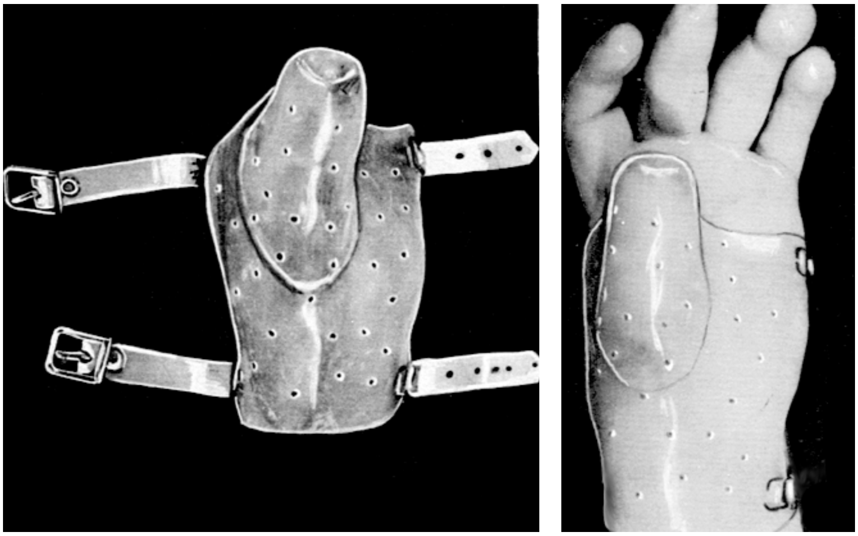


FIGURE 11. ***Thumb CMC palmar abduction, MP-IP extension immobilization splint, type 1 (4).*** *This thumb protector splint, circa 1945, is made of a high-temperature thermosetting material. (Reprinted from Bunnell S [ed]: Surgery in World War II: Hand Surgery. U.S. Medical Department. Washington DC: Office of the Surgeon General, 1955.)*

the celluloid be cut into strips, heated, and cemented with acetone. Other plastic splint materials of the era included acetobutyrate, cellulose acetate, and Vinylite.

In industrial settings, pressure and heat forced these materials to flow conformingly into dies, but the materials could also be shaped by hand using high-temperature heat and molds.

Like later high-temperature plastics, these early materials could not be fitted directly to patients. Bunnell reported that

> A strip of Vinylite softened at one end by immersing in heavy lubricating oil heated over a hot plate to 350°F is quickly laid on a form and pressed about it with a pad of cloth. It hardens at once and can then be trimmed on a bench grinder.[3]

Barsky, in 1945, designed a clear plastic splint to immobilize a thumb 3 weeks after bone and skin grafting procedures (Figure 11). The splint, which was fabricated by the dental department of Northington General Hospital, was designed to protect the thumb until sensation returned.[71] Barsky's plastic splint was unusual, given that most splints were constructed of metal or plaster during WWII.

World War II ended, the Cold War began (1947), and within a few years the United States was involved in the Korean War. Plastics technology continued to evolve in the aeronautic and combat arenas, and new, more sophisticated plastic materials found their way into the commercial market. Although none of these materials were developed specifically for hand splinting endeavors, their considerable allure stemmed from their potential to improve wearability and decrease splint fabrication time in comparison with metal splints.

Celastic, an early plastic composite, was used as a splinting material for about 15 years, beginning in the mid 1950s. It harkened back to celluloid in that it had to be soaked in acetone to initiate curing. Celastic was available in several thicknesses and could be softened again after curing, so corrections and adjustments were feasible. If needed, metal reinforcements could be added as layers were applied. It could be fabricated on a mold or directly on a patient whose skin was protected with several layers of stockinette.[6,27,28,36,79] Although it quickly became obsolete with the introduction of high-temperature thermoplastics, Celastic was important because it was one of the earliest plastic splinting materials readily available to therapists.

Plastic foams of varying levels of rigidity were briefly advocated as splinting materials. At first they were fused to other materials, including elastic wraps[87] and thermoplastic plastics. In 1954, a British physician advocated fused polythene (polyethylene) and polyurethane for hand, foot, neck, and torso splints.[88,89] Beginning as separate sheet materials, the polythene and polyurethane were heated together in a special oven to 120°, at which time the polythene softened and fused to the polyurethane. The heated fused materials were quickly fitted directly to the patient with the heat-resistant polyurethane side next to the skin, acting as a protective barrier. These splints were lightweight, durable, and impervious to moisture and secretions, but they lacked the close contouring capacity of plaster-of-Paris splints, their greatest market rival.

A few years later, plastic foams were used as free-standing splint materials. Durafoam was a thermosetting plastic substance that, when activated with its catalyst in a special plastic bag, produced a plastic foam that remained malleable for approximately 15 minutes. To form it into a flat sheet, the foam, in its plastic bag, was rolled smooth with a rolling pin and then cut, following a predrawn pattern, while still warm from the catalytic reaction. The cut-out splint was then applied directly to the patient and held until it cooled and became rigid.[90]

Eventually, in the early 1960s, Durafoam was sold in prefabricated sheets, but it quickly became evident that this material was more appropriate for adapting ADL equipment than for splinting hands.[91]

Illustrating the level of creativity that exemplified the times, Fuchs and Fuchs, in 1954, reported using toy Erector Set parts for splint construction! Providing almost endless adjustment possibilities, these metal pieces were assembled into an array of fitted splint components, including outriggers, forearm bars, connector bars, and palmar bars. The authors noted that a wrist mobilization splint of Erector parts required about 45 minutes to construct. They also thoughtfully provided part numbers of the most frequently used pieces to facilitate ordering from the Erector set catalogue.[92]

Fiberglass, incorporated in military flak jackets in the late 1940s, found increasing use in automotive components, beginning with the 1953 Corvette with its first-ever plastic composite skin.[85] Fiberglass, in the form of Air-Cast, Orthoply, and Ortho-Bond, was used as a thermosetting splinting material in the mid 1950s to early 1960s.[27,28] It did not gain wider acceptance as a splinting material,[4,6,36] however, until 1964, during the Vietnam conflict, when the U. S. Army Surgical Research Unit, Brook Army Hospital, advocated the use of fiberglass splints for burn patients treated with the open-air (exposure) technique,[96] which was associated with the use of topical antibacterial agents such as sulfamylon cream.[93–95]

Fiberglass was lightweight, durable, nontoxic, and resistant to chemicals, and it could be autoclaved, an important feature in decreasing sepsis in burn patients. To make the required negative plaster bandage mold, a normal subject with a similar-size hand first had to be found. Two key measurements were matched between the patient and the normal subject—the breadth of the palm at the distal palmar crease, and the distance between the distal wrist flexion crease and the distal palmar flexion crease over the fifth metacarpal.[93]

A half-shell plaster cast that incorporated the fingers, thumb, wrist, and forearm in the "antideformity position" was prepared on the normal subject. The cured negative plaster cast was removed from the subject's arm, dipped in paraffin, and cooled, providing a separating layer for the fiberglass, which was applied next. After fiberglass mat was cut to the size of the plaster negative, it was laid on the mold and infused with a thick liquid polyester resin by use of a stiff brush, which pushed the resin into the mat and forced it to contour to the negative cast. When the fiberglass cured, in about an hour, the splint was removed from the plaster negative and hand-sanded to smooth its edges and surfaces. A set of splints was made for each burned extremity, providing a wear-autoclave rotation of sterilized splints.

The combination of open treatment with antibacterial agents and fiberglass splints was adopted by many burn centers throughout the United States during the late 1960s and early 1970s. With the introduction of low-temperature thermoplastics and changing philosophies on burn treatment,[30,97,98] use of fiberglass as a splinting material declined rapidly. Fiberglass was recommended in an updated, "bandage-roll" form in 1990 as a casting material for spasticity management.[99]

During the mid to late 1950s, at about the same time that Celastic, plastic foams, and fiberglass were finding their way into therapy departments, Plexiglas, Lucite, and Royalite, all-high temperature thermoplastic materials, were well on their way to becoming important additions to therapists' splinting armamentaria.[27,28] Because of the inherent strength of these plastics, the narrow bar designs used with metal splints could also be used with splints fabricated with the new plastics. Dealing with commercial sources meant that sheets of plastic were available only in large sizes, i.e., 52 x 88 inches. Band saws were required for cutting splints from the sheets; edges had to be filed and sanded; therapists had to wear multiple pairs of cotton garden gloves to handle the hot material[25]; and fitting was done on a mold, not on the patient, because of the high temperatures required to make the plastics pliable. Despite all this, these high-temperature plastics were enthusiastically welcomed because of their relative ease of malleability and efficiency of construction in comparison with metal.

Experience determined that Royalite was more resilient than Plexiglas and Lucite, which tended to shatter with the cumulating forces accrued with wearing. At first, cut-out splints were heated part by part as the fitting process progressed, but this caused somewhat irregular contours as different splint components were heated and reheated.

Eventually it was discovered that an entire splint could be heated at one time in an oven, greatly reducing the heating time required using a heat gun. Therapists fabricating splints invaded ADL kitchens in therapy departments all over the United States, and the phrase "slaving over a hot stove" took on new meaning. Therapists also learned that the time -consuming construction of negative and positive molds could be eliminated entirely by fitting high- temperature thermoplastic splints directly on patients who were first protected with three or four layers of stockinette. Once removed from a patient's hand or arm, a still-warm splint needed only a few key adjustments to quickly obliterate the extra space caused by the multiple layers of protective stockinette.

On the global front, the Cold War had intensified with the successful launching of Sputnik 1 in 1957 and initiation of the space race. In 1959, the Soviet's Luna 1 unleashed the race for the moon, further escalating tensions between the United States and the Soviet Union. By the end of 1966, the United States' Surveyor 1 had landed on the moon; and 3 years later, Neil Armstrong and Buzz Aldrin walked on the moon.

Plastics were critical to aerospace research because they lightened rocket payloads, and new developments continued to expand uses for plastics and plastic compounds. Materials become more and more sophisticated as job-specific plastic composites were created.

Splinting materials continued to evolve. Aluminum was relegated to splint reinforcement components, and solvent-requiring materials such as Celastic were abandoned in favor of the more practicable high-temperature thermoplastic materials. Therapists became adept at cutting out intricate bar configuration splints on band saws and decreased edge-finishing time to 3 or 5 minutes with a few well-chosen files. New high-temperature thermoplastic materials were assessed for their splinting potential as soon as they became commercially available, including Kydex, Lexan, Merlon, Boltaron, and high-impact rigid vinyl.[4,6,36] Royalite and Kydex eventually proved superior in their durability and relative ease of fabrication; they were used first as primary splinting resources and later, in the 1980s, for specialized narrow-splint components, such as outriggers, for which strength was essential.[11,12]

Although low-temperature thermoplastic materials were enthusiastically welcomed in the mid to late 1960s, they had a rocky beginning. Prenyl[4,6] was unattractive, was difficult to conform to small areas of the hand, and required 10 minutes to harden; and the first Orthoplast, a beautiful plastic with a shiny slick surface, flattened with normal body temperature!

Bioplastic,[4,6,36] a thin, pinkish material with a smooth surface, was successful, and the era of low-temperature thermoplastic materials moved forward with smiles of relief. Bioplastic could be fitted directly on patients, and although it had no stretch and little strength, its easy workability made it an instant favorite. Orthoplast, first called Isoprene to differentiate it from the earlier failed material, was a tremendous success.**** It literally emancipated therapists and patients from the protective gloves, stockinette, ADL kitchen ovens, and electric burners required to mold the high-temperature thermoplastic materials efficiently. Therapists quickly discovered that Orthoplast could be heated and held at a constant temperature in a dry skillet throughout an entire clinic day. This unexpected bonus significantly increased treatment efficiency by providing a constant source of heated material for use whenever needed. San Splint, a material similar to Orthoplast, was marketed in Canada.

To provide crucial strength, the low-temperature thermoplastic materials mandated different splint configurations. Of necessity, splint designs changed from narrow bar shapes to the contoured large contact area designs required for low- temperature material strength.

Still in the Cold War race for space, the 1970s brought additional moon landings, and in 1976, two space probes landed on Mars. In the 1980s, probes sent back photographs of Jupiter and Saturn, and the reusable space shuttles served as platforms for space research and deployment of satellites into orbit. Stealth technology, based on carbon-fiber composites and high-strength plastics, reduced radar signatures of combat aircraft.[85] Plastics had become a part of everyday life, both military and civilian, in the United States.

A new type of splinting material based on polycaprolactones was introduced in the mid to late 1970s. Providing greater conformability and ease of splint fabrication, the first of these new materials, Polyform and Aquaplast, although different from each other in chemical composition and working properties, were instant successes. Spin-offs from earlier plastics research, these and most of the splint materials that followed were created specifically for the commercial splinting market. Kay Splint, Polyflex, and Orfit joined the ranks of available materials in the mid 1980s. The era of designer splinting materials had arrived.

During the 20th century, major advancements in splinting material technology were accomplished. The rapidly escalating transition of materials—from natural-fiber-based materials such as wood and fabric, through metal and plaster, and eventually to a long line of progressively more sophisticated plastic-based materials—was unprecedented. These advancements were not the consequences of focused splinting-material-specific research but rather were by-products of the rapid developments in combat and aerospace technology through five different wars. It is interesting to notice that while materials changed dramatically, underlying design concepts remained surprisingly constant (Figure 12).

Commercial Products

The link between military and commercial evolution is apparent throughout history. National research resources are first directed at societies' most pressing needs, and few conditions have greater priority than survival in war. Based on civilian need, commercial enterprise is an inexorable part of the natural progression of research development.

As the Cold War came to a close in 1990, a strong commercial contingent of multiple independent rehabilitation product supply companies was already well established, each with unique splinting material lines. Product research and development was, and continues to be, based on therapist feedback. With the exception of Orthoplast, which is an isoprene, or rubber-based material, most contemporary splinting

**** References 4, 8, 11, 12, 31, 36, 97, 98, 100.

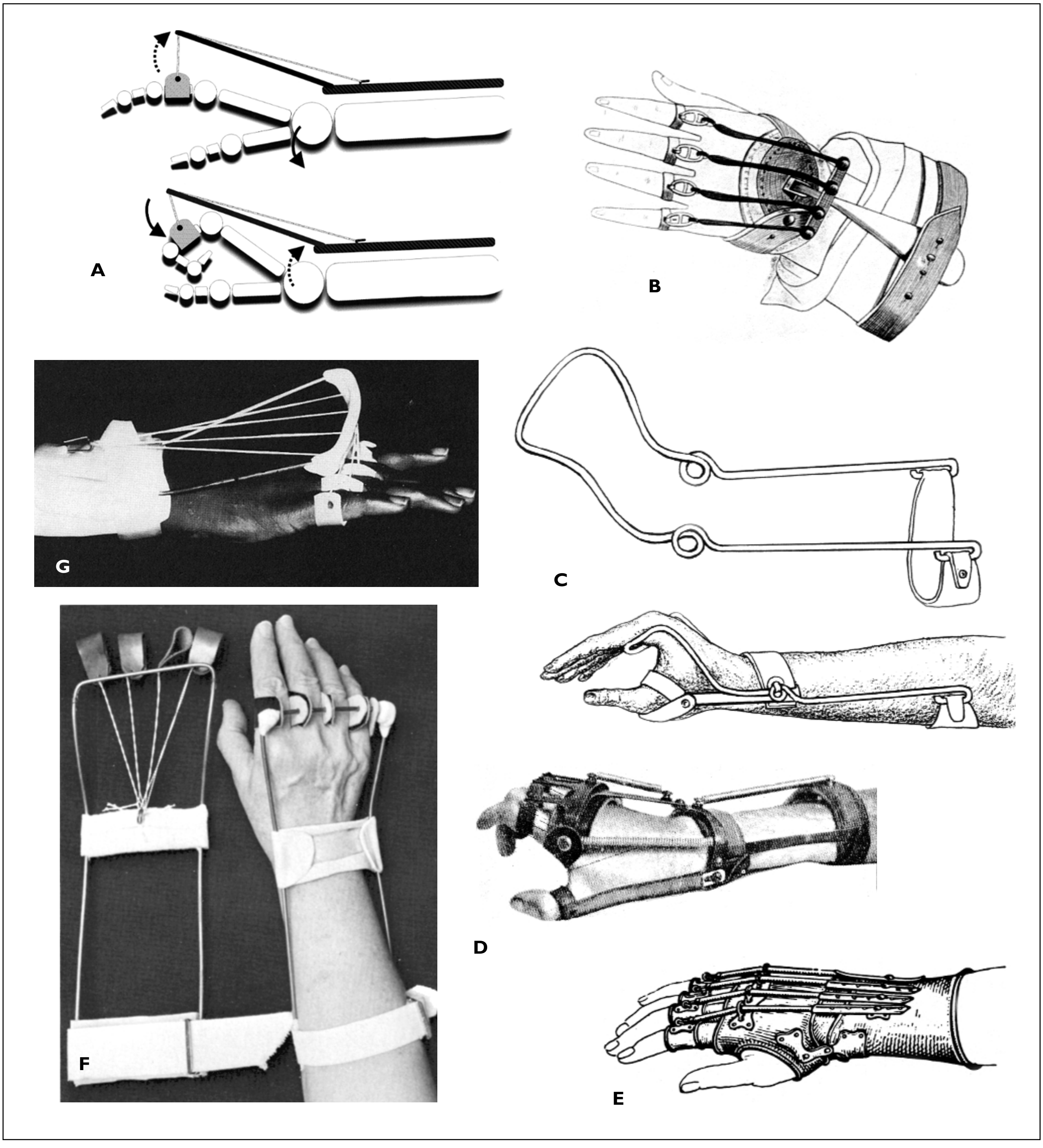


FIGURE 12. Splints from 1819 to 1987. Although they have different configurations, all these splints were designed for radial nerve problems, and all have identical Splint Classification System names if the thumb is excluded. The splints use a pattern of reciprocal MP finger flexion to achieve wrist extension, and wrist flexion to achieve MP finger extension. Splints A, B (1819), F (1978), and G (1987): ***Wrist flexion: index-small finger MP extension / index-small finger MP flexion: wrist extension mobilization splint, type 0 (5).*** *Splints F and G are identical except for the addition of a dorsal forearm trough component.* Splints C (1916) and E (1919): ***Wrist flexion: index-small finger MP extension / index-small finger MP flexion: wrist extension, thumb CMC radial abduction mobilization splint, type 0 (6).*** *These two splints incorporate the thumb CMC joint, and splint C assists the thumb CMC and MP joints.* Splint D (1917): ***Wrist flexion: index-small finger MP extension / index-small finger MP flexion: wrist extension, thumb CMC radial abduction and MP extension mobilization splint, type 0 (7).*** (*(Reprinted from LeVay D:* The History of Orthopaedics. *Park Ridge, NJ: Parthenon, 1990.)* Splints C, D, and E *reprinted from American Academy of Orthopaedic Surgeons:* Orthopaedic Appliances Atlas, vol. 1. *Ann Arbor, Mich.: J.W. Edwards, 1952.* Splint F *reprinted, with permission, from Hollis LI: Innovative splinting ideas. In: Hunter JM, Schneider LH, Mackin EJ, and Bell JA [eds]:* Rehabilitation of the Hand. *St. Louis, Mo.: Mosby, 1978.* Splint G *reprinted, with permission, from Colditz JC: Splinting for radial nerve palsy. J Hand Ther. 1987;1:21; copyright © Hanley & Belfus, Inc.)*

materials are specialized blends of polycaprolactones, providing an almost endless array of potential splinting material properties.[101,102] In addition, companies offer accessory products, such as strapping materials and fasteners, heating units, die cuts of common splints, prefabricated splints, published resource material, and knowledgeable resource personnel. Smaller companies market a wide range of splint components and prefabricated splints. Increasing accessibility of splinting materials is a key factor in the development and success of splinting endeavors.

Surgical Advances

Discussion of the progress in hand surgery over the last 100 years is a book unto itself and is not within the confines of this study. However, several types of surgical procedures have significantly influenced the course of splinting history during the past 50 years.

Introduced in 1966, Swanson silicone implants quickly became the hope of the future for many patients suffering from arthritis and for some who had sustained certain types of traumatic injuries to hand or wrist joints. Demand for the implants quickly escalated, as did need for the very specific postoperative hand splints that controlled the directional forces affecting joint encapsulation.[103–109]

The early passive motion program for zone II flexor tendon repairs described by Kleinert[110–113] was introduced at about the same time; and, later, Duran[114] published a different method for applying passive tension to repaired zone II flexor tendons. Each of these early passive motion programs had its own unique postoperative splint and follow-up routine, as did the two-stage flexor tendon repair described by Hunter in 1971.[115,116] The Kleinert and Duran concepts of early motion for tendon repairs was based on work done by Mason in the 1940s, in which a postoperative splint had also been recommended.[59]

All these surgical procedures depended on sophisticated, well-fitted splints to control the development of scar during the postoperative phases of wound healing. Inexperienced, inept, or unknowledgeable splint fabricators could not be tolerated, since the success of these surgeries relied heavily on correct application of the postoperative splints. Finding a capable and proficient splint maker suddenly became a priority for many hand surgeons.

Advances in Basic Science

Soft Tissue Remodeling

Soft tissue remodeling is a fundamental concept to splinting theory and technique that has been known empirically since ancient times. Slow, gentle, prolonged stress causes soft tissue to remodel or grow. In discussing treatment of contracted joints, Hippocrates wrote,

> In a word, as in wax modeling, one should bring the parts into their true natural position, both those that are twisted and those that are abnormally contracted, adjusting them in this way both with the hands and by bandaging in like manner; but draw them into position by gentle means, and not violently. . . . This then is the treatment, and there is no need for incision, cautery, or complicated methods; for such cases yield to treatment more rapidly than one would think. Still, time is required for complete success, till the part has acquired growth in its proper position.[43]

In 1517, Hans Von Gersdorff advocated gradual correction of joint contractures using splints with turnbuckles for incremental adjustments; and in the mid 1870s, Thomas noted that

> Eccentric forms that cannot be altered in the dead body without rupture of fracture can, during life, be altered by mechanical influences as time and physiological action commode the part to the direction of the employed force.[40]

As marks of beauty, some native tribes insert progressively larger wooden disks into ear lobes or lips, and other tribes gradually add rings to lengthen necks. Orthodontic dentistry is founded on soft tissue remodeling, and contemporary plastic surgeons routinely use tissue expansion techniques to cover soft tissue deficits. Bunnell wrote, "The restraining tissues must not be merely stretched, as this only further stiffens the joints by provoking tissue reaction."[117] Nearly all the surgeons who wrote splinting articles between 1900 and 1960 emphasized the need for slow, gentle traction to effect change in soft tissue.

For clinicians, use of soft tissue remodeling concepts seems to have an almost cyclic pattern of dismissal and rediscovery over time, depending on the most alluring treatment du jour. Through experience, clinicians (surgeons and therapists) learn the devastating consequences of forceful manipulation; they abandon these techniques in favor of slow gentle remodeling methods. Then time passes, and a new procedure is advocated for more rapid results. The procedure is applied, experience shows that the procedure either does not work or increases scar formation, and the cycle begins anew.

Bunnell obviously had a dismal encounter with therapy that was too aggressive. Throughout his distinguished career, he extolled the advantages of splinting and active use of the hand and emphatically condemned forceful manipulation,[3,65,79,117–120] stating that the best therapist was a bilateral upper extremity amputee!

Knowledge is an ever-evolving process, and remodeling concepts are not relegated to the upper extremity alone. In fact, much of our empirical understanding of soft tissue remodeling is founded historically on experiences dating back to antiquity in the treatment of clubfoot deformity.[43] Over the centuries, while there were those who favored "bandaging" and noninvasive treatment, forceful manipulative and surgical correction of clubfoot deformity became increasingly fashionable with surgeons, and few questioned the results they obtained.

This, however, began to change in the late 1940s. Brand[37,38] has been instrumental in bringing biomechanical principles and soft tissue remodeling concepts and research to the arena of hand and upper extremity surgery and rehabilitation. It is insightful to learn of the pivotal experiences that forever altered his approach for managing soft tissue problems.

In 1948, Brand changed from the technique of treating clubfoot deformity practiced by Sir Denis Browne, a pediatric surgeon in England, to the total-contact plaster cast technique that Brand developed in India. In a recent letter to the author, Brand has elegantly described the early career experiences that provoked his interest in soft tissue remodeling and deepened his understanding of this process.

This perceptive transition began when Brand had the opportunity to compare untreated clubfeet in India with feet treated by the Denis Browne manipulation technique in England. Although the feet treated by the English method were "straight," they were capable of little motion, and a noticeable inflammatory response persisted for years. This was in direct contrast to the untreated clubfeet in India, which retained suppleness and showed no inflammation, despite their lack of correct alignment.

Brand developed a method of serially applying total contact plaster casts that slowly and gradually brought a deformed foot into correct alignment by allowing soft tissues to remodel or grow. Because Brand's narration is fundamental to the tissue remodeling concepts on which splinting endeavors are based, the full text of his important and astute letter appears immediately following this article.[121]

By 1949, Brand began applying the same contact casting techniques to the insensitive feet of leprosy patients. Brand's tissue remodeling work became more focused in the mid 1960s with his move to the U.S. Public Health Service Hansen's Disease Center, in Carville, Louisiana, where he continued to treat patients with Hansen's disease and started the biomechanics laboratory that would eventually receive worldwide acclaim.

Brand's investigations into the biomechanical reaction of insensate living soft tissue to pressure opened a fountainhead of better understanding of soft tissue remodeling processes.

Others were also interested in soft tissue remodeling. In 1957, Neumann reported on expansion of skin using progressive distention of a subcutaneous balloon.[122] During the late 1960s and early to mid 1970s, Madden and Peacock described the dynamic metabolism of scar collagen and remodeling; and Madden and Arem noted that the response of noncalcified soft tissue to stress is modification of matrix structure, i.e., soft tissue remodeling.[123,124] In 1994, Flowers and LaStayo demonstrated that for PIP joint flexion contractures, the length of time soft tissues are held at their end range influences the remodeling process, with a 6-day time span resulting in statistically better improvement in passive range of motion than a 3-day span.[125]

While investigation continues into the histologic mechanism for remodeling of different soft tissues,[126–135] one area of agreement is apparent: Application of too much force results in microscopic tearing of tissue, edema, inflammation, and tissue necrosis. Prolonged gentle stress is the key factor in achieving remodeling, and splinting is the only currently available treatment modality that has the ability to apply consistent and constant gentle stress for a sufficient amount of time to achieve true soft tissue growth.[132]

Digital Joint Anatomy and Biomechanics

Digital joint anatomy and biomechanics are better understood today than they were in the early 20th century. Kanavel's 1924 recommendation of the "functional position" for splinting infected hands, with the wrist in 45° dorsiflexion, the MP and IP joints in 45° flexion, and the thumb abducted from the palm and "rotated so that the flexor surface of the thumb is opposite the flexor surface of the index finger," was based on achieving rudimentary use of the hand following injury, "even though only a minimum of motion of the fingers and thumb is retained." He noted that "If such a splint were in universal use, much less would be heard of disability after hand infections."[47,48]

In the same year, Bunnell also advocated the use of the functional position.[117] The position of function subsequently was recommended by leading hand specialists for the next 40 years. During this time, hand surgeons consistently reported problems with MP extension/hyperextension contractures and IP flexion contractures, blaming the deformities on poor splinting technique while at the same time continuing to recommend the "functional position" for hand injuries excluding tendon and/or nerve damage, which mandated other splint positions.

In 1962, James, discussing fractures of the fingers, reported that

> The metacarpophalangeal joints unless held in 60°–90° flexion during treatment will develop within two to three weeks a permanent extensor contracture, limiting flexion. The interphalangeal joints, particularly the proximal, rapidly develop flexion contractures when held in flexion. . . .[136]

Based on empirical experience, Yeakel, in 1964, challenged the use of Allen and Mason's universal splint for "functional position" immobilization of hand injuries, advocating instead the "antideformity position" for the splinting of burn patients.[93–96,137,138]

The University of Michigan Burn Center and Shriner's Burn Center also reported that "antideformity" splinting with burns was preferable to the "functional position."[96,139]

Researchers were also contributing to the growing body of knowledge.[140–142] In 1965, Landsmeer and Long published their decisive paper describing effects of a system of two monoaxial joints controlled by either a two-tendon or three-tendon unit, identifying the important interdependent roles of the extrinsic and intrinsic muscle systems.[143] Hand specialists began to regard the intercalated digital joints as functional units in which action at one or two joints affects the remaining joints or joint within the ray. James coined the phrase "safe position" in 1970, noting,

> The metacarpophalangeal joints are safe in flexion and most unsafe in extension; the PIP joints, conversely, are safe in extension and exceedingly unsafe if immobilized in flexion.[144]

The importance of maintaining collateral ligament length by splinting the MP joints in 70° to 90° of flexion and the IP joints in extension[98,139] had not been fully understood by early specialists, hence the earlier recurring problems with MP hyperextension and IP flexion contractures.

Variations of the "antideformity" splint usually involved minor changes in wrist or thumb position. Devised by deLeeuw, dress hooks glued to fingernails and hooked with rubber bands or sutures to the distal end of splint finger pans were important for achieving and maintaining the "antideformity position."[94,145] Advantages of the "antideformity/safe position" splint†††† quickly became apparent, and use of the "functional position" for patients with acute hand injuries was all but abandoned by the early 1970s.

Mechanical Systems of Splints

Mechanical systems of splints are alluded to or reviewed briefly by several early 20th century authors, including Bunnell,[3,117] Kanavel,[47,48] and Koch.[45] Early splint manuals also dealt with basic concepts of leverage, pressure, and 90° angle of pull, but the information was inconsistently presented and sparse in comparison with the wealth of information on splinting materials and fabrication instructions. Despite being a major element of successful splint design and application, the principles of mechanics were addressed only superficially in related literature published prior to 1980.

Beginning in 1974, Fess applied mechanical concepts to common hand splint designs, identifying through trigonometry and simple scale drawings, basic forces generated by splints.[1,8,12,146,147] Brand emphasized the importance of understanding splint biomechanics as they relate to critical soft tissue viability, responses to stress and force, inflammation and scar forming process, and tissue remodeling.[37,38] Van Lede and van Veldhoven integrated mechanical principles into a rational and systematic approach to creating and designing splints.[35] Boozer and others identified the important mechanical differences between high- and low-profile splint designs.[147–149] Brand[37,38] and Bell-Krotoski[150] emphasize the importance of understanding the transfer of forces in unsplinted joints when a splint is applied.

A thorough knowledge of mechanical concepts of splinting is requisite to treating hand and upper extremity dysfunction from injury or disease. More mechanical principles will be identified as splinting practice continues to evolve.

Agencies

The Office of Vocational Rehabilitation, the Department of Health, Education, and Welfare (DHEW), the U.S. Public Health Service, the National Research Council, the National Academy of Sciences, and the National Academy of Engineering are agencies that have at one time or another influenced the advancement of upper extremity splinting through their support and funding of related grants. The influence of these agencies has far-reaching ramifications, yet few clinicians are aware of the important contributions made by these powerful groups.

It is important to view historical events in context. Beginning at the end of WWI, vocational rehabilitation programs progressively expanded from aiding veterans to assisting civilians with disabilities (1920). By 1940, those who benefited from vocational rehabilitation services included persons in sheltered workshops, the homebound, and workforce personnel. In 1950, Mary Switzer was named director of the Office of Vocational Rehabilitation. Switzer, an economist, career bureaucrat, and long-time advocate of rehabilitation concepts, demonstrated to Congress the economic advantages of rehabilitating the disabled rather than supporting them in long-term care facilities, noting that rehabilitated adults with disabilities become productive, tax-paying citizens.

During Switzer's 20-year tenure, funding for vocational rehabilitation increased 40 fold. Her vision included education of medical and rehabilitation professionals, research and development in medicine and rehabilitation engineering (Figure 13), in-service training programs, and the establishment of rehabilitation centers and sheltered workshops.[151] While Switzer is acknowledged as the "grandmother" of the independent living movement, Brand notes that she is also the "mother and grandmother of much of the present concept" of hand centers in the United States.[152]

In 1939, in the midst of the devastating poliomyelitis epidemics that were sweeping the United States with ever-increasing virulence, the U.S. Public Health

††††Also called the "duckbill" or the "clam digger" splint.

Service published bulletin no. 242, *Care During the Recovery Period in Paralytic Poliomyelitis*, by Kendall, Kendall, Bennett, and Johnson. This $0.29 monograph explained "the line of treatment required during the very long recovery period that follows an acute attack of infantile paralysis." In addition to treatment principles and detailed manual muscle testing instructions, positioning and splinting rationales were clearly defined, and practicable shoulder, elbow, hand, and digital splints were described. Simple plaster splints for thumb palmar abduction, MP flexion, and wrist extension were illustrated, and drawings of heavy-wire-based shoulder abduction splints were included.

In a hand-written note, Florence Kendall recalls,

> Mr. Kendall and I made (to the best of our knowledge) the first lumbricals cuff. It was made for a polio patient at Children's Hospital School in Baltimore, in 1933 (or 1934). In 1933, Dr. Jean McMamara from Australia showed us how she made an opponens cuff out of papier-mâché.

A training grant from the Office of Vocational Rehabilitation to Milwaukee-Downer College financially underwrote one of the earliest splinting manuals written by a therapist.[28] This important splinting manual, written in 1956 by Dorothy Bleyer, OTR, clearly validates that

> ... the occupational therapist has been called upon professionally to fabricate splints and assistive devices as an aid to the patient for restoration or maintenance of function, correction of dysfunction, or substitution for normal function.

She also warned that "the therapist must be careful not to become known solely as a splint or gadget-maker." The 85-page manual reviewed normal functional upper extremity anatomy, purposes of splinting, and precautions and gave detailed instructions for fabricating splints from a wide range of materials. The U.S. government openly supported this candid affirmation for therapists to actively embrace splinting endeavors.

In March and again in June 1967, the DHEW cosponsored, with Harmarville Rehabilitation Center and the Western Pennsylvania Occupational Therapy Association, a 2-day Institute and Workshop on Hand Splinting Construction[4] for physicians, therapists, and orthotists. Faculty included Edwin Smith, MD, Eleanor Bradford, OTR, Helen Hopkins, OTR, Maude Malick, OTR, Helen Smith, OTR, Major Mary Yeakel, AMSC, and Elizabeth Yerxa, OTR. Among those giving presentations, Yeakel, a research occupational therapist with the Army Medical Biomechanical Research Laboratory at Walter Reed Army Medical Center (Washington, DC), introduced the concept of materials science and discussed research in experimental media for splinting.

In 1967, the Committee on Prosthetic-Orthotic Education, National Academy of Sciences–National Research Council published the *Study of Orthotic and Prosthetic Activities Appropriate for Physical Therapists and Occupational Therapists*.[100] This study noted that

FIGURE 13. *Mary E. Switzer, commissioner of the Vocational Rehabilitation Administration, Department of Health, Education, and Welfare, visited the U.S. Public Health Service Hospital at Carville, Louisiana, on Mar 9, 1966, to talk to Dr. Paul Brand, Chief Rehabilitation Branch, about the combined research project proposed by the Carville hospital and Louisiana State University School of Electrical Engineering. The project involved three phases: 1) measure forces/pressures exerted to hands and feet by daily tasks; 2) identify a way of teaching patients with Hansen's disease to sense when they are using too much force and are risking injury; 3) study the pathologic/histologic effects of bruising and damage to soft tissues of the hands and feet. This research was important not only for patients with Hansen's disease but also for patients with other diseases and injuries that resulted in diminished sensibility of the extremities.*

Switzer and Brand each received the renowned Lasker Award in 1960. Switzer was cited for her "great contributions to the training of rehabilitation personnel, rehabilitation research, and her success in bringing about greater cooperation between government and voluntary rehabilitation efforts." She was described as being the "prime architect of workable rehabilitation services." (The Star [Carville, Louisiana]. 1966;25(4):1,7.)

> Inasmuch as the total number of certified orthetists and prosthetists in this country (1,103) is relatively low and their distribution inequitable, it is realistic to expect that occupational therapists and physical therapists will frequently be called on to function in an area for which they may not be specifically prepared upon completion of their formal education program.

The report defined criteria that graduates of therapy programs should meet:

- Know the basic principles involved in prosthetics and orthotics, including anatomy, physiology, pathology, biomechanics, and kinesiology.

- Know basic terminology used in identification of prosthetic and orthotic devices and the components thereof.
- Know the mechanical principles on which operation of a device is based as well as the uses and limitations of various devices.
- Know properties and characteristics of materials used in fabrication of devices; know basis of selection of materials for specific purposes.
- Know the basic principles underlying the application of the following clinical activities regarding patients and device use—evaluation, training and patient education, maintenance, adjustments, and checkout performance.
- Appreciate contributions of other disciplines in these areas.

The study also noted that, "where orthotic service is not available, simple orthotic devices may be furnished by occupational therapists and physical therapists." Closing the door to orthotist-controlled splinting practice, this significant 1967 document freed therapists, as long as they were qualified, to provide splinting services to patients.

Funded by the DHEW and the Veterans Administration and compiled by the Committee on Prosthetic-Orthotic Education, National Academy of Sciences–National Research Council, *Braces, Splints and Assistive Devices: An Annotated Bibliography* was published in July 1969. This extensive work classified and briefly described articles about splints and orthoses of the neck and face, upper extremity, and lower extremity that had been indexed in *Index Medicus* from 1956 through 1968. Nearly 500 articles were indexed according to subject matter and author, creating a user-friendly reference document for clinicians interested in splinting.

In 1970, the First Workshop Panel on Upper Extremity Orthotics[26] of the Subcommittee on Design and Development, National Academy of Sciences, National Academy of Engineering, met to review the current status of upper extremity orthotic practice and design and development work and to discuss future design and development needs. The panel consisted of noted physicians, orthotists, therapists, and engineers in the field, including therapists Lois Barber, Kay Bradley (Carl), Clark Sabine, and Fred Sammons. Hand surgeon Mack Clayton was included on this panel. With orthotists from Rancho Los Amigos, Texas Institute for Rehabilitation and Research (TIRR), Rehabilitation Institute of Chicago (RIC), and New York University–Institute of Rehabilitation Medicine (NYU-IRM), a majority of the major orthotic facilities in the United States were represented.

After reviewing upper extremity orthotic practice for hemiplegia, quadripelgia, and arthritis, the panel considered future needs in design and development. Recommendations included:

- Initiation of a survey to determine the number of patients with hand disabilities, rehabilitation potentials for specific diagnostic groups (including peripheral nerve and burns), and available treatment
- More studies on upper extremity/hand kinematics related to functional performance
- Analysis of effectiveness of current educational programs
- "Survey training programs for occupational therapists to determine the possible need for intensified or expanded educational efforts"

The DHEW, the Veterans Administration, and the National Academy of Sciences funded this panel.

In 1971, Mayerson's Splinting Theory and Fabrication workshop and accompanying manual were supported by a grant from the National Science Foundation and sponsored by the Department of Occupational Therapy, State University of New York (Buffalo, NY). The introduction to the manual quotes from the 1967 *Study of Orthotic and Prosthetic Activities Appropriate for Physical Therapists and Occupational Therapists*, indicating that therapy educational programs were taking the National Academy of Sciences study recommendations seriously. Mayerson also stated in the introduction that occupational therapists, in addition to the training they receive in medical subjects, are skilled in the use of equipment and materials needed to fabricate splints. Hand anatomy and kinesiology, materials science, splint checkouts, and detailed information on fabricating splints in various materials were included in this 114-page manual. The 1971 workshop and manual were based on a prior 1969 continuing education workshop on material science and splinting given by Mayerson at the same facility.

The Second Workshop Panel on Upper Extremity Orthotics[31] met in 1971, to review upper extremity orthotic management of rheumatoid arthritis, peripheral nerve injury, and thermal injuries and to discuss future design and development needs in these areas. Hand surgeon William Stromberg attended this meeting. Early discussion identified the important role orthotics play in post-surgical management of rheumatoid arthritis. The Swanson post-MP implant arthroplasty brace was prominently illustrated in the report.

The panel voiced divergent opinions on splint designs and materials for treating other problems in rheumatoid arthritis. Peripheral nerve injury orthotic intervention was also reviewed. Most panelists agreed that patients with unilateral lesions reject functional orthoses, and the long opponens splint was most frequently cited as the splint of choice for positioning in peripheral nerve injury.

Many of the panelists opted for wrist-driven or finger-driven prehension orthoses for cases in which nerve regeneration was not possible. Brook Army Burn Center treatment and splinting procedures were reviewed for thermal burn patients. Finger MP joint extension, IP joint flexion, and thumb adduction contractures were identified as the most common problems in burns. Subsequent panel recommendations included:

- Develop a method of evaluating the usefulness of splinting in rheumatoid arthritis
- Create a uniform evaluation system for rheumatoid hand and upper extremity functional status
- Establish a close liaison with the American Society for Surgery of the Hand and the American Academy of Orthopaedic Surgeons Committee on Prosthetics and Orthotics
- Conduct a literature search for information on the functional disabilities secondary to anatomic changes in the rheumatoid hand
- Continue concentrating on functional orthotic intervention for rheumatoid arthritis, peripheral nerve injury, and burns

The DHEW, the Veterans Administration, and the National Academy of Sciences funded this panel, noting that it addressed a problem of national significance.

Hand Centers

The establishment of hand rehabilitation centers advanced splinting practice in several ways. The high expectations of referring hand surgeons, therapist specialization expertise, and the sheer volume of patients treated in hand centers meant that therapists quickly honed their splint-fabricating skills to exceptional levels. With the demands of treating large numbers of complicated hand problems, therapists also became aware of the most efficacious splinting techniques, eliminating those that produced mediocre results. In addition, hand centers provided a forum in which clinicians, both surgeons and therapists, could share their experiences and learn from one another. It is difficult to isolate the sequence of hand center development and the role teaching played in that advancement, since they often serve in combined roles.

The first hand rehabilitation center in the United States—the hand center at the University of North Carolina, Chapel Hill—was started as a result of Erle Peacock's 1961 visit to Brand's New Life Center in Vellore, India, where patients with Hansen's disease were treated. Peacock was so impressed with Brand's specialized rehabilitation team concept that he returned to the United States with hopes of starting a hand center here.

The roots of the Chapel Hill center, however, extend further back in time than Peacock's Vellore visit. In 1960, Brand was in the United States to receive the prestigious Albert Lasker Award given by the International Society for the Rehabilitation of the Disabled.[153] At this time, he met Mary Switzer, Commissioner of the Vocational Rehabilitation Administration (VRA), who also received a Lasker Award. With many polio and war victims needing assistance, Switzer had convinced Congress of the importance of rehabilitation and in so doing had been named the first Commissioner of VRA. Brand and Switzer had the opportunity to discuss rehabilitation concepts at length, and she was impressed with his program in India.[154] After this meeting with Brand, Switzer began encouraging surgeons like Robinson and Peacock to visit Brand in India.[152]

On Peacock's return to the States from India, he met Howard Rusk and Mary Switzer in New York, and they encouraged him to submit a grant to start a hand center. In 1962, a 2-year research and demonstration grant for $10,000 from the Office of Vocational Rehabilitation was awarded for the establishment of a hand center, and the Chapel Hill Hand Rehabilitation Center became a reality.[155]

In 1967, Chapel Hill gave its first major course on upper extremity rehabilitation, followed in 1968 by a second course on hand rehabilitation.[155] In addition to intensive anatomy, physiology of wound healing, biomechanics, and kinesiology concepts, splinting theory and technique played an important role in these two seminars, which were taught by surgeons Peacock and Madden, therapists Hollis,[156] DeVore, Hamilton, and Cummings, and aide Denny. Working primarily in plaster, Hollis, DeVore, and Denny were exceptionally skilled splint fabricators, but more important was their understanding of the biomechanics and the transfer of force moments involved in splint application.

Acceptance criteria for the two Chapel Hill seminars were rigorous, and once accepted, participants faced daunting preconference reading assignments. Already working with hands, Mackin attended the 1967 Chapel Hill conference and Fess attended the 1968 conference. Mackin, with Hunter and Schneider, went on to establish the second hand rehabilitation center in the United States, the world-renowned Philadelphia Hand Rehabilitation Center.

The 1970s was a period of expansion for hand surgery and hand therapy. Although many surgeons constructed their own splints from the 1910s through the 1960s, both experienced and new hand surgeons in the 1970s became part of a different generation; these surgeons no longer made splints themselves. An ability to splint opened doors for therapists. Surgeons and therapists worked together to create better interventions for patients, including splinting procedures. Brand and Bell in Louisiana and Swanson and Leonard in Grand Rapids made important contributions to the rapidly growing splinting knowledge base. New hand centers began to flourish throughout the United States, with Nalebuff, Millender, and Philips in Boston,

FIGURE 14. The Splint Nomenclature Task Force members created the ASHT Splint Classification System at a 1991 meeting in Indianapolis, Indiana. Members attending were (front row, from left) *Lori Klerekoper DeMott, OTR, CHT, Maude Malick, OTR, Janet Bailey, OTR, CHT (task force leader), Karan Gettle, MBA, OTR, CHT, and Ellen Ziegler, MS, OTR, CHT;* (back row, from left) *Cynthia Philips, MA, OTR, CHT, Elaine Fess, MS, OTR, CHT, and Jean Casanova, OTR, CHT (1991 Director, ASHT Clinical Assessment Committee). Nancy Cannon, OTR, CHT, also attended but is not pictured.*

Strickland and Fess in Indianapolis, Petzolt and Kasch in California, Wilson and Carter in Arizona, Beasley and Prendergast in New York, and Burkhalter and Evans in Florida.

Others set up clinics in university settings or as independent freestanding enterprises; these clinicians included Brown in Atlanta, Olivett in Denver, Fullenwider in Seattle, Pearson in Florida, and Hershman in New Jersey. These surgeons and therapists were in cutting-edge clinical situations. They, along with many others, learned and shared their knowledge in turn, contributing to the evolving splinting technology through publications and teaching seminars.

Knowledge Dissemination and Organizational Leadership

Seminars and Educational Courses

Seminars and educational courses have always been crucial in the dissemination of splinting information. During the first 60 years of the 20th century, surgeons and orthotists presented papers on splinting design and fabrication at their professional conferences.[‡‡‡‡] However, things began to change in the late 1950s, as therapists' contributions to splinting became increasingly acknowledged. Therapists and orthotists at major polio rehabilitation centers throughout the United States took on increasing teaching responsibilities as demand for information about splinting and bracing of polio victims increased.[49,50,55]

Invited at first to serve as faculty for seminars along with surgeons, therapists progressed over time to conducting independent, splinting-specific seminars. Yeakel and Mayerson's material science workshops of the late 1960s were key to disseminating information about new materials, especially plastics.[4,6,36] Malick taught extensively both nationally and internationally, moving from burn splinting to splinting concepts in general. Several generations of therapists grew professionally with Malick as their splinting mentor.

In 1976, the first Hand Surgery and Hand Rehabilitation symposium sponsored by the Philadelphia Hand Center featured the somewhat revolutionary format (for the times) of surgeons and therapists sharing the podium to address hand surgery and hand rehabilitation topics. Over the succeeding 26 years, the success of the Philadelphia seminar has reached unprecedented proportions. Each year, splinting theory, technology, and methods are showcased in lectures and in hands-on workshops. In addition, vendors are available to demonstrate the newest materials, ancillary splinting equipment, and literature resources.

During the second half of the 20th century, universities, professional organizations, other hand centers, individuals, and commercial vendors have all participated at various levels of intensity and frequency in splinting seminars. The demand for learning and improving splinting skills is ever present. At one end of the continuum, surgeons and therapists continue to advance their knowledge, and new information often translates to new requirements for splinting. At the other end of the continuum, as each generation of therapists enters the clinic environment, practicing and upgrading splinting skills is important for continuing competency.

Professional Organizations

Professional organizations also helped extend splinting practice by supporting continuing education seminars, special interest groups, and informational publications that provided the latest splinting information to practitioners and researchers.[162–164] The American Academy of Orthopaedic Surgeons' 1952 *Orthopaedic Appliance Atlas*[41] and the 1982 *Atlas of Orthotics*[165] were important contributions to the standardization of splint language for the extremities.

Organizations also encourage research and define ethics of practice. The previously mentioned 1967 *Study of Orthotic and Prosthetic Activities Appropriate for Physical Therapists and Occupational Therapists*, by the

‡‡‡‡ References 48, 59, 77, 82, 86, 90, 144, 157–161.

National Academy of Sciences, involved representatives from the American Occupational Therapy Association (Hollis, Zimmerman, Kiburn), the American Physical Therapy Association, and the American Orthotics and Prosthetics Association. This report was an important factor in allowing therapists to fabricate splints for their patients.[100]

Specialty organizations such as the American Society for Surgery of the Hand (ASSH), the ASHT, and the American Association for Hand Surgery (AAHS) provide forums for education and research relating to upper extremity splinting practice. A key factor in defining and maintaining splinting competency, the Hand Therapy Certification Commission (HTCC) assesses therapists' knowledge of splinting theory and practice through carefully researched certification examination questions. While the HTCC certification examination encompasses a much broader scope of practice issues than just splinting, each examination includes a number of splint-related items, depending on representational percentages derived from HTCC's scope of practice research studies.

The ASHT Splint Classification System is an excellent example of how a professional organization can influence a particular body of knowledge. Responding to a member survey that identified wide practice discrepancies in splint terminology and usage, the 1989 Executive Board of the ASHT established the Splint Nomenclature Task Force to create a system that would "conclusively settle the issues regarding splinting nomenclature."[1] This task force, chaired by Jean Casanova, consisted of members of the original splint nomenclature committee and recognized splinting authorities in the field of hand rehabilitation§§§§ (Figure 14). The task force met in 1991 with all members but one in attendance. The end product of this pivotal meeting was the ASHT Splint Classification System, published in 1992.

Based on function rather than form, the Splint Classification System uses the terms *splint* and *orthosis* interchangeably. It describes splints through a series of six divisions that guide and progressively refine a splint's technical name, moving from broad concepts to individual splint specifications.

By linking the six required categories, a scientific name "sentence" is created for a given splint, based on its functional purpose. The six required elements in the system include identification of articular/nonarticular status; location; direction; immobilization/mobilization/restriction; type; and total number of joints included. This valuable and innovative classification system provided, for the first time, a true scientific method for categorizing all upper extremity splints.[166] The Splint Classification System may also be applied to splints or orthoses for the lower extremity.

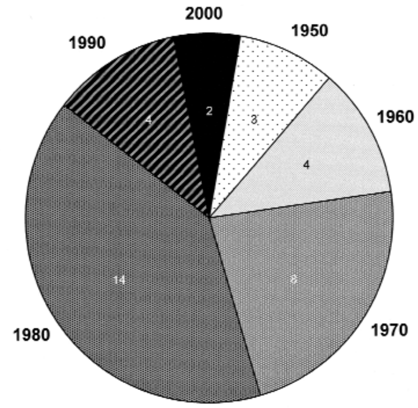


FIGURE 15. The total number of splinting books and manuals published in each preceding 10-year period. Starting in the 1950s, the number of published splinting manuals and books gradually increased for 30 years, peaking in the 1980s.

Publications

Publications define the knowledge base of a field of study. Creation of the *Journal of Hand Therapy* in 1987 was a major advancement for the hand therapy profession. In an almost unprecedented short period of time, this respected professional publication was included, in January 1993, in *Index Medicus,* making splinting and hand rehabilitation information retrievable internationally. The inaugural issue of the Journal included a splinting article by Colditz.[167] In addition to scientific articles on splinting, the Practice Forum section of the Journal routinely presents short papers on splinting technique.

Tracking publication trends for splinting books, manuals, and articles is crucial to identifying and understanding the evolution of splinting theory and practice. Although the majority of the splinting books and manuals reviewed in this study were written by U.S. authors, the analysis here includes both the 1975 and 1988 editions of the splint book by British therapist Nathalie Barr.[13,14]

A tally of manuals and books devoted exclusively to splinting and published from 1950 to 2001 shows a progressive increase in the number of works published through the 1980s and a distinct reduction in numbers during the 1990s (Figure 15). The numbers for the 2000s are skewed, since only one year is included.

Analysis of specific information included in these publications indicates that subject matter in the 1950s focused on splint construction, general splinting concepts, and orthotic designs; the 1970s emphasized construction and general splinting concepts; and the 1980s moved away from general splinting to concentrate on diagnosis-specific splinting and principles of

§§§§ Members of the ASHT Splint Nomenclature Task Force: Jean Casanova, OTR/L, CHT (Director, ASHT Clinical Assessment Committee); Janet Bailey, OTR, CHT (Task Force Leader); Nancy Cannon, OTR, CHT; Judy Colditz, OTR, CHT; Elaine Fess, MS, OTR, FAOTA, CHT; Karan Gettle, MBA, OTR, CHT; Lori (Klerekoper) DeMott, OTR, CHT; Maude Malick, OTR; Cynthia Philips, MA, OTR, CHT; and Ellen Ziegler, MS, OTR/L, CHT.

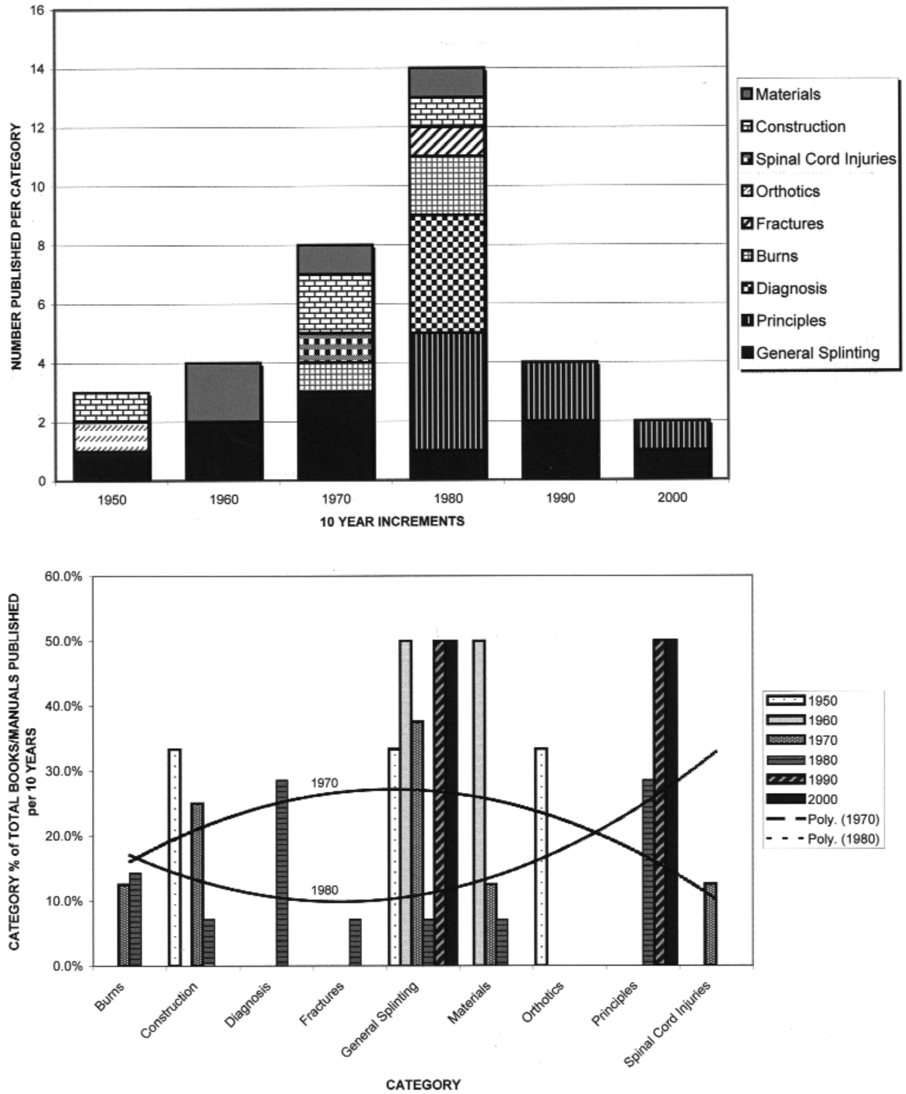


FIGURE 16. Subject matter trends in splint book and manual publishing, 1950 to 2000. Top, *The subject matter of splint books and manuals gradually moved away from detailed particulars of splint fabrication to diagnosis-specific splinting and more sophisticated concepts, including collective guidelines and principles.* Bottom, *Trend lines indicate that a major reciprocal shift in subject matter occurred between the 1970s and the 1980s, changing from materials, construction, and general splinting to diagnosis-specific splinting and principles of splinting. While orthotic books and manuals were important during the 1950s, reflecting the emphasis on treating polio patients, orthotic-specific subject matter in splinting books and manuals declined rapidly beginning in the 1960s.*

splinting (Figure 16). Books and manuals published in the 1990s through 2001 center on general splinting concepts and principles of splinting. Demonstrating progressive development toward more sophisticated levels, the primary motivation for publication changed from how to construct splints in the 1950s, to diagnosis-related splinting in the 1980s and core principles and theory fundamental to splinting in the 1990s and 2000s.

Similar analysis that includes articles in peer-reviewed professional journals as well as books and manuals also shows increasing numbers of splint-specific publications from the 1950s to the 1990s (Figure 17). (Again, the numbers for the 2000s are misleading, since only 1 year of publications is available.) Subject matter analysis indicates a decrease in orthotic and trauma-related publications and a marked increase subjects relating to tendons, design, materials, fractures, joint/ligaments, and carpal tunnel syndrome/over-use splinting concepts.

It is also interesting to view changes in authorship of publications. With the exceptions of one splinting book of which therapists were first and second authors and a surgeon was third author[8] and one book by a noted hand surgeon, therapists wrote all the splint manuals and books included in the above analysis (journal articles not included). This is in distinct contrast to authorship during the first half of the 20th century, when surgeons authored the majority of splint-related publications (Figure 18).

Two hand rehabilitation books have played strategic roles in disseminating splinting information. The

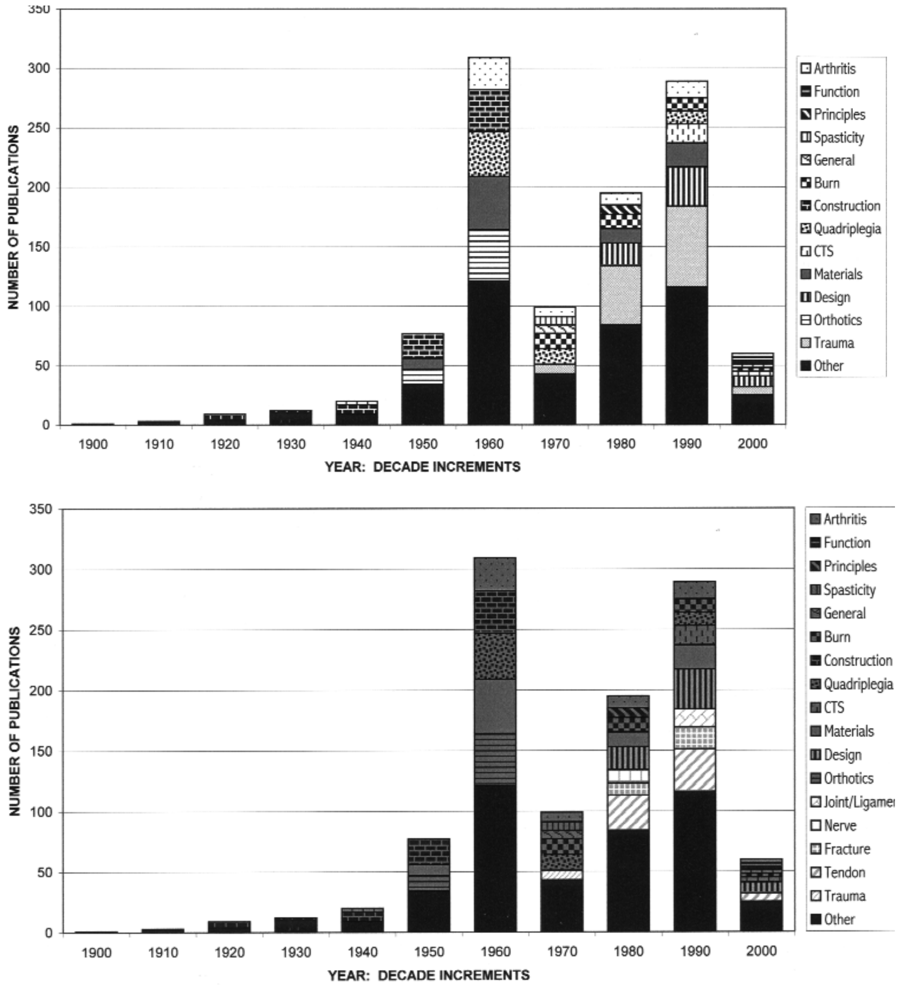


FIGURE 17. Focus of splinting articles, books, and manuals published from 1900 to 2002. The separate categories at the top of each column represent 56% to 60% of publications per decade. Top, *When journal articles were added to books and manuals, splinting publications from 1900 to 2002 showed a steady progressive increase, except in the 1960s, when more splinting publications were produced than in any other decade, before or after. The 1960s were transition years, as the eventual eradication of poliomyelitis resulted in redirection of splinting efforts to other areas, including quadriplegia and arthritis. The pivotal changeover from metal to plastic splinting materials also occurred during this decade. The five most frequent focuses for publications relating to upper extremity splinting during the 1960s included orthotics, splint materials and construction, and splinting quadriplegic and arthritis patients. In contrast, splinting publications in the 1990s revealed an expanding focus.* Bottom, *Publications describing splinting for upper extremity trauma, including tendon, bone, nerve, and joint injuries, increased progressively from the 1970s through the 1990s.*

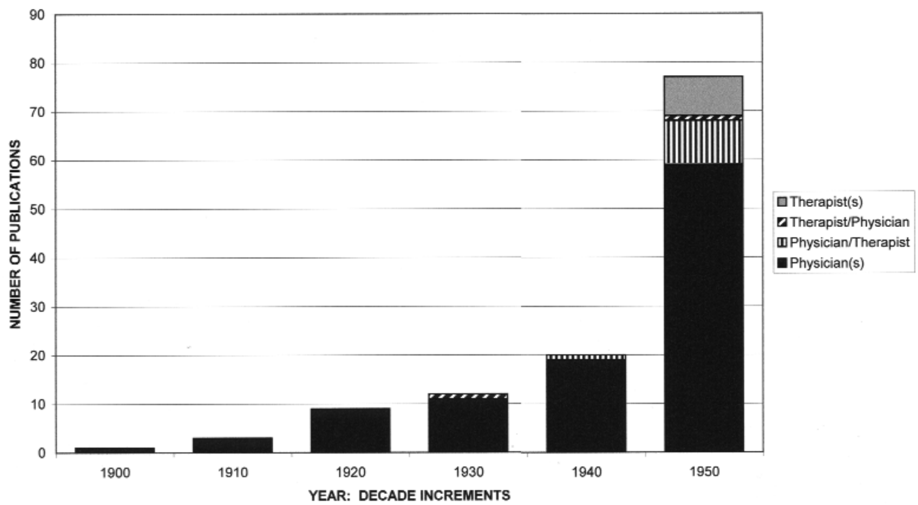


FIGURE 18. Physicians wrote the majority of splinting articles and books published prior to 1960. By the 1950s, splinting articles and books with therapists as lead authors had increased by 900% from earlier years, but physician-authored splinting publications continued to dominate the decade.

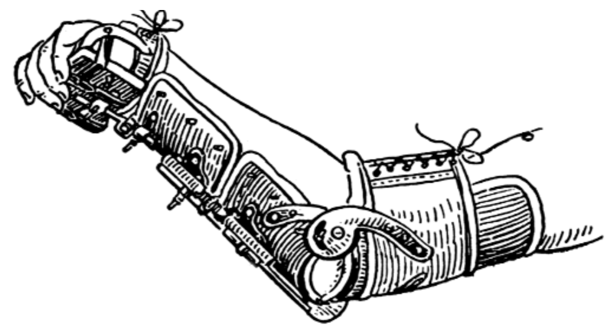


FIGURE 19. Forearm supination, wrist and index-small finger MP extension mobilization splint, type 1 (7). *In this 1905 splint, a series of screw and slide mechanisms allow simultaneous or individual incremental adjustments for forearm supination and wrist and finger MP extension. (Reprinted from American Academy of Orthopaedic Surgeons:* Orthopaedic Appliances Atlas, vol. 1. *Ann Arbor, Mich.: J.W. Edwards, 1952.)*

first edition of Wynn Parry's *Rehabilitation of the Hand*, published in 1958, was unique in its time in that its focus was on conservative treatment of the hand, including detailed information on splinting theory and technique.[168] Based on Wynn Parry's extensive military and civilian experience treating hand and upper extremity problems in Great Britain, subsequent editions continued to define and update important splinting and rehabilitation concepts for surgeons and therapists. The fourth edition of this classic work was published in 1981.[169]

The second important book was based on the first Symposium on Rehabilitation of the Hand, sponsored by the Philadelphia Hand Center in 1976. The first edition of the Philadelphia Hand Center's *Rehabilitation of the Hand*, published in 1978, and edited by Hunter, Schneider, Mackin, and Bell, featured chapters written by therapists and surgeons on a wide variety of topics relating to hand and upper extremity rehabilitation.[170] Indicative of its importance to hand rehabilitation, 10% of the chapters in this first edition were devoted exclusively to splinting, and many other chapters included topic-specific splinting sections. Pulvertaft's prediction in the forward of the first edition was accurate: "There is no need to wish success to the work," he wrote, "for it is assured a special place in the libraries of all who aspire to care for the wounded hand." Now in its fifth edition, *Rehabilitation of the Hand* has no equal, and splinting theory, technique, and application continue to be one of the core components of this great tome.[171]

SUMMARY

Splints from the 19th and 20th centuries are shown in Figures 19 through 24.

In reviewing events concerning the evolution of splinting theory and practice, several main themes become apparent. From a historical perspective, two parallel lines of splinting practice emerged around the mid to late 1880s, with both surgeons and orthotists (appliance makers) fabricating splints. This practice continued through the early 1900s, with few instances of cooperative ventures between the two groups.

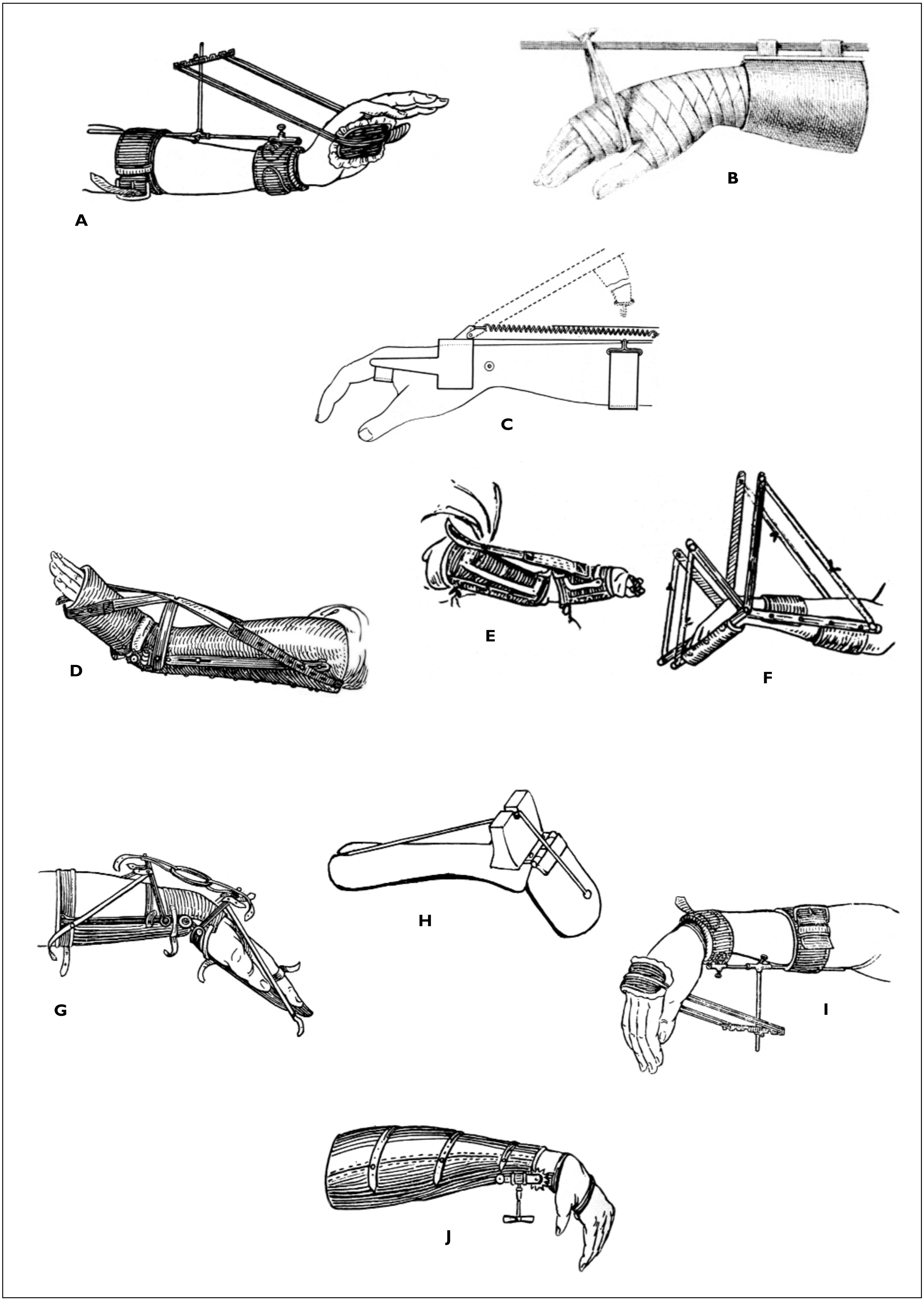
The great polio epidemics, however, changed this mutually imposed dual autonomy, and surgeons and orthotists worked together for the next four decades, along with practitioners of emerging disciplines—physical medicine physicians and occupational and physical therapists—to combat a powerfully overwhelming common foe, poliomyelitis.

A corollary hand surgical specialty began to develop that, at first, had little effect on the situation, because hand trauma was seen as relatively insignificant in comparison with the ravages imposed by polio and infection. It is apparent that the early hand surgeons in the 1920s and 1930s made their own splints, but the reason for this remains unclear. Two rationales may be advanced: 1) with most orthotic departments fully engaged in treating polio victims, patients with hand trauma were given secondary priority by orthotists, thereby forcing hand surgeons to fabricate their own splints; or 2) orthotists were technically unable to provide the highly individualized type of splinting required by hand surgeons.

Although orthotists fabricated splints during WWII, the relatively few numbers of orthotists meant that surgeons, medical corpsmen, therapists, and nurses also fabricated splints, depending on individual hospital sites and conditions. By the end of WWII, most hand surgeons were proficient in splint fabrication, and a few had developed their own commercially available splints.

In the mid to late 1950s, the effectiveness of the polio vaccine was almost immediately apparent in the significant decrease in new cases of polio. The majority of rehabilitative resources, however, continued to be directed to treating the tremendous numbers of polio survivors. These were pinnacle times for orthotists and physical medicine physicians, and the rehabilitation and vocational fields made rapid advances.

FIGURE 20. *These wrist mobilization splints span 40 years, from the oldest (*splint G, *122 years old) to the most recent (*splint C, *82 years old). Although the materials are old fashioned, the mechanical angles of force application are correct for many of the splints. The Splint Classification System allows similar-functioning splints to be grouped together even though their configurations are different.* Splints A (1886), B (1891), and C (1920): ***Wrist extension mobilization splint, type 0 (1).*** Splints D and E (1908): ***Wrist extension mobilization splint, type 1 (5).*** Splints F and G (1908): ***Wrist extension mobilization splint, type 3 (16).*** Splints H (1880), I (1886), and J (1908): ***Wrist flexion mobilization splint, type 0 (1).*** *(All splints reprinted from American Academy of Orthopaedic Surgeons:* Orthopaedic Appliances Atlas, vol. 1. *Ann Arbor, Mich.: J.W. Edwards, 1952.)*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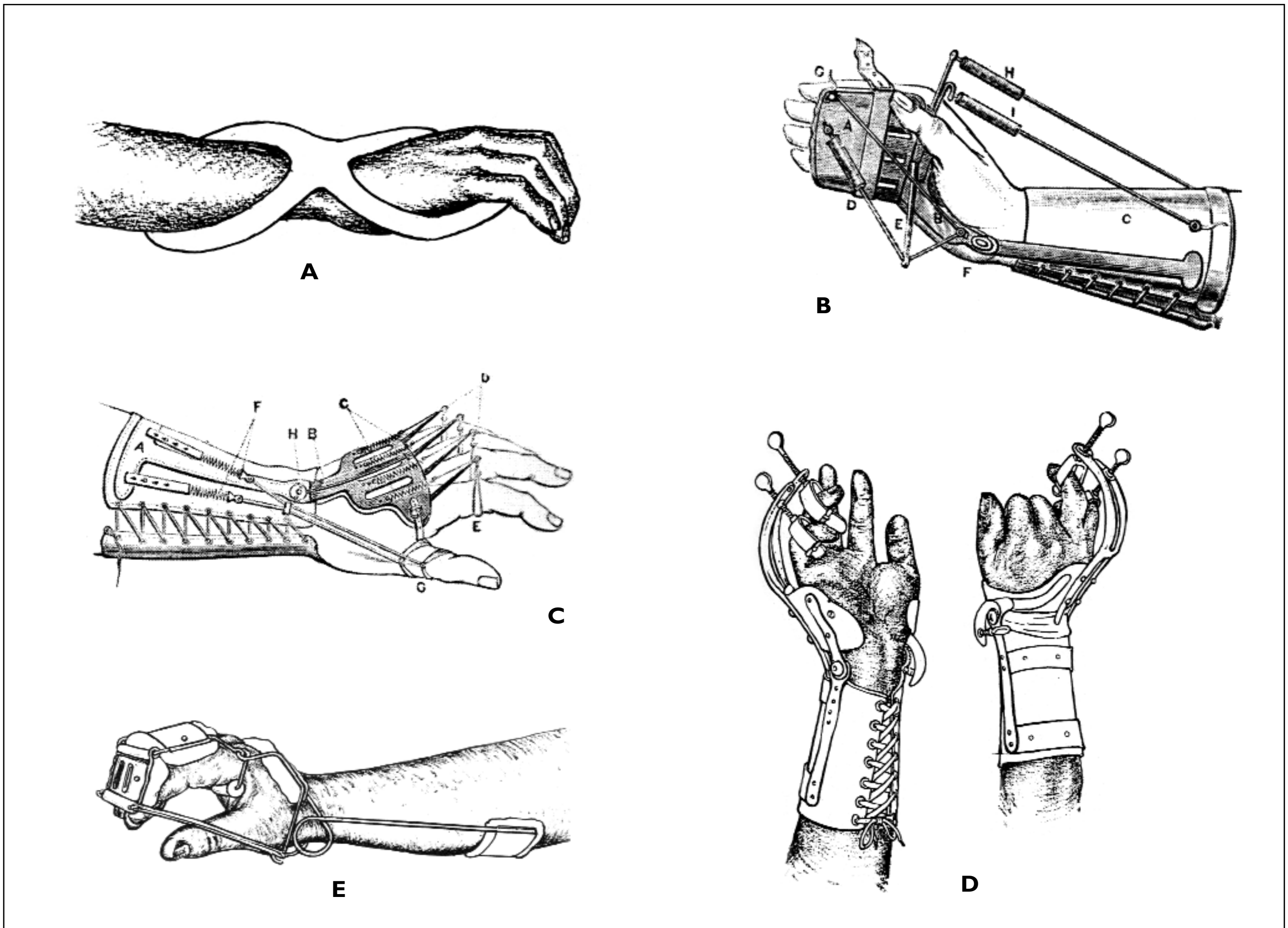
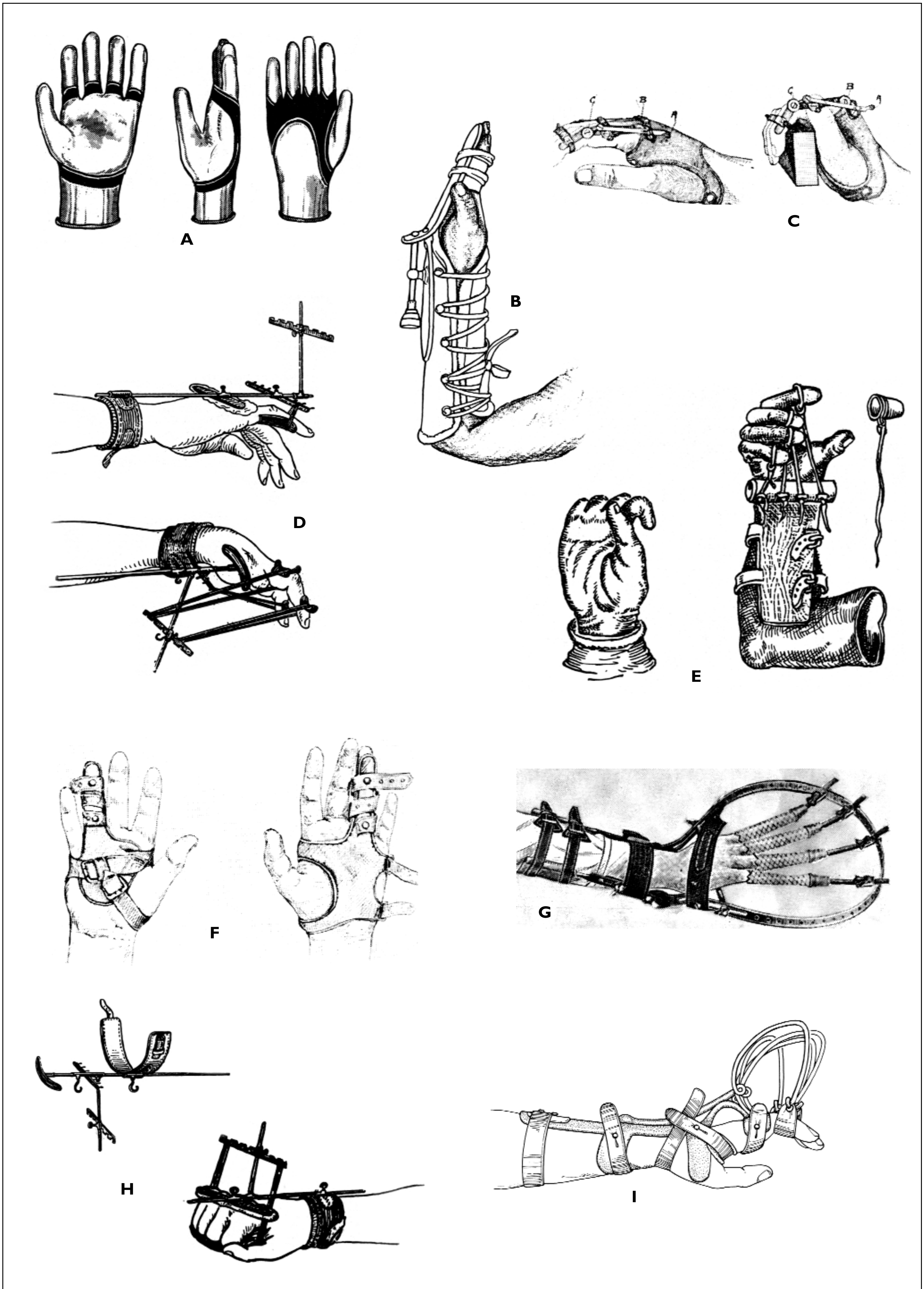


FIGURE 21. Wrist and finger—or wrist, finger, and thumb—joints are identified as primary joints in these splints from 1869 to 1948. Splint A (1943): ***Wrist, index-small finger MP extension mobilization splint, type 0 (5).*** Splint B (1869): ***Wrist extension, index-small finger MP flexion mobilization splint, type 2 (13).*** Splint C (1869): ***Wrist extension, index-small finger MP extension, thumb CMC radial abduction and MP extension mobilization splint, type 0 (7).*** Splint D (1927): ***Wrist, ring-small finger MP-PIP extension mobilization splint, type 0 (5).*** Splint E (1948): ***Wrist extension, index-small finger MP-IP flexion mobilization splint, type 0 (13).*** *All splints reprinted from American Academy of Orthopaedic Surgeons:* Orthopaedic Appliances Atlas, vol. 1. *Ann Arbor, Mich.: J.W. Edwards, 1952, with permission from CRC Press.)*

Specialized surgical procedures for restoration of function of paralyzed extremities, i.e., tendon transfers or spinal surgery, also underwent major advancements.

In the mid to late 1950s, a quiet renaissance began. Several factors combined to propel this movement forward. Splinting materials were changing, hand surgeons were developing their own field of expertise and were becoming busier with surgical cases, therapists were increasingly more interested in splinting activities, and for whatever reason, orthotists were less inclined to be involved in short-term, temporary splinting practice.

FIGURE 22. Of these finger mobilization splints, all but one (splint I) incorporate the metacarpophalangeal joints as primary joints, either alone or in conjunction with the proximal interphalangeal joints. Problems with MP joint passive motion correlate with the splinting historical review in that understanding the importance of maintaining MP joint collateral ligament length was not widely known until the mid to late 1960s. With the exception of the one PIP primary joint splint (splint I, 1970), these splints date from 1647 to 1949. Splint A (1949): ***Index-small finger MP extension mobilization splint, type 0 (4).*** Splint B (1938): ***Index-small finger MP flexion mobilization splint, type 3 (13).*** Splint C (1922): ***Index-small finger MP flexion: index-small finger PIP flexion / index-small finger MP extension: index-small finger PIPextension mobilization splint, type 0 (8).*** Splint D (1908): ***Small finger PIP extension mobilization splint, type 1 (3)*** or ***index finger MP–PIP flexion mobilization splint, type 1 (3).*** Splint E (1647): ***Index-small finger flexion mobilization splint, type 5 (13).*** Splint F (1896): ***Ring finger extension mobilization splint, type 0 (3).*** Splint G (1934): ***Index-small finger extension mobilization splint, type 1 (13).*** Splint H (1908): ***Index-small finger flexion mobilization splint, type 1 (13).*** Splint I (1896): ***Index-small finger PIP extension mobilization splint, type 2 (9).*** *(Splints A through H are reprinted from American Academy of Orthopaedic Surgeons:* Orthopaedic Appliances Atlas, vol. 1. *Ann Arbor, Mich.: J.W. Edwards, 1952, with permission from CRC Press. Splint I is reprinted, with permission, from Fess EE, Philips CA:* Hand Splinting Principles and Methods. *2nd ed. St. Louis, Mo.: Mosby, 1987.)*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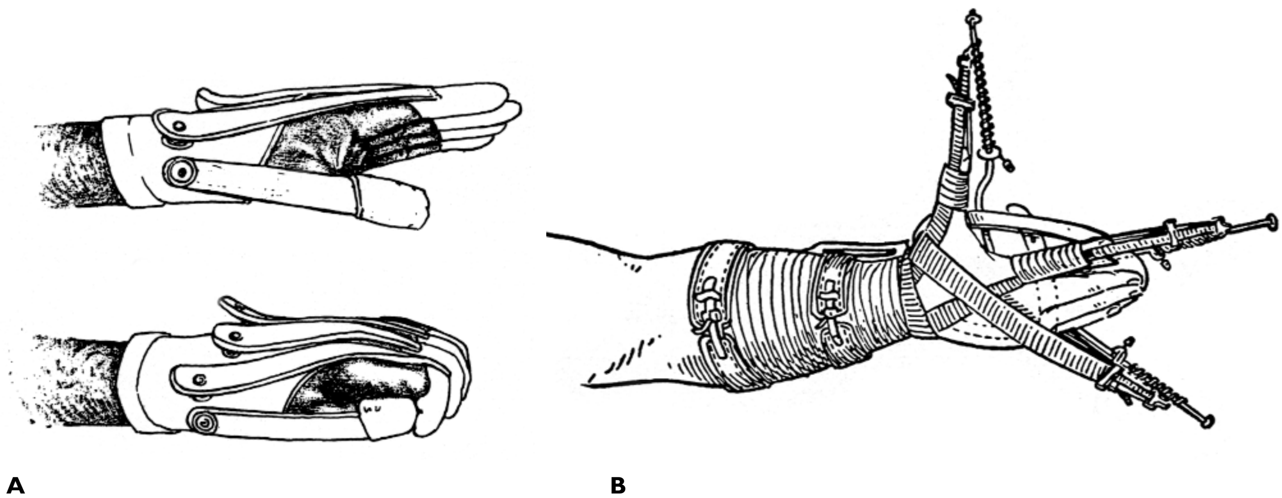

FIGURE 23. Primary joints in these two splints with very different purposes include finger and thumb joints. Splint A (1944): ***Index-small finger extension, thumb CMC radial abduction and MP–IP extension mobilization splint, type 0 (15).*** Splint B (1889): ***Index finger MP, thumb MP distraction and extension mobilization splint, type 5 (7).*** *(Both splints reprinted from American Academy of Orthopaedic Surgeons:* Orthopaedic Appliances Atlas, vol. 1. *Ann Arbor, Mich.: J.W. Edwards, 1952, with permission from CRC Press.)*

The 1960s brought an enormous drop in polio cases, and polio-oriented orthotists and therapists almost literally had to reinvent themselves to find jobs. Looking back, it seems as though therapists were better able to make the transition than were orthotists. There are few clues as to why this occurred, but some articles provide insight. In 1958, Tosberg, a highly respected orthotist, wrote about professional problems of prosthetists and orthotists. He identified poor communication with medical team personnel, the physician in particular, as a commonly encountered problem and urged prosthetists and orthotists to become better acquainted with medical protocol and terminology. He also discussed the need for college-level degrees in prosthetics and orthotics.

In 1963, Engen, also a well-recognized orthotist, presented and later wrote about the technical advances influencing the field of orthotics. The materials he discussed included low-pressure laminates, nylon, dacron, Teflon, Velcro, and anodized aluminum. The high-temperature thermoplastics like Lucite, Plexiglas, and Royalite, with which therapists were learning to make splints, were completely omitted from Engen's discourse, despite the fact that these materials had been available for between 5 and 7 years. Engen also identified patients with arthritis as a potential group of patients who could benefit from better orthotic intervention. Not mentioned were postoperative splinting procedures.

By the late 1960s, therapists were more adept at splinting, and early low-temperature thermoplastic materials were available for clinic use. Surgeons were beginning to do silicone implant arthroplasty, and silicon tendon rod grafting procedures and the importance of early passive motion protocols with flexor tendon repairs were recognized. Powerful government and associated agencies and organizations were actively influencing splinting practice. Between 1967 and 1971, in addition to financially underwriting pivotal splinting publications and seminars, government grants funded several events that significantly affected splinting practice, including a study that permitted therapists to make splints under certain conditions; an expert panel that made recommendations to ensure that therapist educational programs included appropriate splinting capacities; and efforts directed toward splinting patients with arthritis, burns, and peripheral nerve injuries. Orthotists, at least superficially, participated in early decisions that gave therapists the opportunity to assume responsibility for temporary splinting endeavors, so it seems safe to assume that they were not interested in this rapidly expanding field.

By the 1970s, therapists had enthusiastically embraced the field of upper extremity splinting and were off and running. The art and science of splinting knowledge rapidly expanded, alliances with hand surgeons were forged, professional hand therapy organizations were formed, a professional hand journal was launched, a certification commission was created, and therapists never looked back. Splinting expertise opened so many doors for therapists. While splints were frequently the initial impetus for communication, they provided excellent opportunities for therapists to demonstrate to surgeons that through teamwork they could improve patient care not only by splinting but also by providing the highest quality therapy possible. It may be a long time before such rapid advancement is witnessed again.

The long-range repercussions of today's health care regulations on splinting practice are yet to be determined. Using the Splint Classification System to define splinting terminology and its related costs is a natural step toward standardizing splinting practice and improving reimbursement. The Splint Classification System will also help differentiate between hand therapy professionals and hand therapy pretenders. Unqualified or unskilled health care workers ordering from a commercial catalogue of prefabricated splints will not have the knowledge of anatomy, kinesiology, and biomechanics to procure appropriately designed splints, and this will quickly become apparent.

Skill is always a highly sought commodity, and regarding splinting endeavors, two additional concepts are certain. Historical review confirms that over the centuries, splints have been, without interruption, an important element in the treatment of bone and soft tissue pathology. History also indicates that surgeons have been inextricably connected with the evolution of splinting concepts. These two entities, surgeons and splints, will most likely continue into the future together. The question is whether therapists will be part of this future.

Splinting is a common denominator for surgeons and therapists so long as both groups continue to advance their knowledge bases in synchrony with each other. For example, a model of synchronous development is the independent creation of splints by both therapists and surgeons for early active motion programs for tendon repairs.[172–178] Understanding underlying wound healing physiology and timing, biomechanics of tendon motion on repair sites, and the influences healing processes exert throughout the reparative course allows for the creation of appropriately designed splints and exercise protocols. The point is not who conceives a splint, so long as the splint meets all the technical and individual requisites to reach the objectives for which it was created, and surgeon, therapist, and patient work as a team for the betterment of the patient.

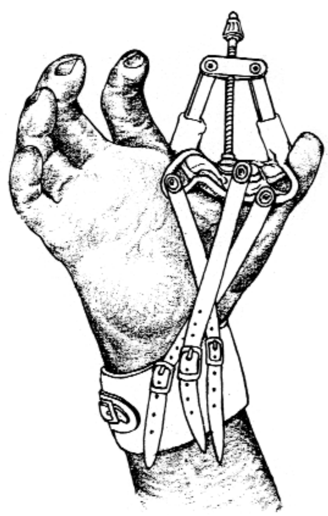

FIGURE 24. ***Thumb CMC palmar abduction mobilization splint, type 1 (2).*** *This splint, which dates from 1946 and was designed to increase thumb CMC joint passive motion, seems over-mechanized in comparison with contemporary CMC mobilization splints. (Reprinted from American Academy of Orthopaedic Surgeons:* Orthopaedic Appliances Atlas, vol. 1. *Ann Arbor, Mich.: J.W. Edwards, 1952.)*

The bottom line is that, when used appropriately and in conjunction with high-quality therapy and surgery, splints make patients better! It will be difficult for health maintenance organizations and third-party payers to ignore this fact so long as surgeons, therapists, and patients continue to work together.

Contemporary therapists must not forget those therapists, surgeons, government officials, and patients who opened the doors of opportunity for our predecessors. Switzer was an essential catalyst, who had both the foresight and the means to effect change. We owe a great deal to her. We must also remember to recognize and thank the early hand therapists like Hollis, Malick, Mackin, Barr, deLeeuw, DeVore, Barber, Bleyer, Mayerson, Yeakel, Von Prince, Sammons, and many others, who forged the initial paths that now have become multi-lane highways to the future. Had these talented and dedicated persons "dropped the ball," this history of splinting would have had an altogether different course.

Acknowledgments

The perception of history is ever changing, and its documentation is dependent on the information available at the time. Additional information and resources are openly sought so that this initial study may continue to grow.

The author thanks therapists Kay Carl and Judy Kiel for having the good sense not to throw out old, moldy splinting manuals and books collected over the years at the Indiana University School of Medicine, Occupational Therapy Program, IUPUI, Indianapolis; Karan Gettle and Robin Janson for their generous sharing of knowledge, books, articles, and splint resources and their unfaltering enthusiasm; and Judy Bell-Krotosky for finding the Brand/Switzer photograph. She also thanks her dedicated husband, Steve Fess, for all the hours he spent tenaciously tracking long-lost references in dusty journals and on eye-blearing microfilm.

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Appendix

20th Century Contributors to Splinting Practice Who Are Cited in the Text

Allen, Harvey S., MD, FACS

Arem, A. J., MD

Bailey, Janet M., OTR, CHT

Barber, Lois M., OTR, FAOTA

Barr, Nathalie R., MBE, FCOT

Barsky, Arthur J., MD

Beasley, Robert W., MD

Bell-Krotoski, Judith A., OTR, FAOTA, CHT

Bennett, George E., MD

Bleyer, Dorothy A., OTR

Boozer, Jeanine A., OTR, CHT

Bradford, Eleanor, OTR

Bradley, T. Kay (Carl), OTR

Brand, Paul W., FRCS

Bricker, Eugene M., MD

Brown, D. Michael, OTR, CWA

Bunnell, Sterling, MD

Burkhalter, William E., MD

Cannon, Nancy M., OTR, CHT

Carter, Margaret S., OTR, CHT

Casanova, Jean S., OTR, CHT

Clayton, Mack, MD

Colditz, Judy, OTR, CHT, FAOTA

Cummings, Johanne, PT

deLeeuw, Carolina F., MA, OTR

Denny, Elisha (splint maker)

DeVore, Gloria, OTR

Duran, Robert J., MD

Engen, Thorkild, CO

Evans, Roslyn B., OTR, CHT

Fess, Elaine Ewing, MS, OTR, FAOTA, CHT

Flowers, Kenneth R., PT, CHT

Fowler, S. Benjamin, MD

Frackelton, William H., MD

Fuchs, Ernest M., OTR

Fuchs, Renate L., OTR

Fullenwider, Lynnlee, OTR, CHT

Gettle, Karan S., MBA, OTR, CHT

Graham, Walter C., MD

Hamilton, George, PT

Hammond, George, MD

Hershman, A. Gloria, OTR, FAOTA

Hollis, L. Irene, OTR, FAOTA

Hopkins, Helen L., EdD, OTR, FAOTA

Howard, Lot D., MD

Hunter, James M., MD

Hyroop, Gilbert L., MD

James, J. I. P., MS, FRCS

Johnson, Robert W., MD

Jones, Sir Robert, ChM, FRCSI (Hon)

Kanavel, Allen B., MD, FACS

Kasch, Mary C., OTR, CVE, CHT

Kendall, Florence Peterson, PT

Kendall, Henry Otis, PT

Kenny, Elizabeth, Sister

Kilburn, Virginia, OTR, FAOTA

Kleinert, Harold E., MD

Klerekoper (DeMott), Lori A., OTR, CHT

Koch, Sumner L., MD, FACS

Landsmeer, J. M. F., Prof. Dr.

LaStayo, Paul, PhD, PT, CHT

Leonard, Judy, OTR, CHT

Littler, J. William, MD

Long, Charles, MD

Mackin, Evelyn J., PT

Madden, John W., MD

Malick, Maude, OTR

Marble, H. C., MD

Mason, Michael L., MD, FACS

Mayerson, Edith R., OTR

McNamara, Jean (physician)

Millender, Lewis H., MD

Nalebuff, Edward A., MD

Neumann, C. G., MD

Olivett, Bonnie L., OTR, CHT

Peacock, Erle E., Jr., MD

Pearson, Shirley L., OTR, MS

Petzoldt, Richard L., MD

Phalen, George S., MD

Philips, Cynthia A., MA, OTR, CHT

Pratt, Donald R., MD

Prendergast (Lauckhardt), Karen, MA, PT, CHT

Pulvertaft, R. Guy, CBE, MD, MChir, FRCS

Robinson, David W., MD

Rusk, Howard A., MD

Sabine, Clark L., OTR

Sammons, Fred, OTR, FAOTA

Schneider, Lawrence H., MD

Smith, Edwin M., MD

Smith, Helen D., MOT, OTR, FAOTA

Strickland, James W., MD

Stromberg, William B., MD

Swanson, Alfred B., MD

Switzer, Mary (Commissioner, Vocational Rehab. Admin.)

Tosberg, William A., CO&P

Trueta, Joseph, MD

Van Lede, Paul, OT, MS

van Veldhoven, Griet, OT/OrthopE

von Prince, Maj. Kilulu, MP, OTR, MS

Wilson, Robert Lee, MD

Wynn Parry, Christopher, MBE, MA, DM, FRCP, FRCS, DPhysMED

Yeakel, Lt. Col. Mary H., OTR, BS

Yerxa, Elizabeth J., EdD, OTR, FAOTA

Ziegler, Ellen M., MS, OTR, CHT

Zimmerman, Muriel, MA, OTR, FAOTA