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Case Studies: Contracture and Stiff Joint Management with Dynasplint®*

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This study investigated the efficacy of using Dynasplint LPS® (low, prolonged-stretch) devices for restoring range of motion in cases where either immobilization stiffness or an established contracture had developed at the elbow or knee. Patients treated with Dynasplint, a force adjustable device for use in clinic and at home and capable of providing low levels of force over prolonged periods of time, resulted in a 61% additional increase in range of motion at the elbow or knee in 13 case studies in spite of the fact that 9 of the 13 subjects had already undergone previous and, oftentimes, intensive physical therapy programs designed for the same purpose of restoring range of motion. Dynasplint knee and elbow devices were found to be highly effective and efficient tools for speeding recovery from immobilization stiffness and to correct established contractures in 13 subjects who had suffered elbow fractures (8), knee fractures (2), surgeries (2), and a stroke (1).

Immobilization stiffness at the knee and elbow, as well as established contractures at those joints, are problems often encountered by many practitioners. Numerous conditions such as elbow and knee fractures, strokes, head trauma, burns, total knee replacements, and knee ligament reconstruction, to name a few, frequently leave the patient with less than normal range of motion. When joint mobility is lost, functional impairment results ranging from an athlete's poor running performance to the elderlies' inability to walk to the bathroom or to feed themselves. Rehabilitation efforts for these individuals must be the most efficacious and efficient, since the frequency of this program is great and costs of providing medical care are of primary concern. This article describes the successful and efficient use of the Dynasplint LPS® (Dynasplint Systems, Inc., 6655 Amberton Drive, Baltimore, MD 21227) device in 13 cases where either immobilization stiffness or an established contracture was a debilitative problem.

With the ever-increasing emphasis placed on decreasing rehabilitation time, in order to reduce the cost of rehabilitation, clinicians are realizing that early joint motion with some form of stretching helps to restore the connective tissue to its normal length in the shortest period of time, thereby assisting the patient in recovering normal joint movement.[3,6] In addition, research clearly demonstrates that stretching methods are best when they incorporate low levels of force over longer periods (a mild stretch throughout most of the day, as opposed to 5 minutes of heavy stretching twice a day).[7,10,14,16] From this, it can be concluded that the clinician's ideal treatment program for a patient with nonosseous, passive joint limitation should be mild stretching, as much as is practical throughout the 24-hour day, 7 days a week, and to start this program as soon as joint motion is allowed.

With this in mind, it becomes important to find practical and effective means for implementing this ideal treatment approach. Dynasplint elbow and knee orthotic devices are one such means and were used in this study because of their adjustability, ease of application, and low profile appearance.

Importance of Connective Tissue

Whenever soft tissue limits range of motion, the limiting component is usually connective tissue. In normal situations, connective tissue prevents abnormal or excessive mobility. This is important for

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joint stability, preventing hypermobility and minimizing risk of dislocations. However, in pathological conditions where joint immobilization was necessary for proper management of the problem, the connective tissue shortens and thickens, causing a loss in range of motion.[10]

Connective tissue tends to shorten very slowly and progressively if it is not opposed by a considerable force. As the tissue contracts and reorganizes, it becomes more dense and usually, within a week, results in restricted range of motion.[10,16]

Not only does shortening occur but, also, in the presence of trauma, edema or impaired circulation, new collagen fibers form in as little as 3 days which restricts motion even more.[10,16]

Physiology of Connective Tissue

Ligaments, tendons, joint capsules, and other related structures fall into the category of "connective tissue." These tissues are composed of a network of collagenous and reticular fibers, elastic fibers, fibrin, and ground substance. Collectively, these elements appear as randomly oriented fibers attached to one another at many intervals throughout the tissue. The lengths of the fibers between the points of attachment determine the degree of motion that can occur in that connective tissue. Therefore, the longer the distance between points of attachments, the greater the range; and conversely, the shorter the distance the shorter the range.[10]

The attachment points themselves can shift or release in response to prolonged tension or they can develop at points where prolonged contact of the fibers may occur. Additionally, the length of the fibers between the attachment points can either increase or decrease with respective presence or absence of an opposing force. This remodeling or reorganization of the connective tissue is an inherent property well documented through research.[10,16–18]

Biophysical Effects of Stretching

When stretched, the connective tissue appears to be viscoelastic in nature. When a force is applied against the tissue and then removed, the tissue behaves as if it has both plastic and elastic properties. The elastic response is shown by recovery of the tissue to its original shortened position, while the plastic response is characterized by permanent elongation. Optimal plastic deformation of the tissue results with applications of long periods of low force stretch. The tissue slowly remodels because a biochemical response, triggered by constant force, results in a loosening and shifting of the fibers' connecting points within the tissue. By contrast, elongation of shortened connective tissue, through short periods of forceful stretching, relies upon attempt to mechanically break or tear the connecting points. Typically, with short periods of high force stretching, the result is a higher proportion of elastic response, less remodeling, and greater trauma and weakening of the tissue.[10,12,16]

With any given stretching force, the resulting proportion of plastic to elastic response depends primarily upon two stretching force variables: time and intensity. Research on these variables has produced three significant findings:[10,16–18]

1) Short duration stretching of high intensity favors the elastic response, while prolonged duration stretching of low intensity favors the plastic response.

2) There is a direct correlation between the duration of a stretch and the resulting proportion of plastic, permanent elongation.

3) There is a direct correlation between the intensity of a stretch and the degree of either trauma or weakening of the stretched tissues.

To summarize, the longest period of low force stretch produces the greatest amount of permanent elongation, with the least amount of trauma and structural weakening of the connective tissues.[10,11,16–18] Consequently, permanent elongation of connective tissue results in range of motion increases for the patient.

It is necessary, for clinical practice, to delineate low force, prolonged-duration stretching from high force, short-duration stretching. Since time and intensity are relative variables in both types of stretching, it is important to understand that any defined limits of time and force categorizing these stretching types are done so on no absolute scientific basis. As an example, 10 minutes of stretching, using 1 lb of force, could conceivably be considered "prolonged" when compared to 2 minutes of stretching with the same force. Conversely, the 10 minutes of stretching just described as prolonged would certainly no longer be considered such if the comparison of 10 minutes were made to 30, 60, or 100 minutes. The same analogy can be made for considering a force "high force" or "low force." However, for practical purposes, any force tolerated satisfactorily for at least 60 minutes per day, cumulatively, will be classified as of the "prolonged-duration" type of stretch and similarly, any force tolerated under 60 minutes per day will be classified as of the "short-duration" type. Defining the force of stretch as either high-force or low force is not necessary since the amount of force tolerated is a variable of the duration over which it is applied.

Review of Clinical Stretching Methods

There exists quite a variety of methods, and means for such methods, for stretching tight, stiff elbows and knees—those affected by shortened connective tissues. Naming all would be near an impossibility, but there are a good number of methods that are used ubiquitously: active-assistive and passive exercise (Fig. 1); Continuous Passive Motion (CPM) machines; traction, both motorized and manual (Fig. 2); hanging weights with pulleys as Sapega described at Temple University and as others have devised;[16] joint mobilization, turnbuckle screws; manipulation, as performed under general anesthesia; serial casts and splints; and dynamic splints[1,2,4,8,9] (Figs. 3–5) achieve some type of stretching force over a period of time.

All methods and means for stretching can be compared for their relationship to the two stretch variables: time and force (Figs. 6 and 7).

At any point on the force-duration curve (Fig. 6), there is defined, in relative terms, how much force an individual patient can tolerate and over what period of time it can be tolerated. Clearly, the high forces involved in manipulation, vigorous passive exercise, and certain active-assistive stretching exercise can be tolerated seconds, or at most, a few minutes before the patient is in painful distress and would need a rest (Fig. 7).

Fig. 1. *Manual stretching. Use of active-assistive and passive stretching technique for gaining knee flexion.*

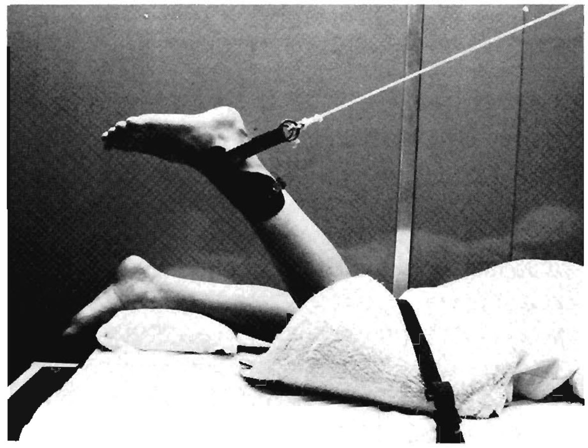

Fig. 2. *Motorized traction. To gain knee flexion.*

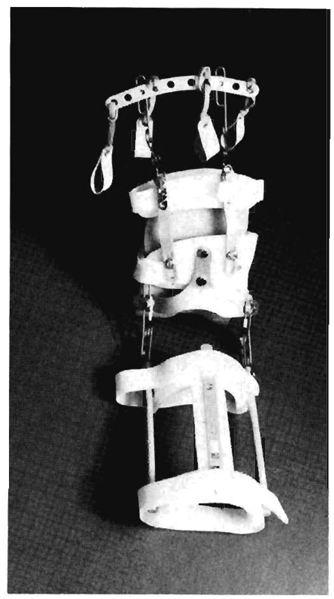

Fig. 3. *Dynamic finger—wrist splint. Using rubber band and coil spring tension.*

With motorized intermittent traction and CPM devices, the connective tissue affected is on a stretch for relatively short time periods, with a rest phase programmed into the cycle. During these rest periods, the unit is in place and operative, but is not actually imparting any substantial stretch force to the shortened connective tissue. In this manner, while the intermittent traction and CPM devices themselves may be in application for long periods (½ hour up to 24 hours), the actual duration of stretch imparted to the shortened connective tissue is of short duration and,

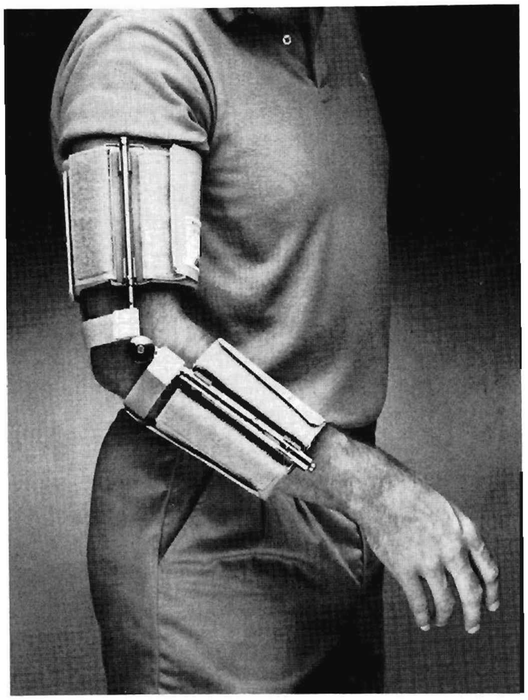

Fig. 4. *Dynasplint—elbow extension.*

in fact, often lasts only a matter of seconds for each revolution per minute.

To illustrate this example, consider a patient using a CPM device 6 hours per day in his home after being discharged from a hospital following total knee replacement. The doctor or therapist may program the CPM device for one revolution per minute. During one complete revolution, the knee extends and flexes through the range of motion programmed in the CPM machine, with a pause of several seconds at the end ranges.

Since elongation of the contractured tissues occurs when a tension load is applied to the tissues, the cumulative stretching force imparted to the tissues is calculated as follows:

Therapeutic stretching time

= (Time CPM is used)(time end range is maintained)

$$= (6 \text{ hours/day}) \times \left(5 \frac{\text{seconds}}{\text{minute}}\right)$$

$$= (6 \text{ hours/day}) \times \left(\frac{60 \text{ minutes}}{\text{hour}}\right) \times \left(5 \frac{\text{seconds}}{\text{minute}}\right) \times \left(\frac{1 \text{ minute}}{60 \text{ seconds}}\right)$$

Therapeutic stretching time with CPM in this example

= 30 minutes/day

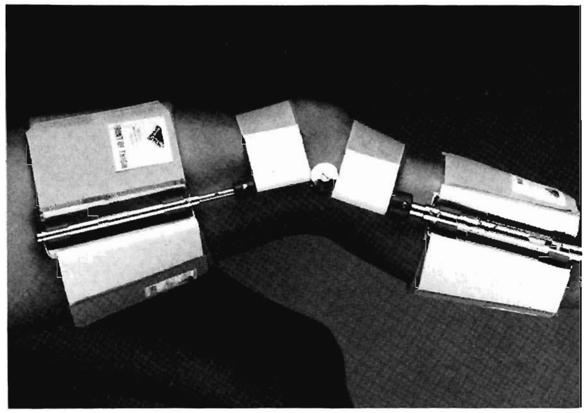

Fig. 5. *Dynasplint—knee extension.*

Using the same example, a patient with 6 hours of dynamic splinting may necessarily require approximately 1 minute rest periods every 14 minutes of continuous use. During the rest periods, the unit would be in place, just as with CPM, but the tension load normally being applied to the contractured tissues would be temporarily arrested by the patient's voluntary flexing of the knee in a case where extension is the problem. The cumulative stretching force imparted to the tissues from a knee extension dynamic-splint is calculated as follows:

Therapeutic stretching time

= (Time dynamic-splint is used)(time end range is maintained)

$$= (6 \text{ hours/day}) \times \left(\frac{14 \text{ minute stretch periods}}{15 \text{ minutes of use periods}}\right) \times \left[\left(4 \frac{[15 \text{ minutes of use periods}]}{1 \text{ hour}}\right)\right] \times \left(\frac{1 \text{ hour}}{60 \text{ minutes}}\right)$$

$$= \frac{(6)\,(4)\,(14)}{60}$$

Therapeutic stretching time with dynamic splinting in this example

= 5.6 hours/day = 5 hours, 36 minutes per day

Therefore, CPM, motorized intermittent traction and the like, should most often be classified as high force, short-duration stretching modalities. CPM, in the author's opinion, was not primarily intended for stretching shortened connective tissues, but rather, is intended to prevent the con-

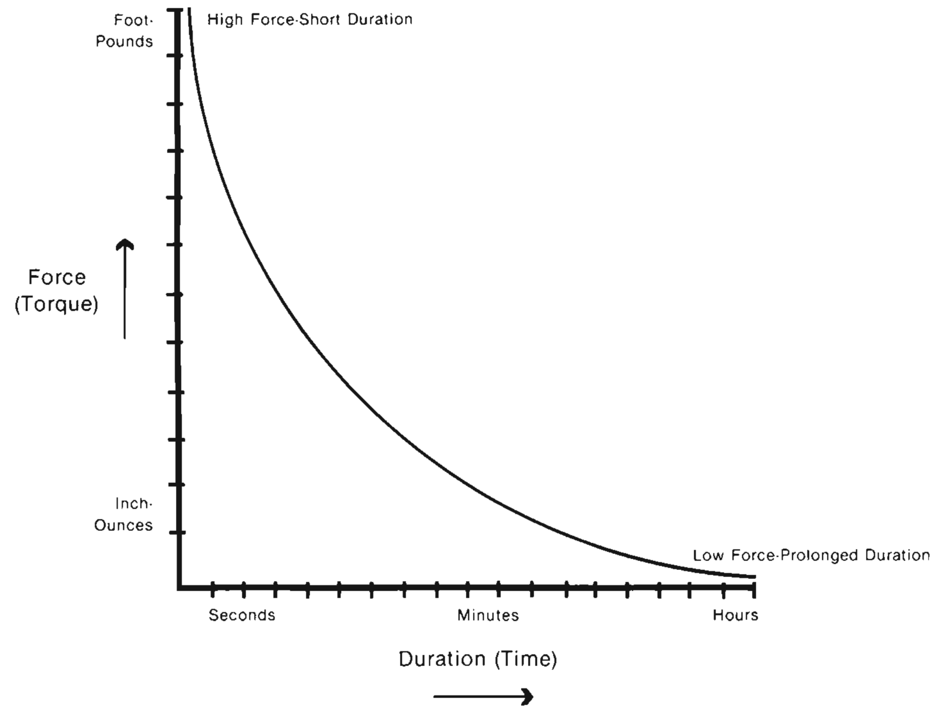

Fig. 6. *Force-duration curve. Indicates the time a particular force can be tolerated by a patient.*

nective tissue from reorganizing in the shortened position in the first place.[13]

On the other hand, well-made serial casts and splints, turnbuckles, hanging weights, dynamic splints, and perhaps some others not mentioned, have been known to be tolerated longer; long enough, in fact, to be classified as of the "low load, prolonged-duration" stretch type, as previously defined.[1,2,4,5,7-9,16] Unfortunately, most devices such as braces with variable locking devices

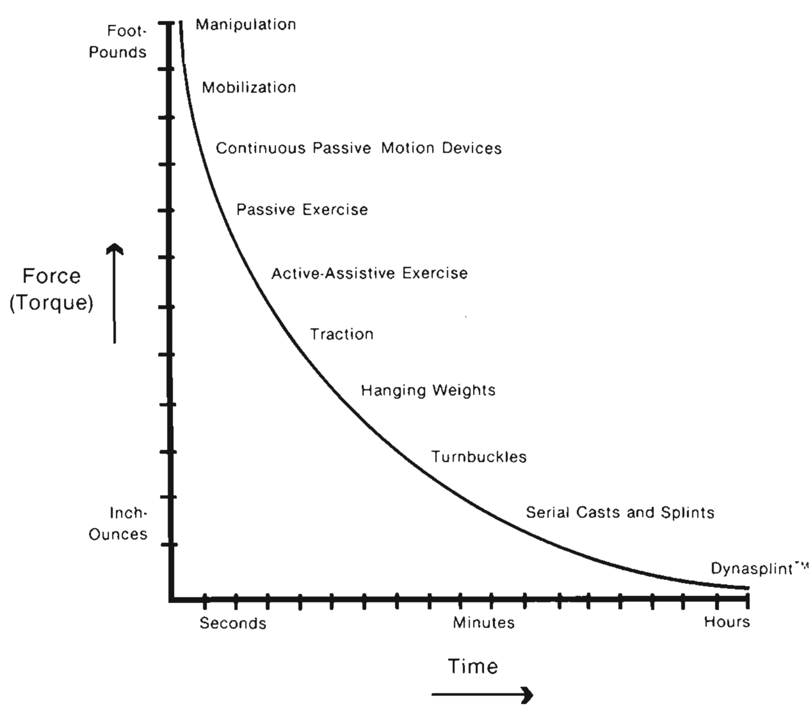

Fig. 7. *Force-duration curve. Also called "Patient-Tolerance Curve"—indicates how much force each particular type of treatment imparts to the patient and how long it can be tolerated in relative terms.*

or turnbuckle screws, hanging weights, and serial splints and casts, have been uncomfortable to the patient and have disallowed functional activities of the limb. Dynamic splints, on the other hand, have been more functional.[7]

CLINICAL STUDY-PROCEDURES

Thirteen subjects with nonosseous, passive elbow or knee range-of-motion restrictions were treated with a Dynasplint LPS unit. Eleven subjects lacked full extension and two subjects lacked full flexion. The average age of each subject group was 36.2 years, which ranged from 18–50 years. The average degree of lost range of motion before treatment was 49° and ranged from 42° to 92°. Other factors relating to sex, diagnosis, and age of the limited joint range are listed in Table 1.

Nine of the 13 subjects had undergone extensive physical therapy treatment programs, where range of motion recovery had long since plateaued, prior to being referred.

Protocols used in the dynamic splint treatment varied slightly from case to case, depending on the tolerance and capacity of each subject. Generally, the force settings on the splint were kept low (½–1 ft-lb) until wearing time was maximized (usually 8–12 hours/day cumulatively). Once the wearing time was maximized, then and only then, was the force setting increased, with such increases being one-half notch on the scale every 2–3 days. One notch on the scale relates to approximately ½ ft-lb of torque. Maximizing wearing time usually took 7–21 days. The force setting usually was maximized in 4–6 weeks, with the maximum force tolerated averaging approximately 2.25 ft-lbs of torque (4.5 on Dynasplint's scale) for the elbow and 4.0 ft-lbs of torque (8.0 on Dynasplint's scale) for the knee.

All subjects were evaluated for range of motion, strength, joint end-feel, inflammation, and other appropriate signs and symptoms related to range of motion loss.

Each subject was properly fitted by the physical therapist with an appropriate unit. The subject and a friend or spouse of the subject, were trained in applying the device properly before the subject was allowed to use it at home.

The physical therapist reviewed each subject for range-of-motion measurements, fitting adjustments and force adjustments at least monthly, but usually every 10–14 days.

When appropriate, as when prior physical therapy had not been given, other modalities and procedures, such as heat, active and resistive exercise, were given to strengthen the extremity and further enhance the patient's recovery. No passive range-of-motion exercise was given to the patient since it is felt by the author that dynamic splinting devices replace the need for manual passive stretching. Oftentimes, in the author's experience, passive stretching actually impaired progresssion in range of motion that would otherwise have been achieved using dynamic splinting alone.

RESULTS

All subjects experienced improvement. The average percentage of range of motion increase was 61% (Table 2).

Visit frequency to the physical therapist was approximately one visit every 8 days.

No remarkable complications resulted in any subject for the duration of the treatment program. However, close monitoring of both the fitting adjustments and force setting effects was important.

Subject compliance was excellent.

CONCLUSION

1) Dynamic splinting is an efficient and highly effective tool to speed recovery from immobilization stiffness and to correct established contrac-

TABLE 1
*Subjects— data prior to Dynasplint application**

Movement lost	No. of cases	Sex		Subjects average age (years)	Average ROM lost	Average duration of disability (weeks)
		Male	Female			
Elbow extension	7	4	3	31	42°	41
Knee extension	4	1	3	50	43°	66
Knee flexion	1		1	36	92°	13
Elbow flexion	1		1	18	75°	14

* Of the 13 subjects, 8 had sustained severe elbow fractures (fracture-dislocation, comminuted, or supracondylar), 2 had had surgeries, 1 had had a stroke, and 2 had sustained severe knee fractures.

TABLE 2
Results; Averages on 13 subjects after Dynasplint application

Movement lost	Degree of loss prior to Dynasplint	Degree of improvement	Degree of loss after Dynasplint	Duration of Dynasplint use (weeks)	Percentage of improvement (%)	No. of visits
					improved degrees / beginning degrees	
Elbow extension	42°	26°	16°	11	62	7
Knee extension	43°	21°	22°	11	49	5
Elbow flexion	92°	62°	30°	22	67	9
Knee flexion	75°	60°	15°	13	80	24
Totals (average for 13 Subjects)	49°	30°	19°	13	61	11 visits

tures, even when other traditional methods have failed.

2) The physical therapy visits necessary for proper management of the splint program were found to be substantially less than those visits needed for more traditional treatment programs, such as manual stretching.

3) Being able to utilize the equipment at home offered the ability to apply mild stretch 7 days a week, for up to 16 hours per day, as opposed to traditional therapy approaches, which require visits to a therapist in order for a treatment to be administered. Normally, this treatment is of the high force, short-duration type stretch, which is less desirable for restoring normal range of motion.

4) Controlling the force and time of stretch were found to be vital for maximizing range of motion restoration and for good patient compliance. Therefore, the close involvement of the therapist for monitoring the dynamic splints force setting, time of wear, and general patient tolerance was found to be important for maximizing successful use of this equipment.

5) The overwhelming conclusion of clinical evidence throughout the literature and confirmed by this study, clearly states that the longest period of low force stretch produces the greatest amount of permanent elongation, with the least amount of trauma and weakening of the connective tissues, thereby more fully restoring range of motion as quickly as possible.

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