Effectiveness of bracing in the treatment of nonosseous restriction of elbow mobility: a systematic review and meta-analysis of 13 studies

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Background: Restriction of elbow mobility is a very frequent complaint after trauma or surgery. The objective of this study was to assess and compare the effectiveness of dynamic, static, or static-progressive bracing in patients with elbow stiffness of traumatic or postoperative origin and without evidence of ossification. For the purpose of this study, effectiveness was measured as the increase in total range of motion, as well as extension and flexion.

Materials and methods: We performed a systematic search of the keywords “elbow AND (stiffness OR stiff) AND (brace OR splint OR conservative)” in the online databases PubMed, EMBASE, CINAHL (Cumulative Index to Nursing and Allied Health Literature), and the Cochrane Library. We included all clinical studies using dynamic or static bracing in patients with elbow stiffness. Eligible outcomes were changes in total range of motion, flexion, and extension; sustainability of results; and complications.

Results: We included 13 eligible studies, providing data on 14 treated groups in 247 patients. The mean age of these patients was $34.5 \pm 10.4$ years, and female patients comprised $46\% \pm 12\%$. The mean duration from the incident to the start of brace treatment was $6.9 \pm 5.1$ months. The mean improvement in range of motion during the course of treatment was $38.4^\circ \pm 8.9^\circ$ (95% confidence interval, $39.5^\circ-41.8^\circ$).

Conclusions: The current evidence strongly supports the use of static-progressive stretching 3 times 30 minutes per day in each direction as a first line of treatment in patients with post-traumatic and postsurgical elbow stiffness. If this treatment fails or if reasons for stiffness other than soft-tissue incompliance are identified, further surgical interventions should be considered.

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Restriction of elbow mobility and elbow stiffness are frequent complaints after elbow trauma or surgery, with an incidence upward of 5%. Postoperative or post-traumatic elbow stiffness may range from a minor nuisance to a major debilitation. A range of motion of 100° (30° to 130°) is required for proper elbow and upper extremity function, and a loss of 50° of motion will result in a functional loss of 80% in activities of daily living. Advanced degrees of elbow stiffness are a major interference even with the simplest tasks of daily living, despite typically being painless. Interestingly, there is no association between the extent of trauma or surgical intervention and the extent of subsequent stiffness.

Capsular shrinkage and soft-tissue contractures were identified as major contributors to elbow stiffness, even after restoration of osseous alignments. It has been shown that the soft-tissue contractures are based on an elevated number of myofibroblasts, although it is not fully clear how this overproliferation is initiated. Genetic predisposition and prolonged immobilization have been reliably identified as major risk factors. Additional contributors include extrinsic factors such as heterotopic ossification, malunions, and contractures after burn injuries, as well as intrinsic factors such as intra-articular cartilage damage, free bodies, and gross osseous incongruence.

Treatment options focus on these contributing factors and can be divided into surgical and conservative. Although surgical excision and release of ossifications and contracted soft tissues seem to be obvious solutions at first, the elbow, especially after previous surgery and/or trauma, can be a fairly inhospitable environment, harboring the potential for a wide range of complications. Even if neurovascular damage is avoided, a successful release can trigger elbow stiffening anew. In the absence of heterotopic ossification, bracing has been used successfully to treat elbow stiffness. The key to this treatment is the viscoelastic nature of connective tissue, that is, its ability to respond with both elastic (temporary elongation) and plastic (permanent elongation) deformity to tensile loading. Plastic elongation can be achieved through manual stretching, but the use of devices is much easier and more straightforward. Naturally, this effect is severely inhibited by ossification of the periarticular soft tissues. In principle, 2 types of such devices exist: static and dynamic splints. Static splints, the more commonly encountered method, use creep loading, for example, by use of a turnbuckle. By definition, creep loading implies the use of a constant force resulting in varying displacement. Creep-based devices have to be worn for long periods of time, up to 12 hours or more daily, and it is not certain that plastic deformity is achieved during each session. Thus, the results are variable, and the prolonged exposure potentially provokes low compliance rates. In addition, complications such as pressure sores and skin breakdown have been reported. Dynamic splints use stress relaxation instead of creep, that is, displacement is constant and force varies. Engineering has proven that stress relaxation leads to plastic deformity more quickly and more reliably than creep. Dynamic splints typically use springs or rubber bands, the latter especially in hand surgery. Finally, an extension of dynamic splinting is static-progressive splinting (SPS). This technique uses the same device as dynamic splinting but with constant tension (e.g., a turnbuckle) instead of a dynamic force (e.g., a rubber band).

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Materials and methods

We performed a systematic search of the keywords “elbow AND (stiffness OR stiff) AND (brace OR splint OR conservative)” in the online databases PubMed, EMBASE, CINAHL (Cumulative Index to Nursing and Allied Health Literature), and the Cochrane Library repeatedly up to August 1, 2012. All publication dates and languages were included.

We included studies that used dynamic, static, or static-progressive bracing in patients with elbow stiffness of traumatic or postoperative origin and without evidence of ossification. Eligible primary outcomes were changes in total range of motion, flexion, and extension. Eligible secondary outcomes were longevity as measured by sustainability of results and complications. Studies in animals, using experimental procedures, or assessing other outcomes than clinical outcome were excluded.

All references from the online search were reviewed in duplicate and independently for eligibility. Disagreements were resolved by consensus. Extracted data from the included studies included sample size, demographic data, and clinical outcome. For statistical analysis, clinical improvements in motion were synthesized as weighted mean difference of pretreatment and post-treatment degrees. Inverse variance was used as weight, and 95% confidence intervals (CIs) were calculated for weighted mean tensile strength.

A subgroup analysis was performed to compare different types of bracing. We used the weighted mean differences and weighted
standard errors for the primary endpoints in each group to calculate $P$ values using generic $F$ tests.

All calculations were performed with intercooled Stata software, version 12 (StataCorp, College Station, TX, USA). An $\alpha$ of 5% was considered significant.

Results

Included studies

Our search algorithm produced 59 studies. Thirteen studies, published between 1976 and 2012, were eligible, providing data on 14 treated groups including 247 patients. The mean age of these patients was $34.5 \pm 10.4$ years, and female patients comprised $46\% \pm 12\%$. The mean duration from the inciting incident to the start of brace treatment was $6.9 \pm 5.1$ months. Table I presents the relevant study characteristics.

Origin of elbow stiffness

Of all cases, 98% ($n = 253$) were due to direct elbow trauma. Eleven articles reported on post-traumatic cases without evidence of heterotopic ossification exclusively. Three articles included other patients with elbow stiffness originating from causes other than elbow trauma, including head trauma ($n = 1$, 0.4%), elbow immobilization for longer than 4 weeks postoperatively ($n = 3$, 1.2%), and upper extremity second- and third-degree burns ($n = 1$, 0.4%). The mean period between the initial trauma and initiation of bracing was $6.9 \pm 5.1$ months.

Assessment of between-study heterogeneity

The most important source of heterogeneity was patient selection. The inclusion criteria varied considerable among studies. The common denominator was a reduction of the arc of motion to less than 100° or flexion of less than 100° after a variable duration of physical therapy, in most cases between 8 and 12 weeks. In addition, there was no clear-cut definition of “stiffness.” Table I shows the differences in duration of treatment. Mathematically, there was evidence for overall heterogeneity for the increase in range of motion ($P < .01$), as well as flexion and extension ($P < .01$ for both).

Treatment protocols

Five studies report on the use of dynamic splints. Lindenhovius et al17 applied dynamic bracing for 31 patients for 6 to 8 hours per day and ended this treatment at the discretion of the patient. Gallucci et al10 started applying dynamic splinting in 17 patients at a mean of 94 days (range, 33-185 days), using the splint all night and 2 times 4 hours per day for 86 days (range, 47-127 days). Hepburn14,15 published 2 studies on a population of 14 patients in total using dynamic splinting for 8 to 12 hours per day for 5 to 7.5 months. Finally, MacKay-Lyons20 reported on the use of dynamic splinting for 12 hours per day for 7.5 months.

Another 5 studies used SPS to treat elbow stiffness. Lindenhovius et al17 applied SPS bracing for 31 patients 3 times 30 minutes per day, again until satisfaction of the patient had been achieved. Doornberg et al8 initiated SPS 52 days (range, 15-200 days) after injury or surgery 3 times 30 minutes per day in each direction for 4 months. Bhat et al4 instructed their patients to wear an orthosis during the daytime for 15 hours and remove it before sleeping and while eating. Treatment was initiated at 7 months (range, 4-24 months) and maintained for 5 months (range, 3-8 months). Ulrich et al27 instructed their patients to use SPS for 30-minute treatment sessions, doing 1 session during the first week, 2 during the second week, and 3 starting in the third week. Bonutti et al4 also treated 20 patients with SPS in 30-minute sessions.

Four studies used static stretching with creep. Sukstahlen and Sukstahlen treated, among other joint problems, 3 patients with static stretching for elbow stiffness. Gelinas et al11 treated 22 patients with a turnbuckle splint worn for 20 hours per day for a mean of 4.5 ± 1.8 months. Green and McCoy12 instructed their patients to wear a turnbuckle splint for “as long as possible” every day. To our knowledge, Dickson7 published the first article on elbow bracing, using static stretching in a 35-year-old patient with elbow stiffness.

Range of motion gained

The mean improvement in total range of motion during the course of treatment was $38° \pm 10°$ (95% CI, 39.5°-41.8°). Dynamic bracing resulted in the largest relative improvement of range of motion, with an increase of $46° \pm 10°$ (95% CI, 43.2°-48.9°). Static-progressive splints resulted in a slightly lesser improvement, with $40° \pm 10°$ (95% CI, 38.1°-41.5°). Static splints had the least improvement, with $34° \pm 6°$ (95% CI, 31.9°-35.6°). This is consistent with a statistically significant difference in improvement of range of motion at $P < .01$ ($F = 7.5611$, $df = 2$) (Table II).

Flexion gained

The mean gain in flexion was $17° \pm 8°$ (95% CI, 16.2°-18.1°). Again, dynamic bracing resulted in the largest improvement of range of motion, with an increase of $28° \pm 8°$ (95% CI, 25.1°-29.3°). Static-progressive splints resulted in a slightly lesser improvement, with $17° \pm 9°$ (95% CI, 15.9°-18.7°). Static splints had the least improvement, with $10° \pm 6°$ (95% CI, 8.6°-12.1°). Again, this is consistent with a statistically significant difference ($P < .01$, $F = 76.2829$, $df = 2$) (Table II).
Extension gained

The mean gain in extension was 23° ± 8° (95% CI, 21.9°-23.9°). The largest improvement was seen with dynamic splinting, measuring 28° ± 11° (95% CI, 24.7°-30.2°), as compared with static splinting, with 27° ± 6° (95% CI, 25.6°-29.0°), and SPS, with 19° ± 9° (95% CI, 17.5°-20.2°). There was a statistically significant difference between these results ($P < .001$, $F = 28.4505$, $df = 2$) (Table II).

Sustainability of results and complications

After treatment, 12 patients (5%) lost range of motion after discontinuing the elbow brace; however, 18 (8%) gained range of motion after stopping the treatment. There was no association between the delay of the start of treatment after the onset of elbow stiffness and the gain in range of motion ($r = 0.39$). There were no surgical releases performed as a secondary treatment in any group, although some patients had heterotopic ossifications removed or infections surgically treated. There were 2 ulnar nerve lesions in the dynamic bracing group and 3 such lesions in the static bracing group ($P = .118$). Bhat et al$^2$ reported pressure sores in 2 patients undergoing SPS bracing and were the only authors to report finding such sores. Ulrich et al$^{27}$ and Gelinas et al$^{11}$ assessed for skin problems and pressure sores but found none in their patient populations. Unfortunately, no study reported on systematic assessment of patient compliance with splinting.

Discussion

Summary of evidence

The exact incidence of elbow stiffness is hard to determine, but it is safe to say that post-traumatic and postsurgical elbow stiffness is a frequent and serious complication. Surgical treatment is an effective treatment option but is
technically complicated and associated with a real potential for severe neurovascular complications and recurrent stiffness. In this study, we assessed the effectiveness and safety of elbow bracing as a conservative treatment option for elbow stiffness. We found that the 3 most common techniques for bracing—static, dynamic, and static progressive—all resulted in a substantial and sustainable improvement in range of motion, in both flexion and extension (Fig. 1).

In this study, we found that bracing is an effective and safe technique in the management of elbow stiffness. All 3 types of bracing led to significant improvements of range of motion, as shown by the 95% CIs (none of which included 0). The statistical comparison of the 3 techniques also showed a significant difference among the groups in flexion and extension gained. However, we believe that this was an effect of the fairly large sample size rather than a truly meaningful finding clinically, especially because the values for the mean improvements are rather close to each other (ie, within 1 SD of each other). Patients treated with static splints failed to gain range of motion of more than 100°, which has been defined by Morrey et al as the minimum arc needed to ensure upper extremity function in daily living. SPS yielded the best post-treatment values, even though it did not result in the largest relative increase. A reason for this might be a slight selection bias, that is, a situation in which patients receiving SPS had less stiffness to begin with, thus having a better ultimate absolute outcome despite less relative improvement. Nevertheless, we think that rather than selection bias, this is merely an effect of time or publication date. The SPS studies, using the newest of the 3 techniques, were published most recently, and present-day elbow stiffness treatment is more aggressive than treatment was in the 1970s. Given the favorable outcome and the patient-friendly protocol of treatment 3 times 30 minutes per day in each direction—flexion and extension—SPS is our treatment of choice. However, our data also support the use of other splinting techniques, and on the basis of this study, there is no obvious superiority of any one treatment based on actual effect size. Thus, if SPS cannot be made available to a patient, dynamic or even static splints are valuable and worthwhile alternatives.

Dynamic, static, and SPS bracing has also been used successfully to mobilize other joints in the upper extremity. Lucado et al reported on 25 patients with post-traumatic wrist stiffness who were successfully treated with static-progressive treatment, resulting in significant improvements in flexion and extension; Disabilities of the Arm, Shoulder and Hand scores; and grip strength. McGrath et al reported similar results for 38 patients with limited forearm rotation after trauma. Boccolari and Tocco reported on the successful use of SPS to treat proximal interphalangeal joint flexion contractures. Suksatien and Suksathien used SPS to treat postsurgical knee stiffness. Finally, Guild and Barillo et al used SPS to improve range of motion in patients with burns and found significant improvements in finger and toe flexion, grasp strength, and function.

Treatment alternatives for elbow stiffness are mostly surgical. A recent review provided data from 655 patients showing an increase in range of motion of 45° ± 21°, or an increase in flexion of 22° ± 21° and an increase in extension of 20° ± 13°, after open surgical release.
though slightly worse, results were seen for arthroscopic release, with an increase in range of motion of 18° ± 27°, or an increase in flexion of 19° ± 11° paired with an increase in extension of 27° ± 12°.5,6 Whereas hard data on the complication rates of surgical treatment of elbow stiffness are scarce, 2 recent studies cite complication rates in the range of 5% to 30%.5,6 In addition, to produce lasting results, postsurgical continuous passive motion is essential. Interestingly, surgical results are not better than the results from bracing.

**Shortcomings**

Our study has potential shortcomings. Like any systematic review, it is highly dependent on the quality of the primary studies included. For example, none of the included studies systematically assessed patient compliance. Given the paucity of high-quality randomized controlled trials on elbow bracing, our results are subject to bias. Furthermore, there is significant heterogeneity among the included studies because of differences in treatment regimens, patient populations, and so on. However, even in the face of these biases, we found strong and consistent evidence supporting the effectiveness of elbow braces.

**Conclusion**

Bracing is an effective treatment for nonosseous, post-traumatic and postoperative elbow stiffness and provides comparable results to surgical intervention but with much lower risks of neurovascular complications. Different techniques exist, but in our assessment, the improvements in range of motion do not differ substantially, with the outcomes for dynamic, static, or static-progressive bracing within 1 SD of each other. We recommend the use of static-progressive stretching 3 times 30 minutes per day in each direction as a first line of treatment in patients with post-traumatic and postsurgical elbow stiffness without evidence of restricting, periarticular ossification. An important reason to recommend the use of static-progressive stretching is the patient-friendly protocol that will likely improve compliance. If this treatment fails or if reasons for stiffness other than soft-tissue incomppliance are identified, surgical intervention should be considered. Future studies may consider evaluating patient compliance and satisfaction with different bracing methods, subjective patient outcome scores, and the cost-effectiveness of various treatment techniques.

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**References**


