REHABILITATION OF MUSCLE INJURIES

Loris Bertolacci
"Controlled experimental and clinical trials have yielded convincing evidence that early, controlled mobilization is superior to immobilization for musculoskeletal soft-tissue injuries. This holds true not only in primary treatment of acute injuries, but also in their postoperative management. The superiority of early controlled mobilization is especially apparent in terms of producing quicker recovery and return to full activity, without jeopardizing the long-term rehabilitative outcome. Therefore, the technique can be recommended as the method of choice for acute soft-tissue injury."
Phases of Healing After an Acute Soft-Tissue Injury

<table>
<thead>
<tr>
<th>Phase</th>
<th>Approximate Days After Injury</th>
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<tbody>
<tr>
<td>Inflammation</td>
<td>0 to 7</td>
</tr>
<tr>
<td>Proliferation</td>
<td>7 to 21</td>
</tr>
<tr>
<td>Maturation and remodeling</td>
<td>&gt;21</td>
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**Acute inflammatory phase.** In this phase, ischemia, metabolic disturbance, and cell membrane damage lead to inflammation, which, in turn, is characterized by infiltration of inflammatory cells, tissue edema, fibrin exudation, capillary wall thickening, capillary occlusions, and plasma leakage. Clinically, inflammation manifests as swelling, erythema, increased temperature, pain, and loss of function. The process is time dependent and mediated by vascular, cellular, and chemical events culminating in tissue repair and sometimes scar (adhesion) formation.

**Proliferative phase.** These changes include fibrin clotting and a proliferation of fibroblasts, synovial cells, and capillaries. The inflammatory cells eliminate the damaged tissue fragments by phagocytosis, and fibroblasts extensively and markedly elevate production of collagen (initially, the weaker, type 3 collagen, later type 1) and other extracellular matrix components.

**Maturation and remodeling phase.** In this phase, the proteoglycan-water content of the healing tissue decreases and type 1 collagen fibers start to assume a normal orientation. Approximately 6 to 8 weeks postinjury, the new collagen fibers can withstand near-normal stress, although final maturation of tendon and ligament tissue may take as long as 6 to 12 months.
Clinicians and therapists face an ongoing dilemma of requiring some new collagen formation for the muscle–tendon unit to carry load and generate torque about a joint while at the same time seeking minimal scar formation in order to minimize stiffness.


<table>
<thead>
<tr>
<th>Weeks after return from initial injury</th>
<th>Hamstring strain (n = 858)</th>
<th>Quadriceps strain (n = 251)</th>
<th>Calf strain (n = 217)</th>
<th>Thigh contusion (n = 123)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>9.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.6&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>2</td>
<td>8.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.2</td>
</tr>
<tr>
<td>3</td>
<td>6.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.3</td>
</tr>
<tr>
<td>4–5</td>
<td>4.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.0&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>6–8</td>
<td>3.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.8</td>
<td>1.3</td>
</tr>
<tr>
<td>9–14</td>
<td>2.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.5</td>
<td>1.1</td>
<td>1.6</td>
</tr>
<tr>
<td>15–22</td>
<td>1.4</td>
<td>2.2</td>
<td>2.1</td>
<td>0.0&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Cumulative risk of recurrence for remainder of season (%)</td>
<td>30.6</td>
<td>22.9</td>
<td>23.8</td>
<td>12.2</td>
</tr>
</tbody>
</table>

<sup>a</sup> Significantly greater than weekly risk of reinjury during following season (p < 0.05).

<sup>b</sup> No recurrence reported during this time period.
In summary, a short period of immobilization after muscle injury is beneficial, but it should be limited only to the first few days after the injury. This rest period allows the scar tissue connecting the injured muscle stumps to gain the required strength to withstand the contraction-induced forces applied on it without a re-rupture, but being restricted to the first few days only, the adverse effects of immobility per se can be limited to a minimum. Experimentally, it has been shown that by day 10 after the trauma, the muscles tested in tension showed failure in the intact part of the muscle, suggesting that the tensile strength of the connective tissue scar becomes greater than that of the muscle tissue at that point. However, the active use of the injured muscle can and should be carefully started before this point, as there is also experimental data showing that beginning active mobilization after the short period of immobilization enhances the penetration of muscle fibers through the connective tissue scar, limits the size of the permanent scar, facilitates the proper alignment of the regenerating muscle fibers, and helps in regaining the tensile strength of the injured muscle.

TREATMENT AFTER 3 TO 5 DAYS

If the acute phases after the injury have passed uneventfully and the recovery of the injured limb seems to be progressing favorably, the more active treatment of the injured muscle should be started gradually using the following specific exercises:
In summary, a short period of immobilization after muscle injury is beneficial, but it should be limited only to the first few days after the injury.

“In fact, somewhat paradoxically, it has actually been shown that by placing the injured muscle to rest (cast immobilization in rats) for the first couple of days after the injury, the excessive scar formation and re-ruptures at the injury site can be best prevented. Immobilization appears to provide the new granulation tissue with the needed tensile strength to withstand the forces created by muscle contractions.

Although immobilization has been shown to result in beneficial effects in the early phase of muscle regeneration, it also has several clinically undesired effects. For example, inactivity has been shown to be associated with a significant atrophy of the healthy muscle fibers, excessive deposition of connective tissue within the muscle tissue, and a substantially retarded recovery of the strength of the injured skeletal muscle throughout the immobilization period. If immobilization is continued past the acute phase (first few days) of muscle regeneration, the deleterious effects become particularly evident during the remodeling phase of muscle healing.”
Figure 2. A schematic illustration of the healing skeletal muscle. Day 2: the necrotized parts of the transected myofibers are being removed by macrophages while, concomitantly, the formation of the connective tissue scar by fibroblasts has begun in the central zone (CZ). Day 3: satellite cells have become activated within the basal lamina cylinders in the regeneration zone (RZ). Day 5: myoblasts have fused into myotubes in the RZ, and the connective tissue in the CZ has become denser. Day 7: the regenerating muscle cells extend out of the old basal lamina cylinders into the CZ and begin to pierce through the scar. Day 14: the scar of the CZ has further condensed and reduced in size, and the regenerating myofibers close the CZ gap. Day 21: the interlacing myofibers are virtually fused with little intervening connective tissue (scar) in between.
Figure 9. Capillary ingrowth to the injured skeletal muscle 5 days after a contusion injury treated by either mobilization (A) or immobilization (B). In the mobilized muscle (A), an intensive ingrowth of new capillaries from all borders of the surviving muscle surrounding the injury toward the nonvascularized center of the injury is seen, whereas in the immobilized muscle (B), the capillary ingrowth to the injured area is almost completely negligible and a large intramuscular hematoma is still visible (on the left side of the wound). Micro-angiograph; bar 300 μm.

Figure 10. A, numerous young, regenerating myotubes are seen in close connection with the capillaries in the regeneration zone of the skeletal muscle injury treated by mobilization 5 days after a contusion injury. B, only a few small myotubes as well as a few capillaries are found in the granulation tissue of the regenerating zone of the injured skeletal muscle when the muscle is treated by immobilization. Van Gieson hematoxylin counterstain. Bar 150 μm.
“In the group treated by five days of immobilisation before mobilisation (IM5-MO), connective tissue was almost totally resorbed during the eight-week follow-up period, and only scanty deposits of Types I and III collagen and fibronectin were observed in the thickened endomysial and perimysial structure of the injured area. However, in the group which had only two days’ immobilisation before mobilisation (IM2-MO), an area of fatty necrosis was seen in the centre of the injured area three weeks after trauma. Eight weeks after injury the deposition of connective tissue in the endomysial and perimysial structure of the injured area was still considerably greater when compared to Group IM5-MO.

A certain period of immobilisation, about five days for rat muscle, is required to allow newly-formed granulation tissue to cover the injured area and to have sufficient tensile strength to withstand subsequent mobilisation. This mobilisation, at the correct interval, seems essential for the quicker resorption of scar tissue and the better structural organisation of the muscle.”
Eleven athletes were assigned to a protocol consisting of static stretching, isolated progressive hamstring resistance exercise, and icing (STST group). Thirteen athletes were assigned to a program consisting of progressive agility and trunk stabilization exercises and icing (PATS group).

The average (±SD) time required to return to sports for athletes in the STST group was 37.4 ± 27.6 days, while the average time for athletes in the PATS group was 22.2 ± 8.3 days.

The average time from date of injury to date of program initiation was 3.4 days (range, 1-10 days) for the PATS group and 4.1 days (range, 2-10 days) for the STST group.

I use this study as an example of healing times but certainly would question the design of the STST group and thus the return to sport given what I think is a poorly designed program.

Loris Bertolacci
Although Sherry and Best have shown a promising clinical outcome, it remains unclear which neuromuscular factors are responsible for the reduced reinjury risk in the PATS group. One hypothesis is that improved neuromuscular control of the lumbopelvic region allows the hamstrings to function at safe lengths and loads during athletic movement, thereby reducing injury risk.

An alternative explanation is that the use of early sub-maximal loading limits the residual adverse effects of scar tissue formed early in the remodeling process.

Figure 1. Sherry and Best (11) compared the effectiveness of two rehabilitation programs in reducing reinjury rates in athletes who sustained an acute hamstring strain. A SS group (N = 11) performed static stretching, isolated progressive hamstring strengthening, and graduated return to activity. A PATS group (N = 13) performed agility exercises beginning with movements primarily in the frontal and transverse planes, then progressing to movements in the sagittal plane. Exercises requiring muscle activity to maintain the spine and pelvis in a desired posture (bridges) were also performed. For each rehabilitation program, athletes progressed from phase 1 to phase 2 when they could walk with a normal gait pattern and do a high-knee march in place without pain. Compared with the SS group, there was a statistically significant reduction in injury recurrence in the PATS group at 2 wk and at 1 yr after return to sport. PATS indicates progressive agility and trunk stabilization; SS, stretching and strengthening.
Evidence based prevention of hamstring injuries in sport

J Petersen and P Hölmich


Phase I (acute): 1–7 days: The goal of this treatment is to control haemorrhaging and minimise inflammation and pain. Early motion exercise is theoretically important to prevent or decrease adhesion within the connective tissue.22 Active knee flexion and extension exercises could be performed during the treatment with ice. It is important that the exercises are pain free to prevent further injury during the rehabilitation.

Phase II (subacute): day 3 to .3 weeks: This phase begins when the signs of inflammation (swelling, heat, redness, and pain) begin to resolve. In this phase it is important to continue muscle action to prevent atrophy and promote healing. Regular concentric strength exercises can begin in this phase when the athlete has achieved full range of motion without pain.

Phase III (remodelling): 1–6 weeks: To avoid the hamstring muscle becoming less flexible after the injury, hamstring stretching can begin in the third phase. Eccentric strengthening can also begin in the third phase. Concentric exercise is begun before eccentric exercise because eccentric contraction causes greater force than concentric contraction. It is therefore important that the eccentric exercises are delayed until the injured muscle is well regenerated to avoid a rehabilitation induced reinjury.

Phase IV (functional): 2 weeks to 6 months: This is achieved by increasing hamstring strength and flexibility to the normal values for the individual athlete. Simultaneously pain-free running activities are increased from jogging at low intensity to running and finally sprinting. Return to competition before this time may result in recurrent or more severe injury.

Phase V (return to competition): 3 weeks to 6 months
Type of acute hamstring strain affects flexibility, strength, and time to return to pre-injury level

C Askling, T Saartok, A Thorstensson

Objectives: To investigate possible links between aetiology of acute, first time hamstring strains in sprinters and dancers and recovery of flexibility, strength, and function as well as time to return to pre-injury level.

Methods: Eighteen elite sprinters and 15 professional dancers with a clinically diagnosed hamstring strain were included. They were clinically examined and tested two, 10, 21, and 42 days after the acute injury. Range of motion in hip flexion and isometric strength in knee flexion were measured. Self estimated and actual time to return to pre-injury level were recorded. Hamstring reinjuries were recorded during a two year follow up period.

Results: All the sprinters sustained their injuries during high speed sprinting, whereas all the dancers were injured while performing slow stretching type exercises. The initial loss of flexibility and strength was greater in sprinters than in dancers (p<0.05). At 42 days after injury, both groups could perform more than 90% of the test values of the uninjured leg. However, the actual times to return to pre-injury level of performance were significantly longer (median 16 weeks (range 6–50) for the sprinters and 50 weeks (range 30–76) for the dancers). Three reinjuries were noted, all in sprinters.

Conclusion: There appears to be a link between the aetiologies of the two types of acute hamstring strain in sprinters and dancers and the time to return to pre-injury level. Initially, sprinters have more severe functional deficits but recover more quickly.
Already at 10 days after the injury, none of the subjects in any group needed crutches during walking, and flexibility and strength for the injured leg were back to 70–92% of the uninjured leg. After the initial six week period, both groups could perform, on average, more than 90% of the uninjured side in the flexibility and strength tests.

These results highlight the question of objective criteria based on tests versus the subjective feeling of aptitude and "security". It is evident that these two criteria do not correlate well here. A 90–95% level of test performance, as is often recommended as a return criterion in textbooks, did not make the athletes confident that they could return safely to full competition and performance.

Figure 4  Mean values (± 1SD) of knee flexion strength in the injured leg expressed as a percentage of the uninjured leg in the sprinters (n = 18) and dancers (n = 15) in the four tests (for absolute values see table 2). *Significantly less strength in the injured than the uninjured leg.

Figure 5  Relative number of subjects in each group plotted against the corresponding time, in weeks, to return to pre-injury level of performance (n = 18 for the sprinters and n = 13 for the dancers).
Diagnosis of an injury is critical in planning the possible progress and outcome rehabilitation of a soft tissue injury but is not the scope of this presentation.

There seems to be a wealth of evidence regards the merits of mobilization versus immobilization. Whilst every injury is different 5 days seems to be the limit for immobilization. (depending on the severity of injury of course).

Given correct diagnosis and proper initial rehabilitation and mobilization the more difficult issue is to regain full mobility, function, concentric and eccentric strength then full functional fitness. Given all the statistics with re-injury this remains the greatest challenge. That is not compromising all the steps in soft tissue rehabilitation and not returning a player to elite sport before every box has been ticked in sequence.

As in ACL rehabilitation where the graft seems to be maturing from 12 to 24 months in soft tissue rehabilitation is that at 6 to 8 weeks post-injury, the new collagen fibers can withstand near-normal stress which makes the large re-occurrence rate in AFL and makes the long time to return to sprinting more understandable given the huge eccentric forces.

But there is very little margin in elite team sports for time so every day of a rehabilitation has to be maximized to ensure successful rehabilitation but ensure almost optimal performance and reduce re-occurrence rates.
“In numerical terms, it is preferable to have the average hamstring strain in a football player return at 3 weeks with a 90% success rate (in the first match back) than for the average injury to take 8 weeks to recover with a 95% to 100% success rate”

BUT IS THIS SIMPLISTIC?
PERFORMANCE & RISK DILEMMAS?

ACL studies have shown that performance in hops and statistics often take up to 18 months to return to normal.

Thus whilst players can return early the other dilemma is whether they will play well after 2/3 weeks rehabilitation given that they may be only performing at 90/95% of their maximal power output and that the true test of an injury is maximal force when fatigued. Also if a good player re-occurs then that usually more than doubles rehab needs given loss of eccentric adaptation.

Thus given the fact that teams lose games due to many reasons (playing unfit players?) simply having a player on the ground at 95% and risk of injury is an interesting debate.
Eccentric Adaptation and Rehabilitation


Localization and quantification of muscle damage by magnetic resonance imaging following step exercise in young women.

Department of Sport Science, University of Aarhus, Aarhus, Denmark.

Eccentric exercise affects muscles differentially according to intensity, duration, and previous exposure to the specific exercise activity. We used T2-weighted magnetic resonance imaging sequences to localize and quantify muscle damage following step exercise and to determine correlations between transverse relaxation time (T2) and other markers of muscle damage. Eight women performed two-step exercise bouts (30 min) separated by 8 weeks. Blood samples, MR scans, measurements of muscle strength, and muscle soreness were obtained immediately before, after, and up to 9 days after each bout. Resting muscle T2 (40.3 +/- 0.6 ms) increased exclusively in m. Adductor magnus (AM) in the thigh performing eccentric contractions and peaked 3 days after bout 1 (73.5 +/- 9.7 ms, P<0.05). Plasma creatine kinase (CK) activity peaked on day 3 after bout 1 and correlated with T2 in AM (r=0.96, P<0.001). After bout 2 CK and T2 were almost unaffected. This indicates that T2-weighted MRI can be applied to identify muscles from which enzymes are being released into the circulation.


MR measurements of muscle damage and adaptation after eccentric exercise.

Department of Kinesiology, Michigan State University, East Lansing, Michigan 48824, USA.

The purposes of this study were, first, to clarify the long-term pattern of T2 relaxation times and muscle volume changes in human skeletal muscle after intense eccentric exercise and, second, to determine whether the T2 response exhibits an adaptation to repeated bouts. Six young adult men performed two bouts of eccentric biceps curls (5 sets of 10 at 110% of the 1-repetition concentric maximum) separated by 8 wk. Blood samples, soreness ratings, and T2-weighted axial fast spin-echo magnetic resonance images of the upper arm were obtained immediately before and after each bout; at 1, 2, 4, 7, 14, 21, and 56 days after bout 1; and at 2, 4, 7 and 14 days after bout 2. Resting muscle T2 [27.6 +/- 0.2 (SE) ms] increased immediately postexercise by 8 +/- 1 ms after both bouts. T2 peaked 7 days after bout 1 at 47 +/- 4 ms and remained elevated by 2.5 ms at 56 days. T2 peaked lower (37 +/- 4 ms) and earlier (2-4 days) after bout 2, suggesting an adaptation of the T2 response. Peak serum creatine kinase values, pain ratings, and flexor muscle swelling were also significantly lower after the second bout (P < 0.05). Total volume of the imaged arm region increased transiently after bout 1 but returned to preexercise values within 2 wk. The exercised flexor compartment swelled by over 40%, but after 2 wk it reverted to a volume 10% smaller than that before exercise and maintained this volume loss through 8 wk, consistent with partial or total destruction of a small subpopulation of muscle fibers.
Eccentric Adaptation and Rehabilitation


Attenuation of protective effect against eccentric exercise-induced muscle damage

School of Exercise, Biomedical and Health Sciences, Edith Cowan University, Joondalup, WA 6027, Australia.

A single bout of eccentric exercise confers a long-lasting protective effect against subsequent bouts of the same exercise. This study investigated how the protective effect was lessened when the interval between the initial and secondary exercise bouts was increased from 4 to 12 weeks. Thirty young men performed two bouts of 12 maximal eccentric actions of the elbow flexors of the nondominant arm separated by either 4 (n = 9), 8 (n = 10), or 12 (n = 11) weeks. Maximal isometric strength, flexed and relaxed elbow joint angles, range of motion, upper arm circumference, muscle soreness, plasma creatine kinase (CK), and myoglobin (Mb) were measured before, immediately after, and for 4 days after exercise. Changes in criterion measures were compared between bouts for each group and among groups by two-way repeated-measures ANOVA. There were no significant differences among groups in the changes in all measures following the first bout. Significantly (p < 0.05) smaller responses in all measures were observed after the second bout as compared with first bout for the 4 and 8 weeks, but only in strength, muscle soreness, CK, and Mb for the 12 weeks. It was concluded that some aspects of the protective effect were attenuated after 8 weeks, and the factors responsible for the effect vary among the measures.


Repeated Bout Effect after Maximal Eccentric Exercise.

School of Human Sciences, St Mary’s College, Twickenham, United Kingdom.

We hypothesized that a bout of high or low volume eccentric exercise would protect against muscle damage following a subsequent high volume bout and that adaptation would be attributable to neural changes, independent of the initial exercise volume. Sixteen males performed either 45 (ECC45) or 10 (ECC10) maximal eccentric contractions using the elbow flexors, followed by an ECC45 bout 2 weeks later. Damage markers were measured for the following 96 h; EMG and work done during the first 10 eccentric contractions were also recorded. CK, soreness, and decrements in MVC and range of motion (ROM) were greater in bout 1 than bout 2 (p < 0.01). Soreness, MVC and ROM were greater after the initial ECC45 bout compared to the initial ECC10 bout and the repeated bouts of ECC45 exercise in both groups (p < 0.01). Median frequency decreased from bout 1 to bout 2 (p < 0.001), no differences between groups were observed. An ECC45 bout of maximal eccentric exercise causes more initial damage than an ECC10 bout of maximal eccentric exercise, although both confer protection from subsequent ECC45 bouts of maximal eccentric contractions, which are attributable, at least in part, to a shift in the frequency content of EMG.
Eccentric Adaptation and its relationship to Rehabilitation.

- **Study 1 & 2:** Takes at least 3 days but up to 7 days to recover from Eccentric Exercise.

- **Study 3:** After 8 weeks Eccentric Adaptation seems to be lost which is why one needs to avoid re-occurrence.

- **Study 4:** Given protection can result from sub maximal eccentric contractions this must be taken into account in a rehabilitation setting for muscle injury.
SUMMARY

To maximize return to play after soft tissue injury and reduce re-occurrence a number of factors seem critical:

- Correct diagnosis. (Not the scope of this presentation).
- Accurate and safe commencement of mobilisation.
- Correct sequence of rehabilitation not compromising any steps. Thus to go through all steps and minimize “time on sidelines” accurate commencement of a rehab process is critical. Too soon is fatal and too long increases “time on sidelines” without justification.
- Accurate assessment of return to play after steps completed.
- Recovery from testing protocol and rehabilitation prior to game. IE Testing at 100% 48/72 hours prior to a game leaves a player in an adaptive and at risk situation.
- Risk benefit ratios.