Hamstring muscle strain injuries: what can we learn from history?

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Hamstring muscle strain injuries remain one of the most challenging issues facing sports medicine.[1] Over the past 100 years, there has been a gradual evolution in our understanding and management of hamstring injuries, but the challenge of optimising the management of the acutely injured hamstring remains. In recent years, increasingly high-quality studies have addressed the aetiology, risk factors and management of hamstring strains.[2–6] Paradoxically, many popular treatment options have little evidence and remain controversial.[7–10] The history of hamstring injury management is characterised as a longstanding dissociation between popular clinical techniques and a limited evidence base. Taking a historical perspective on the management of hamstring muscle strains, this study aims to place the current management strategies in a temporal perspective.

> *"Those who cannot remember the past are condemned to repeat it". George Santayana, Philosopher, 1863 to 1952*

By the mid-18th century, the importance of exercise for health was established, and the physical demands of different forms of exercise were recognised, in a manner not dissimilar to descriptions 200 years later.[11 12] By the start of the 20th century, the Olympics had been re-invented, sport and exercise were recognised as a means of developing character[13] and maintaining health in a world experiencing an explosion in leisure time.[14–16] Given the limitations of the training methodology of the time,[17] it is possible that muscle strains were a common finding, but there is limited epidemiological literature available from the time.

> *"In football we find injuries occur in a poorly conditioned, a fatigued or dazed man, or in a team that is demoralised and receiving a severe beating. These individuals are slowing up, not coordinating, and are apt to be injured."*[18]

Already in 1902, muscle injuries were recognised as occurring in sedentary individuals and those athletes lacking adequate preparation and warm-up.[19] While these assertions appear to have stood the test of time, with modern, professional, well-trained athletes routinely have hamstring injuries, it is now recognised that this is a dramatic oversimplification of the aetiological processes.[2–6] Muscle strains were recognised as occurring at either the musculo-tendinous or within the intramuscular components,[19] and there has been a gradual refinement of this understanding over the past 100 years. In 1966, Bass[20] distinguished between intramuscular (poor prognosis) and intermuscular (good prognosis) injuries. Forty years on, this theme has been readdressed, with further evidence that it is the specific location and pathoanatomical nature of the muscle injury that will determine prognosis, rather than simply symptom severity and injury size.[21–23] Also articulated in 1902 was the belief that *"only a cursory examination is necessary"* to diagnose a hamstring muscle strain[19] and despite evidence to the contrary, this remains a common misconception. Clinical evaluation has consistently been shown to have a high false positive rate when compared with MRI, even in those injuries clinically diagnosed as grade II muscle strain.[24 25] This clinical appearance of muscle strain injury, in the absence of confirmed local muscle pathology, remains a paradox today.

In 1906, management of muscle tears was typically conservative involving *"hold(ing) the limb under a cold water tap as long as you can bear it, and as often as is possible"*,[17] plaster immobilisation *"in the direction of the fibres of the muscle"*[13] (which remained popular until the 1950s,),[26] complete rest for 3 to 6 days,[13 17] followed by *"active work"*,[13] and the use of *"embrocations"* (massage creams).[17] Of note, even at this early stage in the understanding of the hamstring muscle injury, it was recognised that tearing of musculotendinous insertions from the bone requires a longer period of rehabilitation[13] and that surgery may occasionally be indicated for complete ruptures.[19] Over recent decades, the indications for surgical intervention have been further elucidated; surgical repair may provide superior outcomes for a completely ruptured proximal hamstring tendon.[27 28] By contrast, intramuscular injuries are typically treated conservatively and rupture of the distal hamstring tendons, in particular the semi-membranous and semitendinosus appear to be able to be satisfactorily managed conservatively.[29]

By the 1930s, there was an increased interest in, and understanding of the histopathology of acute muscle injuries.[30–32] Remarkable experiments compared physical, chemical, infective and pharmacological injury on rabbit skeletal muscle. These led to clear descriptions of the histological manifestations of acute muscle injury, initially described as *"acute molecular degeneration"*.[32] Additional studies involving contused rabbit muscles further characterised the histological transitions associated with muscle injury into haemorrhage, degeneration, white cell infiltration and proliferation.[30 31] There was infiltration of leucocytes and lymphocytes within 24 h, as well as the progressive damage after the initial insult. While not recognised at the time, these two processes appear related, as it has recently been illustrated that minimising the leucocyte activity at the site of acute muscle injury may limit muscle damage, and enhanced muscle regeneration.[33 34] This principle of reducing the acute inflammatory

phase of muscle injury is the basis for the use of simple anti-inflammatory tools such as ice, and the more controversial pharmaceutical anti-inflammatories.[35] Fishaback[31] also identified that "*muscle proliferation is started by the muscle nuclei set free by the breaking up of severely traumatised fibres*", likely reflecting the mobilisation of satellite cells, critical for the repair process and considered an index of muscle regeneration.[36] This is a remarkable insight into the process of muscle regeneration, identified but not fully understood for over half a century.

The year 1936 saw the clear articulation of the principle of approximating the torn ends of the muscle injury to enhance the healing process, and also the notion that premature disruption of this approximation may increase scarring.[37] Intramuscular scarring is now considered to be a poor prognostic indicator.[38]

> *"If the damaged area is subjected to repeated assault by muscular effort or other movement, stretching and tearing of the newly formed repair tissue take place and create a subacute or chronic process by producing a small plexus of fibrous tissue."*[37]

At the same time as the risks of re-injury from premature return were being articulated, Hitchcock[18] highlighted that pressures were being imposed upon athletes by coaches and others to return to sport prematurely, thereby increasing re-injury risk. Return to play decisions following hamstring injuries continue to vex physicians.[39–41]

It is true that coach and trainer still attempt to exert their influence by calling men yellow at times who claim to have been injured, or try to bring undue influence on the athletic physician to permit an excellent player to return to competition before he should.[18]

Despite being recognised at the time as both lacking consistent efficacy[42] and potentially having a negative impact on muscle regeneration,[43] corticosteroid injections for acute muscle injury were popular through the 1950s and 1960s.[20 42 44] In vitro studies have confirmed the negative long-term consequences of cortisone on muscle injury repair,[45] and as such, despite case series appearing to support its clinical efficacy, this technique remains controversial.[46 47]

> *"(cortisone will)…defer the onset and retarding the rate of muscle regeneration after a simple crushing injury, (but) does not change the course or eventual outcome…"*[43]

The year that Dr Roger Bannister broke the 4 min mile saw a paradigm shift in the management of muscle injury, characterised by an increased emphasis on the specific pathological processes involved determining the nature of the treatment.[26]

> *"Proper treatment of the actual injury must be predicated on a sound appreciation of the pathological changes that develop as a result of the injury."*[26]

Remarkably, by 1954, many of the principles and practices used in the management of muscle injuries today were already articulated (table 1).[26]

> *"…treatment must be designed to minimise the haemorrhage and inflammatory reaction so that there will be as little granulation (scar) tissue formed as possible…"*[26]

The imperative of controlling haemorrhage and inflammation to minimise scar tissue remains unchanged 60 years on. The theme of scar tissue minimisation has been resurrected in recent years, with the identification of numerous medications that may potentially assist in this task.[48–53] While their clinical utility remains to be delineated, 57 years on, this remains an exciting area of research.

Table 1 Management of acute muscle injuries: 1954[26]

Stage one: haemorrhage control
Rest/protection
Compression (24 h)
Water immersion or ice bags 30 to 60 min
Elevation
Re-evaluate at 24 h
Stage two: absorption of blood and exudate (following haemorrhage control)
Local heat (whirlpool bath, shortwave diathermy)
Massage (avoid stimulation of further bleeding)
Avoiding damaged area in the first 48 h
Never vigorous or painful, as this will prolong injury
Graduated exercises
Reduce swelling
Maintain tone and strength of the muscles
Maintenance of general fitness important

In contrast to these underlying principles which have generally withstood the test of time, Delarue[26] also recommended the use of combined intralesional hyaluronidase/local anaesthetic injections, in the management of acute muscle injuries. This modality appears well recognised at the time[26 54] but by the 1970s had lost popularity.[55] Hyaluronidase is an enzyme involved in the breakdown and inactivation of hyaluronic acid and was believed to be of benefit when used in the initial phase of muscle injury.[54] Intriguingly, the in vivo function of hyaluronic acid has recently been elucidated, with its synthesis up-regulated in areas of acute soft tissue injury and functioning to promote and modulate inflammation, as well as potentially minimising scar tissue development.[56] Thus, at least theoretically, minimising any hyaluronic acid excesses in the early phase of an acute soft tissue injury (thereby reducing inflammation) may be of some benefit, although paradoxically hyaluronic acid itself has been advocated for use in soft tissue injuries, with apparently good results.[57–59]

While core stability is now recognised as a critical component of hamstring rehabilitation and athletic performance,[60–62] the concept was first recognised as early as 1958. Writing after the VI British Empire and Commonwealth Games held in Cardiff the same year, Lloyd (1958)[42] recognised that hamstrings strains were one of the most common injuries observed, but also that the risk for all sports injuries may be minimised by an 'alerted posture'.

> *"Alerted posture' means alerting the prime fixer muscles so that quick movements can be carried out by activators and synergists acting on a frame already made firm by the prime fixers."*[42]

By the late 1960s, the use of 'enzymatic preparations' including trypsin, chymotrypsin, streptokinase and streptodornase had replaced hyaluronidase injections.[44 55] The use of oral enzyme preparations in the management of muscle injuries remains popular with some practitioners,[63 64] despite limited scientific evidence of any benefit.[8 10] Other medications such as Hirudoid (a heparinoid)[65] and muscle relaxants[20] were also popular at the time.

Non-steroidal anti-inflammatory drugs (NSAIDs) were first mentioned in the routine management of muscle strain injuries in the late 1960s[20 55 66] and their use has persisted in sports medicine.[67] While they may have a role in limited situations (eg, reducing the incidence of myositis ossificans following muscle contusion injuries), increasing in vitro evidence suggests that NSAIDs may impede regeneration and increase

fibrosis during muscle healing, and hence should be considered relatively contraindicated in muscle strain injuries.[35 68–70]

The 1970s and 1980s saw increasing attention being paid to physiotherapeutic means of rehabilitation. There remained a focus on minimising bleeding and inflammation while maximising regeneration, by the increasingly novel use of cooling, electrotherapy (which was clinically already being used in the latter 19th century),[71] manipulative techniques[72] and specific strengthening programmes.[55 73 74] Sports medicine had started to identify the role that muscular trigger points may play in muscle-related pain (recognised in muscles since the 1930s)[75] perhaps contributing to the false positive (MRI negative)[24 25] muscle injuries.[74] The use of invasive injection techniques such as Traumeel and Actovegin in the management of acute muscle injuries has been promoted in Europe for at least three decades,[63] but their use remains controversial and not established in mainstream sports medicine literature[76] – predominantly due to a lack of scientific evidence.[8] Their clinical use has, however, persisted and despite a lack of substantial evidence, has in recent years expanded beyond Western Europe.

The last two decades have seen an explosion in literature regarding the hamstring muscle strain, with increased understanding of the epidemiology, aetiology and pathophysiology.[2–6] Subtle refinement of techniques for minimising inflammation and maximising regeneration has evolved,[77 78] but many of the underlying principles of treatment have remained unchanged from the mid-20th century. Novel approaches to prevention and treatment continue to appear, but often lack an evidence base.[79] Blood injections have been recognised as potentially therapeutic in sports medicine for over 60 years,[80] and refinement of this in the form of autologous plasma preparations (platelet-rich plasma) has recently been popularised for muscle strain injuries. Currently, the evidence to support this remains limited from the basic science and clinical perspective[36 81–87] – in fact to date the published evidence is only slightly greater than that for the use of hyaluronidase injections, and possibly slightly less than the evidence for the use of corticosteroid injections in acute muscle injuries.

CONCLUSION

Hamstring muscle strains have been recognised as a significant injury for over 100 years. Remarkably, by the mid-20th century, the foundations for our current management strategies were well established. Furthermore, despite the remarkable advances of the past 30 years, we have made only incremental progress in our understanding and management of this complex injury.[1] The history of hamstring injury management is characterised by interventions which over time have failed to become established, typically without evidence ever being produced either for, or against their application. Most novel treatment interventions currently used continue to lack scientific validity; if we are to avoid repeating past mistakes, we must take up the challenge of obtaining high-quality data. To achieve this, we must challenge dogma that underpins 'usual care' and subject all elements of our management strategies to scientific scrutiny.

There is now evidence to use MRI to distinguish MRI-positive and MRI-negative injuries as these have a distinct prognoses and treatments. However, whether MRI or US aids in predicting of prognosis beyond this distinction remains to be determined. Minimising acute inflammation and optimising regeneration remain key goals in hamstring injury management; current techniques having changed little in 40 years and the medical manipulation of these pathophysiological processes warrants further clinical and laboratory research (eg, role of PRP). Finally, the development of scar tissue appears related to recurrent injuries and poor outcomes. Recently identified techniques for inhibition of growth factors involved in the development of scar tissue present an exciting development, but require further high-quality clinical trials in order to establish themselves in the standard management of muscle injuries.

To progress, we must encourage communication among (I) the proponents of published evidence-based, clinical guidelines, (II) those practitioners overtly working outside the recognised scientific evidence base and applying novel therapies based on their personal experience and (III) those researchers able to test novel hypotheses. Typically, these groups have not interacted, likely to the detriment of the profession and patients. We are at the start of the specialist era in Sports and Exercise Medicine, and maintaining status quo is unacceptable. For the credibility of all clinicians in the field of sports injury management, it is vital to accumulate appropriate evidence to progress from the scientific baseline established by our forbearers in the mid-20th century.

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REFERENCES

1. **Mendiguchia J**, Alentorn-Geli E, Brughelli M. Hamstring strain injuries: are we heading in the right direction? *Br J Sports Med* 2012;46:81-5.
2. **Verrall GM**, Slavotinek JP, Barnes PG, *et al.* Clinical risk factors for hamstring muscle strain injury: a prospective study with correlation of injury by magnetic resonance imaging. *Br J Sports Med* 2001;**35**:435–9; discussion 440.
3. **Arnason A**, Andersen TE, Holme I, *et al.* Prevention of hamstring strains in elite soccer: an intervention study. *Scand J Med Sci Sports* 2008;**18**:40–8.
4. **Arnason A**, Sigurdsson SB, Gudmundsson A, *et al.* Risk factors for injuries in football. *Am J Sports Med* 2004;**32**:5S–16S.
5. **Witvrouw E**, Danneels L, Asselman P, *et al.* Muscle flexibility as a risk factor for developing muscle injuries in male professional soccer players. A prospective study. *Am J Sports Med* 2003;**31**:41–6.
6. **Bennell K**, Wajswelner H, Lew P, *et al.* Isokinetic strength testing does not predict hamstring injury in Australian Rules footballers. *Br J Sports Med* 1998;**32**:309–14.
7. **Orchard J**, Best T, Hunter G, *et al.* Response to McCrory *et al*. 'Sports and exercise medicine – new specialists or snake oil salesmen?' *Br J Sports Med* Published Online First: 8 November 2011 doi:10.1136/bjsports-2011-090470.
8. **Orchard JW**, Best TM, Mueller-Wohlfahrt HW, *et al.* The early management of muscle strains in the elite athlete: best practice in a world with a limited evidence basis. *Br J Sports Med* 2008;**42**:158–9.
9. **Franklyn-Miller A**, Etherington J, McCrory P. Sports and exercise medicine–specialists or snake oil salesmen? *Br J Sports Med* 2011;**45**:83–4.
10. **Cook J**. Funky treatments in elite sports people; do they just buy rehabilitation time? *Br J Sports Med* 2010;44:221.
11. **Pugh J**. A Treatise on Muscular Action,1794. A W Lumsden, Loanhead, Midlothian, Scotland.
12. **Mitchell JH**, Haskell WL, Raven PB. Classification of sports. *Med Sci Sports Exerc* 1994;**26**:S242–5.
13. **Wilbur RL**. Personal experiences with football injuries. *Cal State J Med* 1906;**4**:170–2.
14. **Mitchell JK**, editor. *Mechanotherapy, Physical Education, Massage and Exercise*. First edition. London: Rebman Limited 1904.
15. **Roth M**. *Gymnastics*. Second edition. London: Thomas Harrild 1854.
16. **Sandow E**. *Life is Movement*. Portsmouth: Gale and Polden 1900.
17. **Andrews H**. *Training for Athletics and General Health*. First edition. London: C Arthur Pearson Limited 1904.
18. **Hitchcock HH**. Athletic injuries: discussion. *California and Western Medicine* 1936;**45**:262–3.
19. **Crowley DD**. Suturing of muscles and tendons. *Cal State J Med* 1902;**1**:48–54.
20. **Bass AL**. Rehabilitation after soft tissue injury. *Br J Sports Med* 1966:162–72.
21. **Askling CM**, Tengvar M, Saartok T, *et al.* Acute first-time hamstring strains during high-speed running: a longitudinal study including clinical and magnetic resonance imaging findings. *Am J Sports Med* 2007;**35**:197–206.
22. **Askling C**, Tengvar M, Saartok T, *et al.* Sports related hamstring strains–two cases with different etiologies and injury sites. *Scand J Med Sci Sports* 2000;**10**:304–7.

23. **Askling C**, Saartok T, Thorstensson A. Type of acute hamstring strain affects flexibility, strength, and time to return to pre-injury level. *Br J Sports Med* 2006;**40**:40–4.
24. **Verrall GM**, Slavotinek JP, Barnes PG, *et al.* Assessment of physical examination and magnetic resonance imaging findings of hamstring injury as predictors for recurrent injury. *J Orthop Sports Phys Ther* 2006;**36**:215–24.
25. **Schneider-Kolsky ME**, Hoving JL, Warren P, *et al.* A comparison between clinical assessment and magnetic resonance imaging of acute hamstring injuries. *Am J Sports Med* 2006;**34**:1008–15.
26. **Delarue NC**. The treatment of athletic injuries. *Can Med Assoc J* 1954;**70**:408–16.
27. **Cross MJ**, Vandersluis R, Wood D, *et al.* Surgical repair of chronic complete hamstring tendon rupture in the adult patient. *Am J Sports Med* 1998;**26**:785–8.
28. **Klingele KE**, Sallay PI. Surgical repair of complete proximal hamstring tendon rupture. *Am J Sports Med* 2002;**30**:742–7.
29. **Adejuwon A**, McCourt P, Hamilton B, *et al.* Distal semitendinosus tendon rupture: is there any benefit of surgical intervention? *Clin J Sport Med* 2009;**19**:502–4.
30. **Berg GO**. Athletic injuries: discussion. *California and Western Medicine* 1936;**45**:263.
31. **Fishback DK**, Fishback HR. Studies of experimental muscle degeneration: II. standard method of causation of degeneration, and repair of the injured muscle. *Am J Pathol* 1932;**8**:211–18.
32. **Fishback DK**, Fishback HR. Studies of experimental muscle degeneration: i. factors in the production of muscle degeneration. *Am J Pathol* 1932;**8**:193–210.
33. **Toumi H**, Best TM. The inflammatory response: friend or enemy for muscle injury? *Br J Sports Med* 2003;**37**:284–6.
34. **Toumi H**, F'guyer S, Best TM. The role of neutrophils in injury and repair following muscle stretch. *J Anat* 2006;**208**:459–70.
35. **Paoloni JA**, Milne C, Orchard J, *et al.* Non-steroidal anti-inflammatory drugs in sports medicine: guidelines for practical but sensible use. *Br J Sports Med* 2009;**43**:863–5.
36. **Hammond JW**, Hinton RY, Curl LA, *et al.* Use of autologous platelet-rich plasma to treat muscle strain injuries. *Am J Sports Med* 2009;**37**:1135–42.
37. **Thurber P**. Athletic Injuries. *Cal West Med* 1936;**45**:261–3.
38. **Silder A**, Heiderscheit BC, Thelen DG, *et al.* MR observations of long-term musculotendon remodeling following a hamstring strain injury. *Skeletal Radiol* 2008;**37**:1101–9.
39. **Matheson GO**, Shultz R, Bido J, *et al.* Return-to-play decisions: are they the team physician's responsibility? *Clin J Sport Med* 2011;**21**:25–30.
40. **Orchard J**, Best TM, Verrall GM. Return to play following muscle strains. *Clin J Sport Med* 2005;**15**:436–41.
41. **Orchard J**, Best TM. The management of muscle strain injuries: an early return versus the risk of recurrence. *Clin J Sport Med* 2002;**12**:3–5.
42. **Lloyd K**. Some hazards of athletic exercise. *Proc R Soc Med* 1959;**52**:151–7.
43. **Sissons HA**, Hadfield GJ. The effect of cortisone on the regeneration of skeletal muscle after injury. *J Bone Joint Surg Br* 1953;**35-B**:125–30.
44. **Phillips N**. Rehabilitation at a Professional Football Club. *Br J Sports Med* 1968;**3**:197–203.
45. **Beiner JM**, Jokl P, Cholewicki J, *et al.* The effect of anabolic steroids and corticosteroids on healing of muscle contusion injury. *Am J Sports Med* 1999;**27**:2–9.
46. **Levine WN**, Bergfeld JA, Tessendorf W, *et al.* Intramuscular corticosteroid injection for hamstring injuries. A 13-year experience in the National Football League. *Am J Sports Med* 2000;**28**:297–300.
47. **Stevens KJ**, Crain JM, Akizuki KH, *et al.* Imaging and ultrasound-guided steroid injection of internal oblique muscle strains in baseball pitchers. *Am J Sports Med* 2010;**38**:581–5.
48. **Bedair HS**, Karthikeyan T, Quintero A, *et al.* Angiotensin II receptor blockade administered after injury improves muscle regeneration and decreases fibrosis in normal skeletal muscle. *Am J Sports Med* 2008;**36**:1548–54.
49. **Huard J**, Li Y, Fu FH. Muscle injuries and repair: current trends in research. *J Bone Joint Surg Am* 2002;**84-A**:822–32.
50. **Chan YS**, Li Y, Foster W, *et al.* The use of suramin, an antifibrotic agent, to improve muscle recovery after strain injury. *Am J Sports Med* 2005;**33**:43–51.
51. **Chan YS**, Li Y, Foster W, *et al.* Antifibrotic effects of suramin in injured skeletal muscle after laceration. *J Appl Physiol* 2003;**95**:771–80.
52. **Negishi S**, Li Y, Usas A, *et al.* The effect of relaxin treatment on skeletal muscle injuries. *Am J Sports Med* 2005;**33**:1816–24.
53. **Fukushima K**, Badlani N, Usas A, *et al.* The use of an antifibrosis agent to improve muscle recovery after laceration. *Am J Sports Med* 2001;**29**:394–402.
54. **Gartland JJ**, MacAusland WR. Use of hyaluronidase in soft tissue injury and its influence on experimental bone repair. *Arch Surg* 1954;**68**:305–14.
55. **Merry PH**. The physio-therapeutic aramentarium in the treatment of sports injuries. *Br J Sports Med* 1970;**5**:100–5.
56. **Chen WY**, Abatangelo G. Functions of hyaluronan in wound repair. *Wound Repair Regen* 1999;**7**:79–89.
57. **Petrella RJ**, Cogliano A, Decaria J, *et al.* Management of Tennis Elbow with sodium hyaluronate periarticular injections. *Sports Med Arthrosc Rehabil Ther Technol* 2010;**2**:4.
58. **Petrella MJ**, Cogliano A, Petrella RJ. Original research: long-term efficacy and safety of periarticular hyaluronic acid in acute ankle sprain. *Phys Sportsmed* 2009;**37**:64–70.
59. **Petrella RJ**, Petrella MJ, Cogliano A. Periarticular hyaluronic acid in acute ankle sprain. *Clin J Sport Med* 2007;**17**:251–7.
60. **Hibbs AE**, Thompson KG, French D, *et al.* Optimizing performance by improving core stability and core strength. *Sports Med* 2008;**38**:995–1008.
61. **Sherry MA**, Best TM. A comparison of 2 rehabilitation programs in the treatment of acute hamstring strains. *J Orthop Sports Phys Ther* 2004;**34**:116–25.
62. **Leetun DT**, Ireland ML, Willson JD, *et al.* Core stability measures as risk factors for lower extremity injury in athletes. *Med Sci Sports Exerc* 2004;**36**:926–34.
63. **Muller-Wohlfahrt H**, Eder K, Schmidtlein O. *Diagnosis and Treatment of Muscle Strain and Muscle Fiber Rupture in Elite-Level Athletes*. Munich, Germany. Booklet 2006.
64. **Hartmann G**. A Physical therapy approach to management of grade I, II bicep femoris injury in elite athletes: presentation handout. In: *UK Athletics: Management of the Acute Hamstring Symposium*. London: Olympic Medical Institute 2006.
65. **McKechnie RL**. A trial to establish the efficacy of applications in athletic injuries specifically using hirudoid. *Br J Sports Med* 1972;**6**:119–20.
66. **Muckle DS**. A double-blind trial of ibuprofen and aspirin in the treatment of soft-tissue injuries sustained in professional football. *Br J Sports Med* 1980;**14**:46–7.
67. **Gerrard DF**. Renal abuse from non-steroidal, anti-inflammatory agents in sport. *N Z Med J* 1998;**111**:107–8.
68. **Reynolds JF**, Noakes TD, Schwellnus MP, *et al.* Non-steroidal anti-inflammatory drugs fail to enhance healing of acute hamstring injuries treated with physiotherapy. *S Afr Med J* 1995;**85**:517–22.
69. **Shen W**, Li Y, Tang Y, *et al.* NS-398, a cyclooxygenase-2-specific inhibitor, delays skeletal muscle healing by decreasing regeneration and promoting fibrosis. *Am J Pathol* 2005;**167**:1105–17.
70. **Shen W**, Prisk V, Li Y, *et al.* Inhibited skeletal muscle healing in cyclooxygenase-2 gene-deficient mice: the role of PGE2 and PGF2alpha. *J Appl Physiol* 2006;**101**:1215–21.
71. **Jacoby GW**. *Electrotherapy*. First edition. London: Rebman Limited 1901.
72. **Cibulka MT**, Rose SJ, Delitto A, *et al.* Hamstring muscle strain treated by mobilizing the sacroiliac joint. *Phys Ther* 1986;**66**:1220–3.
73. **Wise DD**. Physiotherapeutic treatment of athletic injuries to the muscle–tendon complex of the leg. *Can Med Assoc J* 1977;**117**:635–9.
74. **Halvorson GA**. Sports medicine – muscular strain. *The West J Med* 1986;**144**:734–5.
75. **Kellgren JH**. A Preliminary account of referred pains arising from muscle. *Br Med J* 1938;**1**:325–8.
76. **Wright-Carpenter T**, Klein P, Schäferhoff P, *et al.* Treatment of muscle injuries by local administration of autologous conditioned serum: a pilot study on sportsmen with muscle strains. *Int J Sports Med* 2004;**25**:588–93.
77. **Croisier JL**, Ganteaume S, Binet J, *et al.* Strength imbalances and prevention of hamstring injury in professional soccer players: a prospective study. *Am J Sports Med* 2008;**36**:1469–75.
78. **Croisier JL**, Forthomme B, Namurois MH, *et al.* Hamstring muscle strain recurrence and strength performance disorders. *Am J Sports Med* 2002;**30**:199–203.
79. **Szalai K**, Illy A. Sacral epidural steroid injections used for the prevention of hamstring injuries. *Phys Educ Sport* 2005;**3**:37–44.
80. **Heald GB**. *Injuries in Sport: A General Guide for the Practitioner*. First edition. London: Oxford University Press 1931.
81. **Karli D**, Robinson B. Platelet rich plasma for hamstring tears. *Practical Pain Management* 2010;**10**:10–14.
82. **Sánchez M**, Anitua E, Orive G, *et al.* Platelet-rich therapies in the treatment of orthopaedic sport injuries. *Sports Med* 2009;**39**:345–54.
83. **Sanchez A**, Anitua E, Andi I. Application of Autologous Growth Factors on Skeletal Muscle Healing (oral presentation). Presented at the 2nd World Congress on Regenerative Medicine Conference, Leipzig, Germany. May 18-20, 2005, Oral Presentation.
84. **Creaney L**. Platelet-rich plasma and the biological complexity of tissue regeneration. *Br J Sports Med* 2011;**45**:611.
85. **Creaney L**, Hamilton B. Growth factor delivery methods in the management of sports injuries: the state of play. *Br J Sports Med* 2008;**42**:314–20.
86. **Hamilton B**, Knez W, Eirale C, *et al.* Platelet enriched plasma for acute muscle injury. *Acta Orthop Belg* 2010;**76**:443–8.
87. **Hamilton BH**, Best TM. Platelet-enriched plasma and muscle strain injuries: challenges imposed by the burden of proof. *Clin J Sport Med* 2011;**21**:31–6.