Clinical predictors of time to return to competition and of recurrence following hamstring strain in elite Australian footballers

Price Warren[1], Belinda J Gabbe[2], Michal Schneider-Kolsky[3], Kim L Bennell[1]

1. Centre for Health, Exercise and Sports Medicine, School of Physiotherapy, University of Melbourne, Melbourne, Australia

2. Department of Epidemiology and Preventive Medicine, Monash University, Melbourne, Australia

3. Department of Medical Imaging and Radiation Sciences, Faculty of Medicine, Nursing and Health Sciences, Monash University, Melbourne, Australia

What is already known on this topic

Past history of a hamstring strain and having a lateral hamstring strain are predictors available in the early clinical assessment that appear to relate to greater time to return to competition. Apart from imaging, few studies have evaluated the accuracy of early clinical assessment findings as predictors of time to return to competition and recurrence

What this study adds

This study demonstrates that in elite Australian football several clinically obtainable parameters in the post-acute setting following a hamstring strain contribute to the prediction of the expected time to return to play and to the likelihood of suffering a recurrence. Past history of hamstring strain and being unable to walk at normal pace pain free within 24 hours of injury were independent predictors of being unable to return to play in less than 4

weeks from the time of injury. All players with medial hamstring strains returned to play successfully and did not suffer a re-injury. The use of NSAID's in the post acute period may influence both time taken to return to play and risk of recurrence. Past history was the sole independent predictor of suffering a recurrence upon returning to play.

ABSTRACT

Objective: To investigate early clinical predictors of time to return to competition and of recurrence following hamstring strain

Design: Prospective observational study

Setting: Elite level of Australian Football competition

Participants: 59 players who suffered a hamstring strain in 2002 season

Predictors: Clinical assessment by a physiotherapist and questionnaire

Main outcome measures: Time taken to return to play and recurrence of hamstring injury within 3 weeks.

Results: Players taking more than one day to walk pain-free were significantly more likely p=0.018) to take longer than three weeks to return to competition (AOR 4.0; 95% CI 1.3, 12.6. Nine players (15.2%) experienced an injury recurrence, all involving the biceps femoris. Recurrence was more likely in players who reported a hamstring injury in the past 12 months (AOR 19.6; 95% CI: 1.5, 261.0; p=0.025).

Conclusion: Time to walk pain-free and previous hamstring injury are predictors of time to return to competition and recurrence, respectively, and should be included in a clinical assessment to aid in prognosis.

INTRODUCTION

Hamstring muscle strains are common in sports which place high demands on running speed and power such as soccer [1, 2] and athletics.[3] They are also common in Australian football, a game that involves frequent periods of explosive and high intensity sprinting, extended periods of sustained running, heavy physical clashes, and a combination of running and kicking.[4]

In the Australian Football League (AFL), the elite level of competition, hamstring strains are the most common injury, resulting in the greatest number of lost playing days.[4] The recurrence rates for hamstring strain are also high. Greater than 30% of hamstring strains in the AFL recur within the season, despite concentrated rehabilitation and prevention efforts.[4] Returning players are particularly at risk of re-injuring their hamstring during the first three weeks back from injury.[4]

In the initial stages of treatment of a player with a hamstring strain, clinicians are often questioned about the likely prognosis. Theoretically, the results of an early clinical examination together with other relevant information from the subjective assessment should enable the clinician to predict the expected time to return to competition and whether the injury is likely to recur. Limited evidence suggests that greater reported pain at the time of injury,[5] strains in the biceps femoris component [6] and strains sustained via slow sustained stretching rather than explosive activity [7] are associated with the time taken to return to play. However, few studies have evaluated the accuracy of early clinical assessment findings as predictors of time to return to competition and recurrence. Therefore, the aim of this study was to assess whether clinical assessment findings could predict the

time taken to return to competition, and a successful return to play as evidenced by a lack of recurrence, following hamstring injury in elite Australian football players.

METHODS

Participants

Players from the 10 Victorian based AFL clubs who sustained a hamstring strain as clinically diagnosed by club medical personnel during the 2002 season and missed at least one match were invited to participate (n= 59). The criteria for diagnosis of a hamstring muscle strain were: acute onset of posterior thigh pain, palpable hamstring muscle tenderness; reproduction of the pain on hamstring stretch and; reproduction of pain by resisted contraction of the hamstrings. Players were excluded from the study if they: were unavailable for clinical testing within three days of injury onset; sustained a hamstring injury within six weeks of the end of their playing season as this would preclude adequate return to play follow-up; or had clinical signs and symptoms suggestive of a diagnosis other than a hamstring strain. The study was approved by the Human Research Ethics Committee of The Alfred Hospital. Written informed consent was obtained for all participants.

Procedure

Questionnaire

Demographic information, functional progression (including time taken to walk and ascend stairs pain-free), use of anti-inflammatory medication (NSAID's), mechanism and timing of injury and past history of hamstring injury in the previous 12 months were obtained by questionnaire.

Clinical assessment

The clinical assessment consisted of five tests assessing hamstring flexibility, neural mobility, pain provocation and site of the injury. All assessments were completed by one of two experienced sports physiotherapists. The order of testing was standardised and the non-injured leg was measured first for each test. The tests selected were commonly used clinically,[8] referenced in the literature [9-11] and reliable.[8, 12, 13]

The passive straight leg raise (PSLR) test provides an indication of hamstring muscle length [14] with the knee in full extension. A bubble inclinometer (Fabrication Enterprises.Inc., New York, USA) was placed on the anterior tibial border 15cm below the tibial tuberosity. At the first point of reported stretch or discomfort/pain in the hamstring, the angle between the leg and the horizontal was recorded. The value used was the difference between the injured leg compared to the non-injured leg. This test was repeated and the average of the two measurements was recorded. The test was considered positive if there was pain provocation and a >10°deficit in the injured leg compared with the uninjured leg.

The active knee extension (AKE) test is another measure of hamstring muscle length taken in a position of 90°hip flexion. The reliability of the test has been established by Gabbe et.al. [13] and the method described by these authors was used for the current study. For this test, the hip was maintained in 90°hip flexion by a specially constructed frame. At the point of maximal active knee extension (or onset of pain), the angle between the vertical and the tibia was recorded by an inclinometer as per the PSLR test. The value used was the difference between the injured leg compared to the non-injured leg. The test was repeated and the average of the two measurements was recorded. The test was considered positive if

6

there was pain provocation and a >10°deficit in the injured leg compared with the uninjured leg.

The active slump test assesses pain-sensitive neuromeningeal structures that have been suggested as a potential source of pain in the posterior thigh in hamstring injuries.[15-18] In the sitting position the player was instructed to clasp his hands behind his back, to tuck his chin onto his chest and to slump, bringing his shoulders towards his hips with full cervical, thoracic and lumbar flexion. Next, full active dorsiflexion of the foot of the injured leg was requested and the player asked to actively extend his knee until he felt a stretch or hamstring pain. The player was then asked to extend his neck to a neutral position and describe the change in sensation that occurred in the hamstring. The test was considered positive if the player's original hamstring pain was decreased and then reproduced with cervical flexion.

A test of pain provocation evaluated whether the hamstring pain could be elicited by isometric contraction of the hamstring muscles. This was performed in prone lying with approximately 15 degrees knee flexion. The examiner also palpated the hamstrings in prone lying to locate the region (medial or lateral hamstrings) relating to the player's pain.

Outcome Measures

Time to return to competition in days from the initial injury to the time of the first match back from injury was recorded. The decision to return to competition was made by the club medical team who had no knowledge of the results of the measurements included in this study. The data were categorized into taking 3 weeks or less to return to play or taking more than 3 weeks to return to play.

A hamstring injury was considered a recurrence if the player reported pain in the same hamstring muscle compartment in the same leg which fulfilled the same criteria for a hamstring injury within three weeks of returning to play. Given that the majority of re-injuries in the AFL occur during the first three weeks,[19] completing three matches without recurrence was considered a successful return from injury.

Data Management and Analysis

Data were analyzed using SPSS (version 11.5) (Chicago, USA). Height and weight were included as continuous variables. A number of variables were categorised for analysis to aid in interpretation. The outcomes of interest were time to return to play ($\leq$ 3 weeks, >3 weeks) and recurrence of injury within three weeks (no, yes). Univariate associations between the potential predictors and outcomes were assessed using chi-square or Fisher exact tests for categorical variables, and independent t-tests or their non-parametric equivalents for continuous variables. Backward, step-wise logistic regression analyses were used to identify independent predictors of time to return to competition and hamstring injury recurrence. Variables demonstrating a p-value less than 0.20 on univariate testing were included in the multivariate models. Adjusted odds ratios (AOR) and 95% confidence intervals (CI) of the odds ratios were calculated.

RESULTS

Characteristics of the study cohort

The cohort of 59 players represented 95% of Melbourne based AFL players who sustained a hamstring injury resulting in at least one missed game during 2002.[20] The median (range)

time from injury until examination was 2 (0-3) days. The mean (range) age of the players was 24 (17-33) years while the mean (range) height and weight was 186 (174-200) cm and 88 (74-107) kg, respectively. Twelve (20%) players reported that they had sustained a hamstring injury during the previous season.

The majority of the hamstring injuries occurred during competition (63%). Forty-one players (69%) reported a running-related mechanism for their hamstring injury. Forty two (72%) injuries involved the biceps femoris muscle. Eighteen (31%) players (14 with biceps femoris injury and 5 with medial hamstring injury) were taking NSAID's in the first three days following their hamstring strain with the ratio of medial and lateral hamstring strains similar (29% and 31% respectively); nine of these (50%) were taking them at the time of injury, suggesting that nine players were specifically prescribed NSAID's for the initial post-injury period. Forty-one players (69%) took longer than 24 hours until they were able to walk at normal pace pain free, while 46 (78%) took longer than 24 hours until they were able to ascend stairs at normal pace without pain.

The time taken to return to competition ranged from one to 8 weeks with a median of 26 days. Twenty-six players (44%) returned to competition within three weeks. Only two players took longer than six weeks to return to competition, one taking seven and the other eight weeks. Nine players (15%) experienced a recurrence of their hamstring injury within the first three weeks of returning to play. Six of these (66%) had a recurrence in the first week of returning to competition, with two in the second week and one in the third. In all cases, players were unable to participate in at least three games (range 3-7 games) following their recurrence.

Predictors of time to return to competition following hamstring injury

On univariate testing (Table 1), only time to walk pain-free was significantly associated with time to return to competition. There was no association between height, weight and age and time to return to competition following hamstring injury.

Table 1: Univariate results of the association between the variables and taking greater than 3 weeks to return to competition

Variable		n	% of players within each strata of predictor variable	RR [95% CI]	p-value
Time to walk pain-free	*≤ 1 day (reference)*	*30*	*30.0*	-	
	> 1 day	*29*	*58.6*	*2.0 [1.0, 3.7]*	*0.027*
Time to ascend stairs pain-free	*≤ 1 day(reference)*	*24*	*29.2*	-	
	> 1 day	*35*	*54.3*	*1.9 [0.9, 3.7]*	*0.056*
Past history (within 12 months) of a hamstring injury	*No (reference)*	*47*	*38.3*	-	
	Yes	*12*	*66.7*	*1.7 [1.0, 3.0]*	*0.077*
Hamstring region injured	*Medial (reference)*	*17*	*29.4*	-	
	Lateral	*42*	*50.0*	*1.7 [0.8, 3.8]*	*0.149*
Slump test	Negative(reference)	38	50.0	-	
	Positive	21	33.3	0.7 [0.4, 1.3]	0.217
Active Knee Extension test	Negative(reference)	47	40.4	-	
	Positive	12	58.3	1.4 [0.8, 2.6]	0.265
Taking Non-Steroidal Anti-Inflammatories in	No (reference)	41	48.18	-	

the first 3 days	Yes	18	33.3	0.7 [0.3, 1.4]	0.271
Mechanism of injury	Running (reference)	40	47.5	-	
	Non running	19	36.8	0.8 [0.4, 1.5]	0.441
Pain provocation test	Negative(reference)	16	43.7	-	
	Positive	43	44.2	1.0 [0.5, 1.9]	0.976
Passive Straight Leg Raise test	Negative(reference)	49	44.9	-	
	Positive	10	40.0	0.9 [0.4, 2.0]	0.999

N.B. Significant variables are shown in italics.

Time to walk pain-free, a history of hamstring strain in the previous 12 months, the region of the hamstrings injured and the time taken to ascend stairs pain-free met the criterion for inclusion in a multivariate model. Players who reported taking more than one day to walk pain-free following injury were significantly more likely (AOR 4.0; 95% CI 1.3, 12.6) to take longer than three weeks to return to competition compared to those walking pain-free within one day (p=0.018). Players with a previous history of hamstring injury were also at elevated risk of a delayed return to competition (AOR 4.2; 95% CI: 1.0, 18.0) but this just failed to reach significance (Table 2). All other variables were eliminated by the step-wise procedure.

Table 2   Independent predictors of return to competition more than 3 weeks following injury

Variable		n	AOR (95% CI)	p-value
Time to walk pain-free	≤ 1 day (reference)	30	-	

following injury	> 1 day	29	4.0 (1.3, 12.6)	0.018
Past hamstring injury within 12 months	No (reference)	47	-	
	Yes	12	4.2 (1.0, 18.0)	0.050
Hamstring region injured	Medial (reference)	17	-	
	Lateral	42	2.3 (0.6, 8.6)	0.217
Time to ascend stairs pain-free	≤ 1 day (reference)	24	-	
	> 1 day	35	1.2 (0.2, 9.2)	0.879

Risk factors for a recurrence of hamstring injury

All players with medial hamstring strains (n=17) returned to play successfully and did not experience a recurrence in the first 3 weeks. Thus, analysis of the predictors for recurrence was restricted to lateral hamstring strain cases only (n=42). Nine (21%) players with a lateral hamstring strain sustained a recurrence within the first three weeks of returning to play.

The univariate results are shown in Table 3. A history of hamstring strain in the previous 12 months was associated with injury recurrence while the presence of an AKE deficit of greater than 10° just failed to reach statistical significance. Time to walk pain-free, taking NSAID's, PSLR test, pain provocation test, time to ascend stairs pain-free, slump test, mechanism of injury, age, height and weight were not univariately associated with hamstring injury recurrence.

Table 3: Univariate results of the association between the variables and the recurrence

of hamstring injury

Variable		n	% of players within each strata of predictor variable	RR (95% CI)	p-value
Past history (within 12 months) of a hamstring injury	*No (reference)*	*34*	*11.8*	-	
	Yes	*8*	*62.5*	*5.3 (1.8, 15.4)*	*0.006*
Active Knee Extension test	Negative(reference)	34	14.7	-	
	Positive	8	50.0	3.4 (1.2, 9.9)	0.050
Time to walk pain-free following injury	≤ 1 day (reference)	23	30.4	-	
	> 1 day	19	10.5	2.9 (0.7, 12.3)	0.149
Taking non-steroidal anti-inflammatory drugs in first 3 days	No (reference)	29	10.3	-	
	Yes	13	46.2	4.5 (1.3, 15.1)	0.160
Passive Straight Leg Raise test	Negative*(reference)*	35	20.0	-	
	Positive	7	28.5	1.4 (0.4, 5.5)	0.631
Pain provocation test	Negative*(reference)*	9	88.9	-	
	Positive	33	75.7	0.8 (0.6, 1.1)	0.655
Time to ascend stairs pain-free	≤ 1 day *(reference)*	28	25.0	-	
	> 1 day	14	14.3	1.8 (0.4, 7.3)	0.692
Slump test	Negative*(reference)*	28	25.0	-	
	Positive	14	14.3	0.6 (0.1, 2.4)	0.692
Injury mechanism	Non-Running *(reference)*	11	18.2	-	
	Running	21	22.5	0.8 (0.2, 3.3)	0.999

A past history of hamstring strain, time to walk pain-free, use of NSAIDs in the first three days and the presence of an AKE deficit were included in the multivariate model. Players who reported sustaining a hamstring injury in the previous season were more likely (AOR 19.6; 95% CI: 1.5, 261.1) to experience a recurrence within 3 weeks of return to competition than those without a previous history (Table 4). The remaining variables were not significant independent predictors of recurrence.

Table 4   Independent predictors of recurrence of a lateral hamstring injury within 3 weeks of return to competition

Variable		n	RR 95% CI	p-value
Past history of a hamstring injury	No (reference)	34	-	
	Yes	8	19.5 [1.5, 261.1]	0.025
Time to walk pain-free following injury	≤ 1 day (reference)	23		
	> 1 day	19	6.3 [0.4, 98.6]	0.188
Active Knee Extension test	No deficit (reference)	35		
	>10° deficit	8	6.4 [0.7, 62.8]	0.109
Taking non-steroidal anti-inflammatory drugs in first 3 days following injury	No (reference)	29		
	Yes	13	5.4 [0.7, 44.0]	0.110

DISCUSSION

14

This study examined simple clinical assessment findings and player characteristics to identify early clinical predictors of time to return to competition and early recurrence following hamstring injury in elite male Australian footballers. Time to walk pain-free and a past history of hamstring injury were significant independent predictors of time to return to competition, and early recurrence of hamstring injury, respectively. Combined with the finding that no medial hamstring strain recurred, the findings of this study provide useful prognostic information for clinicians actively involved in the treatment of hamstring injuries.

The time taken to walk pain-free post injury is a simple prognostic indicator for clinicians and players. A player taking longer than 24 hours to achieve pain-free walking was four times more likely to need more than 3 weeks to return to competition compared to players walking pain-free within 24 hours of injury. It is likely that this parameter provides an indicator of injury severity, justifying its inclusion in hamstring injury grading systems.[21] Using the regression co-efficients from the multivariate model, an inability to walk pain-free within one day combined with a past history of hamstring injury resulted in a 93% chance of taking longer than three weeks to return. This important information can be conveyed to the coach and player in the post-acute stage.

Other known predictors for hamstring injury were not associated with time to return to play or recurrence of injury except for a past history of hamstring injury. A past history of hamstring injury is well established as a predictor of future hamstring injury [4, 5] and our study confirms its importance as a predictor of short term recurrence, highlighting the need for primary prevention. No association was found between lateral strains and taking more

15

than three weeks to return to competition. This contrasts to imaging studies involving Australian Football players where biceps femoris strains take longer to return to play.[5, 6, 22]. This contrast may be due to the sample size in this study where only the strongest predictors of outcome were able to be identified.

Fifteen percent of the players experienced a recurrence of their hamstring injury within the first three weeks of returning to play with the majority of these occurring in the first match, which is consistent with previous reports of hamstring injury recurrence rate in the AFL.[19] All medial hamstring strains returned to competition without re-injury, providing a useful clinical prognostic indicator. This may be due to the relatively reduced stretching forces on the semitendinosis and semimembranosis during what appears to be the critical late swing phase of sprinting.[23] A history of hamstring injury in the previous 12 months was a significant predictor of hamstring recurrence. This may be due to any combination of inadequate rehabilitation, the effects of ongoing pathology, healing and scar formation [6] or due to previously injured muscle being more susceptible to eccentric damage than uninjured muscle,[24] possibly contributed to by altered hamstring firing patterns.[18, 25, 26] Given that lateral hamstring strains and those with a past history are more likely to recur, the presence of these factors should dictate that a thorough rehabilitation be carried out in order to reduce the possibility of recurrence in the first three weeks of returning to competition. It may also be debated as to whether the return to play should be delayed in these players to facilitate greater healing of the injured muscle.

In recent years MRI and ultrasound imaging are often used in conjunction with clinical assessment to diagnose and predict the severity of hamstring strains in elite level Australian football players,[6, 22, 27] MRI parameters of the longitudinal length,[6, 22] and the cross-

sectional area of the injury [27] show good correlation with injury severity. Several studies found that MRI negative hamstring strains have a significantly faster rehabilitation time compared with MRI positive strains and are less likely to recur.[6, 27, 28] In the only study [29] comparing the clinical and radiological estimation of the duration of rehabilitation of an acute hamstring strain in elite footballers, the clinical examination was moderately more accurate than that of MRI. As return to play is a risk management decision,[30] the factors revealed in the present study should be further highlighted in the risk management equation about the best time to return to play.

Taking NSAID's in the first few days following a hamstring strain was the only alterable parameter in the post-acute assessment and, although not significant in this study, may be an influence in both the time taken to return to play and risk of recurrence. Despite NSAID's being recommended immediately following a muscle strain [31-33], their current use in AFL football appears to be a decision based on clinical experience. Thirty-one percent of players were taking NSAID's in the days following their hamstring strain (similar ratio of medial and lateral hamstring strains) with nine of these specifically prescribed NSAID's for the initial post-injury period. There may be merit in delaying NSAID's for a few days following hamstring injury as their earlier use may interfere with the chemotaxis of cells which is necessary for the repair and remodeling of regenerating muscle [32]. Alternatively, it might also be argued that by limiting pain and inflammation, other changes predisposing to injury at new sites such as inflammation-induced atrophy and/or pain inhibition are reduced, allowing rehabilitation to proceed at a faster rate.

The strengths of this study were its high capture of injured athletes (95% of all eligible cases), its prospective nature and the rigorous assessment methodology used. Nevertheless,

there are a number of limitations that warrant mention. Firstly, the study population was restricted to elite Australian football players. Whether the results can be extrapolated to other levels of Australian football participation or other sporting populations where hamstring injuries are prevalent cannot be ascertained but requires further study. Another limitation was that the decision of when to return to play was left up to the discretion of the medical personnel and it is possible that they were more conservative if the player had a past history of hamstring strain.

While the cohort number for a study of hamstring injuries was relatively large compared to previously published studies,[15, 34-37] the study was insufficient to identify all but the largest effects, particularly for modeling predictors of recurrence. A larger study could better examine the association between clinical assessments and outcome for variables with small to moderate effects. Nevertheless, the present study did identify useful clinical prognosticators for hamstring injury.

Conclusion

This study identified important early clinical parameters for hamstring injury prognosis. Defining the severity and expected return to play timescale is important in guiding rehabilitation and in team planning. Some of these factors also present as warning signs that a player might be at risk of suffering a recurrence in the first few weeks after returning to play. Players with a past history of a hamstring strain on the same leg in the preceding season and unable to walk pain free within twenty four hours, have a significant chance of taking four or more weeks to return to play. Players with a lateral hamstring strain and a past history of a hamstring strain are at a greater risk of suffering a recurrence in the first three

weeks of returning to competition. These parameters are important in the early assessment post hamstring injury.

References

1.   Ekstrand J, Gillquist J. Soccer injuries and their mechanisms; A prospective study. Medicine and Science in Sports and Exercise 1983;**15**:267-270.
2.   Askling C, Karlsson J, Thorstensson A. Hamstring injury occurrence in elite soccer players after preseason strength training with eccentric overload. Scandinavian Journal of Medicine & Science in Sports. 2003;**13**:244-250.
3.   Stanton P, Purdam C. Hamstring injuries in sprinting-the role of eccentric exercise. Journal of Sports and Physical Therapy 1989;**10**:342-349.
4.   Orchard J, Seward H. Epidemiology of injuries in the Australian Football League, seasons1997-2000. British Journal of Sports Medicine 2002;**36**:39-45.
5.   Verrall GM, Slavotinek JP, Barnes PG, Fon GT. Diagnostic and prognostic value of clinical findings in 83 athletes with posterior thigh injury: comparison of clinical findings with magnetic resonance imaging documentation of hamstring muscle strain. The American Journal of Sports Medicine 2003;**31**:969-73.
6.   Connell DA, Schneider-Kolsky ME, Hoving JL, Malara F, Buchbinder R, Koularis G, et al. A longitudinal study comparing sonographic and MR imaging assessment of acute and healing hamstring injuries. American Journal of Sports Medicine 2004;**34**:1008-1015.

7.   Askling C, Saartok T, Thorstensson A. Type of acute hamstring strain affects flexibility, strength, and time to return to pre-injury level. British Journal of Sports Medicine 2006;**40**:40-41.
8.   Sullivan MK, Dejulia JJ, Worrell TW. Effect of pelvic position and stretching technique on hamstring muscle length. Medicine and Science in Sports and Exercise 1992;**24**:1383-1389.
9.   Malliaropoulos N, Papalexandris S, Papalada A, Papacostas E. The Role of Stretching in Rehabilitation of Hamstring Injuries: 80 Athletes Follow-Up. Medicine and Science in Sports and Exercise 2004;**36**:756-759.
10.   Hennessy L, Watson AWS. Flexibility and posture assessment in relation to hamstring injury. British Journal of Sports Medicine 1993;**27**:243-247.
11.   Brown A, Salmond S, Maxwell L. Asessment of hamstring flexibility which test? New Zealand Journal of Physiotherapy 1993:33-34.
12.   Gadjosik R, Lusin G. Hamstring muscle tightness. Physical Therapy. 1983;**63**:1085-89.
13.   Gabbe BJ, Bennell KL, Wajswelner H, Finch CF. Reliability of common lower extremity musculoskeletal screening tests. Physical Therapy in Sport. 2004;**5**:90-97.
14.   Gadjosik RL. Passive extensibility of skeletal muscle: review of the literature with clinical implications. Clinical Biomechanics 2001;**16**:87-101.
15.   Kornberg C, Lew P. The effect of stretching neural structures on grade one hamstring injuries. The Journal of Orthopaedic and Sports Physical Therapy. 1989;**10**:481-487.
16.   Massey A. The Slump Test : an investagtion of the movement of pain sensitive structures in the vertebral canal in subjects with low back pain. In: Postgraduate Diploma Dissertation. Adelaide; 1982.
17.   Maitland G. Vertebral Manipulation, 5th edition: Butterworth & Co; 1986.
18.   Turl SE, George KP. Adverse neural tension: a factor in repetitive hamstring strain? Journal of Orthopaedic & Sports Physical Therapy. 1998;**27**:16-21.
19.   Orchard J, Best TM. The management of muscle strain injuries: an early return versus risk of recurrence. Clinical Journal of Sport Medicine 2002;**12**:3-5.
20.   Orchard J, Seward H. AFL Injury Report 2002. Sport Health 2003;**21**:18-23.
21.   Oakes BW. Hamstring muscle injuries. Australian Family Physician 1984;**13**:587-591.
22.   Koulouris G, Connell DA. Evaluation of the hamstring muscle complex following acute injury. Skeletal Radiology 2003;**32**:582-589.
23.   Thelen DG, Chumanov ES, Hoerth DM. Hamstring muscle kinematics during treadmill sprinting. Medical Science in Sports and Exercise 2005;**37**:108-114.
24.   Brockett CL, Morgan DL, Gregory JE, Proske U. Damage to different motor units from active lengthening of the medial gastrocnenious muscle of the rat. Journal of Applied Physiology 2002;**92**:1104-1110.
25.   Orchard JW. Recurrent Hamstring Injury in Australian Rules Football. Medicine & Science in Sports & Exercise. 1998;**30**:S52.
26.   Lehman GJ, Lennon D, Tresidder B, Rayfield B, Poschar M. Muscle recruitment patterns during the prone leg extension. BMC Musculoskeletal Disorders 2004;**5**:3.
27.   Slavotinek JP, Verrall GM, Fon GT. Hamstring Injury in Athletes: Using MR Imaging Measurements to compare extent of muscle injury with amount of time lost from competition. American Journal of Roentgenology 2002;**179**:1621-1628.
28.   Gibbs N, Cross T, Cameron M, Houang M. The accuracy of MRI in predicting recovery and recurrence of acute grade one hamstring muscle strains within the same season

in Australian Rules football players. Journal of Science and Medicine in Sport 2004;**7**:248-58.

29.	Schneider-Kolsky ME, Hoving JL, Warren P, Connell DA. A Comparison Between Clinical Assessment and Magnetic Resonance Imaging of Acute Hamstring Injuries. The American Journal of Sports Medicine 2006;**34**:1008-1015.

30.	Orchard J, Best T, Verrall G. Return to Play Following Muscle Strains. Clinical Journal of Sport Medicine. 2005;**15**:436-441.

31.	Kujala U, Orava S, Jarvinen M. Hamstrings injuries. Current Trends in Treatment and Prevention. Sports Medicine 1997;**23**:397-404.

32.	Clanton TO, Coupe KJ. Hamstring strains in atheltes: diagnosis and treatment. The Journal of the American Academy of Orthopaedic Surgeons 1998;**6**:237-248.

33.	Best TM, Hasselman CT, Garrett WEJ. Clinical aspects and basic science of muscle strain injuries. Bone and Muscle 1994;**4**:77-90.

34.	Verrall GM, Slavotinek JP, Barnes PG, Fon GT, Esterman A. Assessment of physical examination and magnetic resonance imaging findings of hamstring injury as predictors for recurrent injury. Journal of Orthopaedic and Sports Physical Therapy. 2006;**36**:215-24.

35.	Verrall GM, Slavotinek JP, Barnes PG. The effect of sports specific training on reducing the incidence of hamstring injuries in professional Australian Rules football players. British Journal of Sports Medicine 2005;**39**:363-368.

36.	Sherry MA, Best TM. A comparison of 2 rehabilitation programs in the treatment of acute hamstring strains. The Journal of Orthopaedic and Sports Physical Therapy 2004;**34**:116-125.

37.	Brockett CL, Morgan DL, Proske U. Predicting hamstring strain injury in elite athletes. Medicine and Science in Sports and Exercise 2004;**36**:379-387.