Lower limb pathology and injuries in adolescent athletes: A systematic review

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1. Introduction

The adolescent athlete is unique in many aspects, both physiologically and psychologically, when compared to other athletes.[20] An understanding of these differences is essential for sports physiotherapists to provide an appropriate, holistic management of the adolescent athlete. There is much literature regarding children in sport, the veteran athlete, the female athlete and sports injuries in general, however the adolescent athlete has received little attention in the literature.[16, 20]

Adolescence is a distinct period of rapid growth and development between childhood and adulthood. [17, 19] Van de Loo and Johnson[20], state that the pubertal growth spurt, along with the neonatal period, comprise the most rapid periods of growth. Puberty marks the onset of adolescence and the timing of onset is quite variable; with girls generally commencing puberty two years earlier then boys.[16,20] Growth and development occurring during adolescence results in changes in the musculoskeletal system and impacts on the injury profile of these athletes, for example: the junction between the epiphyseal plate and metaphysis is prone to shear injury; and the apophyses are relatively weak and prone to traction injuries such as avulsion fractures and apophysitis.[2]

Adolescent athletes are often playing sport at very high volumes, intensities and frequencies, occasionally, at, or near, professional/elite levels. They will rapidly change from one sport to another during the school year, with little time for recovery and transition. Together with these sporting demands, adolescent athletes are also school students; sitting for long periods at poorly designed desks and chairs; and carrying heavy school and sports bags. Adolescence, being the transition from childhood to adulthood, is also associated with marked psychological development: the search for identity and independence; the desire for attention and praise; the need to belong and fit in; the awareness of body image; and peer pressure.[20]

In order to understand how adolescent athletes differ from children and adults in terms of musculoskeletal development, pathology and injuries, and how theses differences may impact on sports physiotherapy, a systematic review of the literature was performed. The review focussed on the lower limb, as lower limb accounts for a large proportion of sporting injuries and is the site of many conditions and pathologies unique to this age group.[2] The review was conducted to: provide evidence of the paucity of literature relating to adolescent athletes; to evaluate the quality of the existing literature; and to explore the themes emerging from this literature.

2. Method

2.1. Search Strategy

An electronic search, using the University of Melbourne's SuperSearch : MetaSearch tool, of the following data bases were performed in April 2007: University of Melbourne Library Catalogue; Web of Science (ISI); MEDLINE (ISI); CINAHL PLUS (EBSCO); PsycINFO (CSA); BIOSIS Previews (ISI); PubMed; and University of Melbourne ePrints Repository (UMER – ePrints). Keywords in the search strategy included: adolescent athlete, hip, pelvis, knee, ankle, foot, thigh, leg, avulsion fracture, apophysitis, perthes', osgood schlatter, slipped capital femoral epiphysis, osteochondrosis, patellofemoral pain, anterior cruciate ligament and sports injuries. Adolescent athlete was the primary key word in all searches. The search was then refined by including 'and' each of the above keywords separately. The PEDro and Cochrane data bases were also searched using the above keywords.

2.2. Inclusion Criteria

The title and abstract of each study identified from the search strategies were assessed. Studies were included in the review if they satisfied the following criteria: (1) studies of the adolescents including high school aged or those aged between 12-18 years (if a comparatively small number of participations were either younger or older, or a paediatric or adult group was used as a comparison, the study was included); (2) studies of injuries/conditions of the lower limb and pelvis; (3) studies addressing sports related injuries/conditions; (4) studies of Musculoskeletal/orthopaedic injuries/conditions; (5) data driven studies; and (6) studies that were available in full through the University of Melbourne's SuperSearch : MetaSearch tool.

Excluded from the review were: (1) studies that were not data driven including review papers and current concept papers; (2) studies of upper limb or spinal injuries/conditions; (3) studies whose participants were either children (<12yo/primary school aged) or adults (>18yo) (unless used as a comparison/control group); (4) studies that reviewed non sports related injuries/conditions; (5) studies that reviewed congenital deformities/syndromes; (6) studies addressing medical or psychological aspects of adolescents and (7) studies that were not available in full text.

2.3. Data extraction

Data was extracted from each study using a critical review form.[10] The key elements extracted were related to quality of the study and included: purpose of the study; literature review; study design; biases; sample; consent; outcome measures; results; conclusions and clinical implications. This data extraction

method provided a comprehensive account of the quality of each study from which a quality assessment could be made.

2.4. Quality Assessment

The validity of the studies was assessed using an assessment quality check list. This checklist included a list of questions aimed at assessing elements of a study that may predict quality. A scoring system was developed to rate each of these individual elements as well as obtain in overall score for each study (Table 1).[4]

3. Results

3.1. Search Strategy Yield

The electronic search of the selected databases identified 167 published studies. Searches of PEDro and Cochrane data bases failed to find any articles. Table 2 outlines the search yield for each individual search. After applying the inclusion/exclusion in the order outlined in the inclusion criteria, 12 studies for inclusion in the systematic review were identified.[1,3,5,6,8,9,11,12,13,14,15,18] The details of these studies are outlined in table 3.

3.2. Descriptive aspects of the reviewed studies

The descriptive aspects of the reviewed studies are outlined in table 3. All 12 studies reported an age range between 12-18 or high school age except two studies, one included subjects as young as 11 years and the other included subjects up to 19 years. One of the studies included an adult comparison group ranging in age from 20-53 years. The sample sizes ranged from 1 to 421, with one study reporting athlete exposures rather than the number of athletes, this sample size was 359 040 and 28 318 for each group.

There were 3 single case studies which explored uncommon or rare injuries/management of the knee which are particular to adolescents. One was of an ACL reconstruction rehabilitation of a female athlete with hypermobility syndrome, the other two were unusual/complicated avulsion fractures of the tibial tubercle.

The knee was the focus of 9 articles. Five articles addressed issues surrounding the ACL; 2 of these on neuromuscular control; 1 each on: the post-operative pain experience differences between adolescents and adults; the natural history of ACL versus reconstruction; and hypermobilty syndrome. Of the remaining articles focussing on the knee the injuries/conditions addressed were: patella tendinopathy; articular cartilage repair/autologous chondrocyte transplantation; a

combined type III tibial tubercle avulsion and a Salter-Harris type IV proximal tibial physeal fracture; and a type III fracture of the tibial tubercle with avulsion of the tibialis anterior muscle. The ankle (neuromuscular control combined with the knee), shin/leg (medial tibial stress syndrome), lower limb (cross country running) and mixed (lacrosse) were the body region of focus for one article each.

Nine articles looked at both genders, with the 3 single case studies reporting on 1 female and 2 male athletes. The sports that were addressed in the studies were: basketball – 1; mixed sports – 3; cross country running - 2; and lacrosse and gymnastics - 1 each.

The study designs for the 12 articles reviewed were: cohort (4); case study (3); case control (2); case study design (1); cross-sectional controlled cohort (1) and case series (1). Five studies compared males versus females; 2 studies compared maturity related differences – 1 between adolescents and adults and the other between pre-adolescents and adolescents; 1 study compared the natural history of an injury to an intervention; 1 study compared a no pain group to a pain group; 1 study compared different sports settings; and 4 studies had no control or comparison group.

2.3. Quality aspects of the reviewed studies

This review was not examining treatments or clinical interventions and as such common quality assessment criteria, such as those used by PEDro and Cochrane,[7] were not appropriate. Quality and validity of each study was therefore limited to a qualitative process of best evidence synthesis. Table 4 outlines the quality assessment scores for each study.

The total quality score for the 12 studies reviewed was 117.5 out of a possible 180 (65.28%). The range of scores was from 13 down to 5 out of a possible fifteen points for each study. Only 6 studies received a score of 75% or higher. The elements that scored well (>75%) were: the purpose being clearly stated (87.5%); relevance of literature review (83.33%); the appropriateness of study design (95.83%); the description of the sample (100%); the description of the intervention/methods (87.5%); the appropriateness of analysis of results (83.33%); and the appropriateness of conclusions drawn (100%). The elements that scored poorly (<50%) were: no biases being present (20.83%); justification of sample size (16.67%); validity of outcome measures (20.83%); and reliability of outcome measures (45.83%).

4. Discussion

4.1. Knee

4.1.1. ACL

Landing from a jump and the cutting manoeuvre have been identified as the most common mechanisms of injury for ACL ruptures.[2] ACL ruptures occur at 4-6 times higher rates in girls then boys after puberty: there is no difference in rates pre-puberty.[5,14] Two of the higher quality studies investigated these skills in male and female basketballers: Quatman et al,[14] landing from a jump; and Ford et al,[5] the cutting manoeuvre. Quatman et al,[14] compared aspects of the vertical jump in pre-adolescent and adolescent athletes. In this study boys demonstrated: a significant increase in vertical jump height, a significant decrease in landing ground reaction forces; a maintenance of take off ground reaction forces; and a significant decrease in loading rate, post-puberty. The authors concluded that boys appeared to undergo a neuromuscular spurt at puberty. Girls in contrast demonstrated: no change in vertical jump height; no change in landing ground reaction forces; a significant decrease in take off ground reaction forces on the dominate side only; and a significant decrease in loading rate. Girls ground reaction forces in both landing and take off, and the rate of loading was significantly higher than boys. Thus, it was concluded that girls did not undergo a neuromuscular spurt at puberty. Girls demonstrated increased relative landing ground reaction forces and a decreased ability to attenuate landing forces compared with boys, post puberty.

Ford et al,[5] investigated the cutting manoeuvre. They found that females had increased knee valgus and ankle eversion angles compared with males. The increased knee valgus angle was significant at initial contact and there was a trend in this direction at maximum. The authors suggested that females may rely more on ligaments, rather than musculature, to absorb a significant portion of ground reaction forces in cutting, than males, and that ligament dominance may be a risk factor in ACL injuries in adolescent female athletes. The authors also concluded that knee valgus angle and ankle eversion angle, may be a factor in the gender related differences in ACL injury rates in adolescent athletes. The findings of this study seem to support those of Quatman et al,[14] in that adolescent girls appear not to have the same neuromuscular control as boys of this age group.

The authors of both these studies suggested that, although anatomical and hormonal factors may contribute to the increased rate of ACL injuries in adolescent female athletes, they are difficult and controversial to modify, and that the greatest opportunity for risk identification, modification and intervention, may therefore lie with biomechanical and neuromuscular factors. Both studies advocated the introduction of neuromuscular training in female adolescent athletes, Quatman et al,[14] advocating this training take place at or near the onset of puberty. It would appear that neuromuscular training should involve both jumping/landing skills and the cutting manoeuvre. Sports physiotherapists are in an ideal situation to be involved in the screening and implementation of such programs in adolescent athletes.

Tripp et al,[18] examined differences in pain, catastrophizing, and effective distress (depression and anxiety) 24 hours post ACL reconstructive surgery between adolescent and adult athletes. They found that there was a significant difference between the groups for pain, catastrophizing, and anxiety. Adolescent athletes reported greater pain and catastrophizing than adults; however, if controlled for catastrophizing, there was no difference between the groups. The aspects of catastrophizing that were significant were pain related helplessness and rumination (dwelling/mulling over). The authors suggested that the relative lack of understanding of injury, lack of experience with recovery and potential threat to competition in adolescent athletes maybe a factor in the differences demonstrated in this study. Identifying differences in pain experiences between adolescents and adults may assist sports physiotherapists to better deliver rehabilitation to adolescent athletes post ACL surgery. Clinically, the results of this study would suggest that 'pre-hab' is very important in the adolescent athlete undergoing ACL reconstruction and that sports physiotherapists should devote a significant portion of this 'pre-hab' to education and discussion regarding the injury, rehabilitation, recovery and return to sport.

4.1.2. Tendinopathy

Purdam et al,[13] investigated the reliability and validity of five squat-based loading tests, specifically, the decline squat and hop as potential examination tools in patella tendinopathy in adolescent basketball. They demonstrated that the single decline squat was the most simple and effective test in terms of reliability and validity in evoking a pain response and discriminating changes of loading response with increased load in adolescent basketballers with patella tendinopathy. They recommended the single leg decline squat as a specific objective assessment tool in patella tendinopathy. The authors also suggested that the single leg decline squat may be a simple, effective and easy to administer treatment tool in the rehabilitation of patella tendinopathy. They could not support nor advocate the use of the standard double leg squat for assessment or treatment in patella tendinopathy.

4.1.3. Cartilage

Articular cartilage injuries are most prevalent in the skeletally immature, however, there is limited information and literature on articular cartilage injury/repair in adolescents or whether maturity effects the function of the knee post injury/repair.[11] Mithofer et al,[11] followed 20 adolescent athletes with full thickness articular cartilage lesions of the knee who were treated with autologous chondrocyte transplantation for a mean of 47 months post surgery. Functional outcome was evaluated by subjective patient outcome rating, knee activity scores, and level of athletic participation. The authors found good to excellent results in 96% of athletes, that is, they were able to participate in regular high

impact, pivoting sports at the recreational level or higher and that the shorter the preoperative duration of symptoms, the better the functional outcome. All athletes who had symptoms for less then 12 months returned to their previous level of competition, whereas only 33% of athletes who had symptoms for greater than 12 months returned to their previous level of activity. The mean preoperative duration of symptoms of those athletes who returned to their previous level of activity was 15 months. The authors reported that the results in adolescent athletes were comparable to the best results in the adult population. Clinically, for the sports physiotherapist, this would indicate, early detection of articular cartilage damage in adolescent athletes and subsequent referral to an orthopaedic surgeon within 12 months is crucial to gain the best functional outcome for the adolescent athlete.

4.1.4. Avulsion Fractures

Two single cases studies on rare avulsion fractures of the knee were presented. Avulsions fractures are common in adolescent athletes; particularly about the knee.[2] Therefore it is important to briefly address these two case studies, despite their low quality rating, to highlight the need to recognise these fractures and to arrange prompt surgical management: these fractures are associated with serious potential complications and long term sequelae. Kaneko et al,[9] presented a type III fracture of the tibial tubercle with avulsion of the tibialis anterior muscle in the adolescent male athlete. This was only the third case of a tibial tubercle avulsion fracture by the tibialis muscle. Curtis,[3] presented a combined type III tibial tubercle avulsion and a Salter-Harris type IV proximal tibial physeal fracture, a combination that had not being previously reported in the literature. The avulsion in this case was of the periosteum, perichondrium, MCL and tibialis anterior. Both athletes were male, one 14 years old and the other 15 years old. One injury occurring during landing and the other jumping; both athletes felt a snap/pop, had immense pain, instability/weakness and significant swelling immediately. Radiology was used in both cases to determine the extent of the injury, to classify the injury and to plan the subsequent surgery. Both athletes underwent open reduction internal fixation and both had excellent outcomes.

4.2. Cross Country Running

Two studies investigated cross country running in high school aged athletes. [12,15] Overuse injuries appear to be high in both recreational and elite cross country runners, however there is little data regarding the adolescent athlete. Plisky et al, [12] investigated medial tibial stress syndrome, as is the second most common injury in cross country running, specifically addressing the relationship of this pathology with navicular drop and Rauh et al,[15] investigated the epidemiology of cross country running. Plisky et al,[12] found no relationship between navicular drop, normalised navicular drop, normalised navicular neutral height, or navicular

drop right to left difference and MTSS. They concluded that navicular drop may not be an appropriate measure to identify runners who may develop MTSS.

Rauh et al,[15] followed 11 female and 12 male high school cross country teams over 1 season, collecting data pre-season and at each training and competition session. Girls and boys were similar with regard grade level and running experience. Girls reported significantly more previous injuries and injuries through out the season then boys, even though boys ran longer distances. Most injuries were minor and occurred during training, with season ending injuries being less frequent, however girls had a 4x higher rate of initial injuries resulting in more then fifteen days lost training/competition, then boys. The shin had both the highest initial injury and re-injury rate. Runners with a Q angle $>20^{o}$ were twice as likely to be injured then runners with Q angle $<20^{o}$; a larger proportion of girls had a Q angle $>20^{o}$. The only statistically significant risk factor when baseline characteristics and training practices were included were a Q angle of $>20^{o}$ and a running injury in the preceding season. No significantly increased injury risks were found in relation to overall mileage, mileage by running pace, surface, or terrain for the overall sample or within gender. The authors concluded that the incidence of lower limb injuries is high in adolescent cross country runners, especially in girls. Large Q angles and previous running injuries had a greater risk of running injuries.

5. Conclusions

There is paucity in the literature regarding adolescent athletes and their musculoskeletal development, pathology and injuries of the lower limb. This is evidenced by this systematic review and is highlighted in the literature reviews of most of the articles analysed. Furthermore, there is limited high quality data driven studies addressing this topic. Given the unique physiologically and psychologically, the high physical demands and pressures, and the increasing participation and injury rates of the adolescent athlete, more attention needs to be paid to this group of athletes in both the literature and in sports medicine and sports physiotherapy.

Despite this, a number of themes have emerged from this review which may have some impact on clinical sports medicine and sports physiotherapy. Firstly, it appears that adolescent girls are at much higher risk of injury with regard non contact ACL injuries and running related injuries with neuromuscular control, Q angle and previous injury, appearing to be significant factors.[5,12,14,15] Secondly, it seems that boys undergo a neuromuscular spurt at puberty, which girls do not, and that neuromuscular training, involving jumping/landing and cutting, at or near puberty in females may assist in preventing ACL injuries.[5,14] Thirdly, adolescent athletes have a different pain response post ACL surgery than adults, with catastrophizing being the significant factor.[18] 'Pre-hab', including education and discussion regarding the injury, rehabilitation, recovery and return to sport may

be more important in the adolescent athlete undergoing ACL reconstruction than their adult counterparts. Fourthly, adolescent athletes who have a full thickness articular cartilage lesion of the knee are able to return to their previous level of sport after autologous chondrocyte transplantation if preoperative symptoms are less than twelve months.[11] Early detection and referral of these lesions is important for the best functional outcome. And lastly, it is important for the sports medicine clinician to be aware of avulsion fractures and/or fractures involving the growth plates, particularly around the knee, in the adolescent athlete as these injuries are more common in this age group and may be associated with serious potential complications and long term sequelae.

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Table 1. Quality Assessment Checklist

Question	Response/Decision Rule
Was the purpose of study clearly stated?	0 = not clearly stated .5 = partially stated 1 = clearly stated
Was the literature review relevant?	0 = no literature review or not relevant .5 = limited literature review or limited relevance 1 = literature relevant for study
Was the study design appropriate to study aims?	0 = not appropriate for study aims .5 = not ideal, but appropriate for limitations in sample size 1 = ideal study design
Were any biases present?	0 = yes. A number of biases that would influence the results significantly .5 = some, but limited effect on results of study 1 = no biases present
Was the sample described in detail?	0 = no, limited details provided .5 = yes, but some details missing 1 = yes, explicate description of sample
Was the sample size justified?	0 = no, not mentioned or implied .5 = not explicitly mentioned, but implied 1 = explicitly mentioned
Was informed consent gained?	0 = not gained or not mentioned 1 = explicitly mentioned
Were the outcome measures are valid?	0 = not addressed or implied. No outcome measures .5 = not addressed, but implied 1 = explicitly addressed
Were the outcome measures are reliable?	0 = not addressed or implied. No outcome measures .5 = not addressed, but implied 1 = explicitly addressed
Could the study be replicated?	0 = no, no or limited description of methods .5 = some but not all details of methods described 1 = yes, a detailed description of the methods were provided
Were the results reported in terms of statistical significance?	0 = No, descriptive results only .5 = some results, but not all were given in statistical significance 1 = yes
Was the analysis was appropriate?	0 = no .5 = somewhat 1 = yes
Were the conclusions were appropriate?	0 = no, not at all .5 = somewhat appropriate 1 = yes, very appropriate
Were the clinical implications of the results were reported?	0 = no, not addressed .5 = not explicitly stated, but implied 1 = explicitly stated
Were the limitations of the study were acknowledged?	0 = not acknowledged .5 = not explicitly stated, but implied 1 = explicitly stated

Table 2. Results of Search Strategy Yield

1st Keyword	'and'	2nd Keyword	Search results
Adolescent Athlete	'and'	hip	10
Adolescent Athlete	'and'	pelvis	3
Adolescent Athlete	'and'	knee	29
Adolescent Athlete	'and'	ankle	12
Adolescent Athlete	'and'	foot	6
Adolescent Athlete	'and'	thigh	2
Adolescent Athlete	'and'	leg	8
Adolescent Athlete	'and'	avulsion fracture	8
Adolescent Athlete	'and'	apophysitis	8
Adolescent Athlete	'and'	perthes'	2
Adolescent Athlete	'and'	osgood schlatter	4
Adolescent Athlete	'and'	slipped capital femoral epiphysis	1
Adolescent Athlete	'and'	osteochondrosis	3
Adolescent Athlete	'and'	patellofemoral pain	3
Adolescent Athlete	'and'	anterior cruciate ligament	14
Adolescent Athlete	'and'	sports injuries	54
TOTAL			**167**

Loretta O’Sullivan

Table 3. Identified studies of the adolescent athlete in relation to musculoskeletal development, pathology and injuries of the lower limb – descriptive aspects

Author	Study Design	Age Range	Gender	Area/s of Body	Sport/s Involved	Diagnosis Injury	Control Comparison	Sample Size
Tripp et al	Case control	16-18 20-53	both	knee	mixed	ACL reconstruction Post-op pain experience	Adult group	20
Hardin et al	Case study	15	Female	knee	Basketball	ACL reconstruction Hypermobility Syndrome	No	1
Ford et al	Case Control	12-18	both	Knee ankle	Basketball	Neuromuscular control ACL	Males vs females	126
Purdam et al	Cross-sectional controlled cohort	14-18	both	knee	Basketball	Patella Tendinopathy	Pain and no pain group	50
Mithofer et al	Case series	12-18	both	knee	mixed	ArticularCartilage Repair Autologous Chondrocyte Transplantation	no	20
Quatman et al	Cohort	11-16	both	knee	Basketball	ACL Neuromuscular Control	Puberty vs Post-puberty Males vs Female	34
Hinton et al	Case study design	High School Age	both	mixed	Lacrosse	All injuries	Male vs female High School vs summer camp	359 040 high school & 28 318 summer camp exposures
Plisky et al	cohort	14-19	Both	Shin/Leg	Cross Country Running	Medial Stress Syndrome Navicular Drop	Males vs Female	105
Rauh et al	cohort	High School Age	Both	Lower limb	Cross Country Running	All injuries	Males vs Female	421
Curtis	Case study	15	male	knee	Basketball	combined type III tibial tubercle avulsion and a Salter-Harris type IV proximal tibial physeal fracture	No	1
Aichroth et al	Cohort	11-15	Both	knee	mixed	ACL rupture	Natural History vs Reconstruction	60
Kaneko et al	Case study	14	male	knee	gymnastics	Type III fracture of the tibial tubercle with avulsion of the tibialis anterior muscle	No	1

Table 4. Study Quality Assessment Scores

Quality score	Tripp et al	Hardin et al	Ford et al	Purdam et al	Mithofer et al	Quatman et al	Hinton et al	Plisky et al	Rauh et al	Curtis	Aichroth et al	Kaneko et al	Total 12
Purpose of study clearly stated	1	1	1	1	1	1	1	1	1	1	0	.5	10.5
Literature review relevant	1	.5	1	1	1	1	1	1	1	1	.5	0	10
Study design appropriate to study aims	1	.5	1	1	1	1	1	1	1	1	1	1	11.5
No biases present	.5	0	.5	.5	.5	.5	0	0	0	0	0	0	2.5
Sample described in detail	1	1	1	1	1	1	1	1	1	1	1	1	12
Sample size justified	0	0	0	0	0	0	0	1	0	.5	0	.5	2
Informed consent gained	1	0	1	1	1	1	.5	1	1	0	0	0	7.5
Outcome measures are valid	1	0	0	0	.5	.5	.5	0	0	0	0	0	2.5
Outcome measures are reliable	1	0	1	1	.5	1	0	1	0	0	0	0	5.5
Intervention described in detail (could be replicated)	1	.5	1	1	1	1	1	1	1	0	1	1	10.5
Results reported in terms of statistical significance	1	0	1	1	1	1	.5	1	1	0	0	0	7.5
Analysis was appropriate	1	1	1	1	1	1	1	1	1	0	0	1	10
Conclusions were appropriate	1	1	1	1	1	1	1	1	1	1	1	1	12
Clinical implications of the results were reported	.5	1	1	1	.5	.5	0	.5	.5	.5	.5	.5	7
Limitations of the study were acknowledged	1	0	0	.5	1	1	1	1	1	0	0	0	6.5
Total 15	13	6.5	11.5	12	12	12.5	9.5	12.5	10.5	6	5	6.5	117.5/180

Loretta O’Sullivan