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Cover Letter

Dear Editor of Clinical Biomechanics,

REF: Submission of manuscript titled "Orthopaedic sport biomechanics – a new paradigm".

We would like to submit the mentioned manuscript as an Invited Article to Clinical Biomechanics. Each author has been involved in (1) the conception and design of the study, or acquisition of data, or analysis and interpretation of data, (2) drafting the article or revising it critically for important intellectual content, (3) final approval of the version to be submitted.

We suggest the following two potential reviewers.

1. Prof Mario Lamontagne
URL: http://www.health.uottawa.ca/profiles/mlamon.htm
Email: mlamon@uottawa.ca
2. Prof Christer Rolf
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26 April 2007

Clinical Biomechanics

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Authors: Kai-Ming CHAN, Daniel Tik-Pui FONG, Youlian HONG, Patrick Shu-Hang YUNG, Pauline Po-Yee LUI

Response to editor

1. **It is essential that your revised paper complies exactly with ALL aspects on our Guide for Authors (www.elsevier.com/locate/clinbiomech).**

>>

Response to reviewer 1

1. **It is suggested that Figure 2 should be cited in line 96 to descript the four steps in the sequence of injury prevention.**

>>> *Figure 2 is deleted, but the content is cited..*

2. **In line 142, "Systematic review on a specific sport injury summarizes the findings and provides the best overview." Suggest using past tense as "□summarized the findings and provided the best overview."**

>>> *Revised accordingly. Line 118.*

3. In line 36, the citation of reference "Abernethy et al, 2002□.." should follow by 'et al.' and keep consistence in the following text.

>>> *"et al" is revised as "et al." throughout the entire paper.*

4. In line 361, the sentence of "Joint kinetics, such as valgus torque at knee and supination torque at ankle" is not complete. Suggest revising it.

>>> *Revised as "Joint kinetics, such as valgus torque at knee (Withrow et al., 2006) and supination torque at ankle (Markolf et al., 1989), are also often reported.". Line 334.*

5. In line 368, "to reduce artefacts introduced by□." is suggested revising as "to reduce artifacts introduced by□."

>>> *Revised accordingly. Line 341.*

6. In line 388, "Operative treatment procedures to a specific problem vary." is suggested revising as "Operative treatment procedures vary with the specific problem".

>>> *Revised accordingly. Line 359.*

7. In Figure 3, it is suggested that more detailed description of the four captured camera images should be addressed to help readers understand the image-matching technique.
>> Figure 3 is deleted, but the detail description is added.

8. In Figure 4, the two finite element models should be added with the quotation of (a) and (b).
>>> Figure 4 is deleted.

Response to reviewer 2

General: The text is a bit too long, and the manuscript can easily be shortened without losing any major scientific information. Also, the references are quite many (the number is 143), and therefore, I would suggest that the authors should make an effort to reduce the number of references.
>>> Reference amount is reduced to 122.

General: I would like to ask the authors to mention whether there is any controversy. They should underline even better why there is a need for "Orthopaedic Sports Biomechanics".
>>> We tried to elaborate the need in the second and third paragraphs in Introduction. In the past, orthopaedics specialists relied a "trial-and-error" approach. In recent decades, biomechanists started to contribute by studying the underlying injury mechanism and the effect of the treatment. Therefore, with respect to the emerging new research approach, this papers summarizes the current knowledge for the better understanding of biomechanics and orthopaedics specialists in understanding what they could contribute to the current practice of sports medicine.

1. Lines 10-12. Please delete the sentence □"This interdisciplinary synergy will become□"
>>> Revised accordingly.

2. Line 15. Please add the following key words: treatment, evaluation, long-term.
>>> Revised accordingly.

3. Line 31. The range (7.1-18.7%) is very wide. I suggest the authors give more detailed information here.

>>> Revised as "It accounts for 7% (Jones and Taggart, 1994) or even as much as 22% (Burt and Overpeck, 2001) of attendances to accident and emergency departments, which are comparable to traffic accidents, domestic accidents, and occupational injuries.". Line 16.

4. Lines 47-48. A reference is needed.

>>> The reference (Viano et al., 1989) was already included after the sentence in line 36.

5. Line 60. Please write□"there is emerging research"□

>>> Revised accordingly. Line 42.

6. Lines 73-74. Please delete□"The role of orthopaedics in sports medicine is shown in the outer"□

>>> Revised accordingly. Line 55.

7. Line 85. How does Biomechanics provide quantitative objective assessment □ please give at least one example.

>>> In the same paragraph, we mentioned that examples are elaborated in the following sections (Line 70). Several examples showing the biomechanics quantitative assessment are described in Section 4, from line 326.

8. Line 124. Recent studies have shown higher incidence.

>>> This is deleted. Line 100.

9. Lines 166-167. The authors write □"tibial varum"□ please revise the English

>>> This term "tibial varum" is not incorrect. It means "bow leg". Line 143.

10. Lines 166-178. Please mention the difference of injury risk between females and males.

>>> This paragraph aims to identify the risk factors to sport injury. Here, different risk factors are identified for different gender. It is not the aim to compare the injury risk among gender in a specific kind of sport or activity.

11. Line 178. Please discuss the risk of development of osteoarthritis in the long-term after ACL injury/reconstruction. This would in fact be one of the most important issues, i.e. from prevention to long-term sequels.

>>> This is added. Line 153.

12. Line 182. It is enough to write □"Etiology"□

>>> Some papers used "aetiology" and some "etiology". As this is a review paper, it was our purpose to include similar terms for this issue. Other terms are pathology, pathogenesis, and pathomechanism. Line 159.

13. Lines 235-247. The Hall-transducers should be explained in more detail. A figure would be fine too.

>>> If we add details on Hall transducers, we will have to also do that to DVRT, liquid mercury strain gauge, and so on. Readers should refer to the cited reference to know more about these equipments.

14. Line 297. What is □"sensing"□?

>>> "Sensing" is to sense – this is elaborated as "to detect foot and ankle motion plus plantar pressure in order to predict the supination torque" immediately after introducing the 3-step mechanism. Line 272-274.

15. Line 417. Do the authors have any conclusion in terms of immediate evaluation of treatment? Why is it important?

>>> We already concluded that "these biomechanics evaluations provide evidence for orthopaedics specialists to consider or re-consider the prescription to specific musculoskeletal problems", as they could learn the immediate effect of their treatment. Line 387-388.

16. Line 440. The authors write□"The decision to return an injured or rehabilitated athlete to sports is empirical"□ this is partially true, but there are some criteria, like muscle strength, endurance, etc. Please mention these criteria as well

>>> These criteria are already elaborated in the same paragraph. For ACL patients, the criteria are limb strength, patient-reported outcomes, knee stability, limb symmetry, postural control, power, endurance, agility and so on. Line 411-430.

17. Lines 462-473. Please add a short paragraph on "Clinical relevance".

>>> This is added as "The clinical relevance is for the orthopaedics and biomechanics specialists to understand what they could contribute to injury prevention, objective assessment of immediate treatment outcome, and long-term monitoring of rehabilitation progress for making suggestion to return to sports.". Line

435-438.

Title Page

Title: Orthopaedic sport biomechanics – a new paradigm

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Abstract

This article proposes a new paradigm, "Orthopaedic sport biomechanics", for the understanding of the role of biomechanics in preventing and managing sports injury. Biomechanics has three main roles in this paradigm: (1) injury prevention, (2) immediate evaluation of treatment, and (3) long-term outcome evaluation. Related previous studies showing the approach in preventing and managing anterior cruciate ligament rupture and anterior talofibular ligament tear are highlighted. Orthopaedics and biomechanics specialists are encouraged to understand what they could contribute to the current and future practice of sports medicine.

Keywords
Injury prevention, sports medicine, treatment, evaluation, long-term

1. Introduction

Sports cause traumatic injuries (Chan et al., 1993). It accounts for 7% (Jones and Taggart, 1994) or even as much as 22% (Burt and Overpeck, 2001) of attendances to accident and emergency departments, which are comparable to traffic accidents, domestic accidents, and occupational injuries. Since most sports-related traumatic injuries impair the musculoskeletal system, these patients are normally referred to sports medicine clinics in orthopaedics specialty (Chan, 1992). Early in 1975, Nicholas (1975) described Sports Medicine as a multidisciplinary science which involved physiology, physical education, bioengineering and medicine. Since the main purpose is to deal with the musculoskeletal injuries sustained in sports, orthopaedics specialty plays a significant role in the development of sports medicine as a viable academic discipline (Ogden, 1980; Riffer, 1986).

Ten years ago, orthopaedics and sports physical therapists still relied on a "trial-and-error" approach – they provided patients with numerous types of treatments without accurately knowing their effectiveness (Powers, 1998). In order to provide effective treatment, the mechanisms of injury or the resulting pathomechanics should be identified (Bahr and Krosshaug, 2005). Since most musculoskeletal injuries are caused by imbalance of internal muscle force and external environmental force, resulting in damage to the anatomical biological tissues and structures, biomechanics analysis helps studying these forces and their effects, and establishes the injury mechanism (Viano et al., 1989). By understanding the pathomechanics of sports injury, biomechanics studies enhance the development of injury prevention in sports medicine (Elliott, 1999), which is a rapid growing research field in order to promote safety in sports (Timpka et al., 2006). In 1996, Magee and McFarland (1996) postulated that advanced computer technology in 21st century will allow accurate diagnosis for sports medicine, as well as prediction of various surgical or physical therapy treatment outcomes. In the recent decade, there is emerging research utilizing sports biomechanics as a tool for sports injury prevention and management (Ubell et al., 2003; Weerapong et al., 2005). This is a synergy of orthopaedics and biomechanics in the research and development of sports medicine.

This paper summarizes the current knowledge and proposes a new paradigm, “Orthopaedic sport biomechanics”, for the understanding of the role of biomechanics in preventing and managing sports injury. Related previous studies on sport-related knee and ankle injuries, with specific attention on anterior cruciate ligament (ACL) rupture and anterior talofibular ligament (ATFL) tear respectively, are highlighted for better elaboration of the new paradigm.

2. The new paradigm – “Orthopaedic sport biomechanics”

Figure 1 shows the new paradigm “Orthopaedic sport biomechanics”, flowing counter-clockwise from “Sports Participation”. When a sport injury or trauma involving musculoskeletal system occurs, orthopaedics specialist takes up the role to manage it. This involves clinical diagnosis (Chan et al., 1995; Chan and Hsu, 1991; Rae et al., 2005), operative and conservative treatments (Fredericson and Wolf, 2005; Jones and Amendola, 2007), and subsequent rehabilitation training (Kvist, 2004; Zoch et al., 2003). The aim is to cure the patient, let him recover and return to sports (Podlog and Eklund, 2004).

Biomechanics is an integral of this new paradigm, which is shown in the inner shaded part. It has three main roles – (1) it helps in the prevention of musculoskeletal sport-related injury and trauma, (2) it provides quantitative objective assessment to evaluate the immediate outcome of treatment, either operative or conservative, (3) it acts as an objective tool to monitor the long-term rehabilitation progress, and to indicate if an athlete is adequately recovered to a satisfactory level for returning to sports. These three main roles of biomechanics are elaborated in the following sections.

3. Biomechanics for injury prevention in sports

In 1987, van Mechelen and co-workers (1992) proposed a “Sequence of injury prevention” and is now widely adopted by various researchers in sport-related injury prevention researches. The first step is to identify the extent of the sports injury problem by epidemiology studies (What is the problem?). The second step aims to identify the risk factors (Who are most likely to get injured?), establish the aetiology (Why are they injured?) and mechanism (How do they get injured?). The third step is to introduce preventive measures to tackle the problem. Finally, the effectiveness of the preventive measures is assessed by repeating the epidemiology study in step one. With the advance of biomechanics technique in sports medicine in recent decade, biomechanics assessment is often conducted before the costly, large-scale and time-consuming epidemiology study. Such biomechanics assessment aims to evaluate if the risk factors are suppressed, if the aetiology is eliminated, or if the mechanism is prohibited. If these elements are significantly inhibited, the preventive measures are assessed to be biomechanically effective in laboratory. When deemed necessary, the final prospective cohort epidemiology study could be conducted to evaluate the ultimate effect on injury incidence rate. If the injury incidence rate could be significantly reduced, the preventive measures are assessed to be clinically effective.

3.1 Identifying biomechanics-related risk factors

Epidemiology is the study of disease in relation to populations (Rose and Barker, 1978). In sports medicine, epidemiology studies regard sports injuries, either acute or chronic, as disease (Armsey and Hosey, 2004). In the "Sequence of injury prevention with biomechanics assessment", epidemiology provides information to establish the extent of the sports injury problem. These epidemiology studies provide descriptive information for identifying the prevalence in different body sites, the incidence rate of different injury types, the severity of the injury, and also the sports with the majority of the injuries. For example, Majewski and co-workers (2006) conducted a 10-year study and found that sport-related knee injuries contribute to 39.8% of all athletic injuries, with the ACL lesion as the majority (20.3%). Among athletes and non-athletes, ruptures of ACL are seven times more common in athletes. The sports leading to most ACL injuries are soccer and skiing.

When looking at the broad spectrum of athletic injuries, Garrick and Requa (1988) reported that ankle sprain is the single most common injury in sports, despite that knee injuries dominate as the most common injured body sites. Ferran and Maffuli (2006) reported that the ATFL is the weakest ligament at the lateral ankle, and is involved in practically all lateral ankle sprains. The attendance rate at a casualty ward was reported to be 7 per 1000 person-years (Holmer et al., 1994). In Hong Kong, a survey on athletes of all levels (national, competitive and recreational) reported that most ankle sprains are sustained in running and jogging (25%), racquet sports (20%) and ball games (19%) (Yeung et al., 1994). However, a recent analysis on medical records (Fong et al., 2006a) from an accident and emergency department reported that most sport-related ankle injuries are sustained from basketball, soccer and hiking – This implied that epidemiology studies should be conducted in different settings to obtain a better overview. Systematic review on a specific sport injury summarized the findings and provided the best overview (Fong et al., 2007a), but yet does not encounter the biomechanics information that is essential for later injury prevention (Viano et al., 1989). In 1996, Winston and co-workers (1996) proposed a new approach, "Biomechanical epidemiology", which aimed to apply biomechanical principles to the epidemiological study, in order to provide the essential information for biomechanists for further injury analysis. Then, prospective cohort or epidemiology studies started to include data collection of more information, i.e., demographic, anthropometric and biomechanics data of the injured athletes, in order to locate if any of them is risk factor (Bahr and Holme, 2003).

In athletic injury, risk factors are often classified as intrinsic and extrinsic, with the former referring to biomechanics, conditioning, maturational stage and somatotype, and the latter referring to weather, field conditions, rules and equipment (Taimela et al., 1990). Risk factors could be also classified as passive or dynamic, as being demonstrated in a model for anterior cruciate ligament (ACL) injury (Hughes and Watkins, 2006). Some risk factors are not changeable – female are more predisposed to ACL injury during the pre-ovulatory phase of the menstrual cycle (Hewett et al., 2007), and players with previous ankle injury history are at higher risk to sustain ankle sprain injury (Kofotolis et al., 2007). In a specific sport, i.e. badminton, athletes with previous injury history were also more prone to re-injury (Yung et al., 2007). However, some risk factors are related to the human and sports biomechanics, the use of equipment, and the athletes' behaviour, which could be preventable. For example, female athletes having greater dynamic valgus and higher abduction loads are at increased risk of ACL injury (Hewett et al., 2005). Female having increased tibial varum, calcaneal eversion range of motion, less accurate passive joint inversion position sense, higher extension range of motion at first metatarsophalangeal joint, and less coordination of postural control are at greater risk of sustaining ankle sprains (Willems et al., 2005a). For male, greater talar tilt, slower running speed, less cardio-respiratory endurance, less balance, decreased dorsiflexion strength, less coordination, and faster reaction of the tibialis anterior muscle at ankle are the risk factors (Willems et al., 2005b). In the use of equipment, wearing shoes with air cells in the heel, and not performing pre-game stretching, are identified to be risk factors to sustain ankle injuries in recreational basketball players (McKay et al., 2001). In long-term, ACL injury and subsequent reconstruction was found to be risk factor for developing osteoarthritis (Seon et al., 2006). These additional details of identified risk factors from epidemiology studies provide information for biomechanists to establish the aetiology and also the mechanism of injuries.

3.2 Establishing aetiology and mechanism

Association between risk factors and sports injury can be causal or noncausal. Aetiology, also termed as etiology, pathology, pathogenesis, or pathomechanism, refers to the causal type risk factor necessarily present for an injury to occur (Meeuwisse, 1994). With the contribution of biomechanics analysis to this sports injury causation model, numerous studies were conducted to identify the aetiology of some specific sports injuries. For example, human biomechanics test in laboratory suggested that arm position during a cutting maneuver influenced the valgus moment at knee, which could be an aetiology for ACL injury (Chaudhari et al., 2005). A posteriorly positioned fibula predisposes a normal subject to ankle sprain injury (Eren et al., 2003). The delayed peroneus longus muscle activation time could cause lateral ankle sprains (Santilli et al., 2005). The information of identified aetiology further helps establishing the injury mechanism.

The understanding of the injury mechanism is also a key component of preventing sports injury (Bahr and Krosshaug, 2005). The most direct way is to study the real injury in a biomechanics laboratory, however, this is obviously unethical. Moreover, mimicking injury in laboratory is also practically very difficult or impossible. In rare situations, accidental sports injuries had unfortunately (or fortunately) occurred in a video-taped event or competition, which provided some valuable information for injury biomechanics analysis. In 1977, Zernicke and co-workers (1977) reported the first such analysis with video data of a human patellar tendon rupture during a weight-lifting competition. The study group further derived mathematical equations to study the load on the patellar tendon before, and most importantly, during the rupture. Qualitative analysis on video data of injuries was also performed by several research groups to describe the injury mechanism. For example, ACL injury mechanism was described to be a forceful valgus knee force combined with rotation of the tibia from a systematic video analysis (Olsen et al., 2004). For ankle sprain, video analysis suggested that the mechanism involves lateral or medial forces from tackles, creating corresponding eversion or inversion rotation of the ankle, thus causing the athlete to land with the ankle in a vulnerable inverted position (Andersen et al., 2004). Recently, Krosshaug and Bahr (2005) from the Oslo Sports Trauma Research Center developed a promising model-based image-matching technique for quantitative analysis of injury, by reconstructing three dimensional human motions from video sequences, from several or even just one camera. This technique could be applied to videos of real injuries to determine the predicted kinematics data such as joint angles, and even kinetics information such as ground reaction force, joint loading and torques (Krosshaug et al., 2007; in press). To date, this is the latest advance biomechanics technique for sports injury analysis.

However, the applicability is still limited – it would be possible to collect videos from commercialized elite sports events, especially soccer and basketball with every moment being recorded and replayed in multi-views, but it would not be feasible for most other sports, especially those in amateur, high-school, and recreational playing levels. Planning a similar study with this approach, i.e., to varsity competitions, is therefore not cost-effective and feasible, as one may need to spend a lot of effort video-taping competitions and "wait" for injuries. To cope with this, different approaches had been adopted, as summarized by Krosshaug and co-workers (2005). Most approaches are biomechanics investigations: in-vivo ligament strains and loading measurements, cadaver biomechanics experiments, mathematical modelling and simulation of injury, and measurement or estimation of "close to injury" situations. In-vivo strain of ligament is often measured by differential variable reluctance transducer (DVRT), liquid mercury strain gauge, and Hall-effect strain transducers (Woo et al., 1999). Studies of in-vivo strain of ankle ligaments with cadaver ankles revealed that ATFL is elongated in plantarflexion and shortened in dorsiflesion, but the reverse is found in calcaneofibular ligament (CFL) and posterior talofibular ligament (PTFL) (Ozeki et al., 2002). Butler and Walsh (2004) added that every ligament at lateral ankle does relax when the loaded is less than 5N, however, the ATFL does not relax to same extent as the other ligaments. Therefore, during a supination sprain, the taut ATFL acts as the primary restraint in inversion for the plantarflexed ankle, to bear most of the supination torque. For ACL, numerous studies were done with a robotic/universal force-moment sensor (UFS) device on cadaver knees, as summarized by Woo and co-workers (2005, 2006). In human subjects, intra-operative test was performed (Fleming et al., 2001), as well as functional dynamic motions such as squatting (Beynnon et al., 1997) with implanted transducers under local anaesthesia.

There are also some approaches employing inverse dynamic calculation to obtain joint and ligament biomechanics, or utilizing the finite element analysis technique to simulate the injury mechanism. For the knee, Mommersteeg and co-workers (1997) employed the inverse dynamics modelling approach to determine the function of the knee ligaments for the understanding of failure mechanism of ACL. Finite element models were developed by various research groups to study the effect of anterior tibial loads, knee flexion, graft stiffness and tunnel angle on the biomechanics of ACL and knee joint (Pena et al., 2005; Song et al., 2004). For the ankle, Corazza and co-workers (2003) employed a mathematical model of ankle joint to investigate the effect of anterior drawer test on the human ankle joint. Wright and co-workers (2000) developed a series of muscle model drive simulations and revealed that taping or bracing eliminates the spraining mechanism and leads to decreased ankle sprain susceptibility.

The measurement or estimation of “close-to-injury” situations is also a widely adopted approach. For example, ankle inversion platforms were used in studying a simulated ankle sprain motion (Karlsson et al., 1992), and unanticipated cutting tasks were performed in studying the critical moment which ankle sprains usually occur (Dayakidis et al., 2006). Running and cutting maneuvers (Besier et al., 2001), stop-jump task (Yu et al., 2006) and reactive jumping task (Sell et al., 2006) were investigated to study the biomechanics of the knee during these “close-to-injury” situations. All these attempts, although not studying the real injury situations, still provide information to understand and quantify some undesired motions which should also be avoided. This allows experiments to collect comprehensive biomechanics information with sufficient subjects, in order to better understand the injury mechanism with certain generalizability.

3.3 Designing preventive measures

After identifying the risk factors and understanding the mechanism, biomechanics contributes to the design of preventive measures. Prophylactic devices, which include footwear, brace and taping, are one of the most popular preventive measures. For the ankle, the mechanism of sport-related ankle sprains were identified as landing with in inverted and plantarflexed ankle position with forced ankle inversion, therefore, high top shoes, brace and taping were designed to attempt to prevent such undesired ankle orientation and motion during sports (Garrick and Requa, 1973). For the knee, prophylactic braces were design to limit the horizontal tibial force and thus prevent ACL rupture (Najibi and Albright, 2005). For a specific sport, i.e. softball, sliding to the bases was found to be responsible for most recreational softball injuries in the lower extremity, therefore, quick-release bases that break away upon a slide were introduced to reduce the injury rate (Janda et al., 1990).

Recently, there is an innovative attempt in designing a “sprain-free sport shoe” for supination ankle sprain injury in sport (Chan, 2006). Ankle injuries were identified as one of the most popular sport-related injuries. Among, over 80% were ligamentous sprains sustained from a sudden explosive supination spraining mechanism, which happened before the peroneal muscles could react to compensate the motion. Therefore, an intelligent "sprain-free sport shoe" is being designed in order to produce a resistive torque to the supination torque before the peroneal muscles react. A three-step mechanism is employed, which involves (1) sensing, (2) identification, and (3) correcting. Firstly, sensors are embedded in the shoe to detect foot and ankle motion plus plantar pressure in order to predict the supination torque. Secondly, a safe supination torque limit is determined as a standard to identify if a supination motion is hazardous. Finally, a corrective device activates and generates resistive torque in a short time (within 50ms) to attenuate the supination torque, in order to delay or stop the motion, until the peroneal muscles react. A testing device was also designed for the evaluation purpose, i.e. a "supination sprain simulator" was recently designed to simulate ankle supination sprain mechanism for the evaluation of shoes and braces for ankle protection (Chan et al., 2007). These examples show the application of biomechanics is an essential element in designing preventive measures to prevent sport-related injuries.

The biomechanics information is also useful in designing exercises or interventions, and even proposing changes in rules and playing strategy for injury prevention. Proprioception training on balance board (Caraffa et al., 1996; Verhagen et al., 2004), muscle function training by plyometric-based exercise (Irmischer et al., 2004), reaction training on ankle disk (Sheth et al., 1997), introducing compulsory warm-up and cool-down sessions (Hume and Steele, 2000) and landing skill practice (Myklebust et al., 2003) were designed for prevention ankle sprain and ACL rupture incidence. Injuries in rugby were believed to have association with match speed and the impact forces during physical collisions and tackles. Gabbett (2005) introduced a limited interchange rule to the game, and found that the injury rate was significantly reduced in a one-year prospective study. It was suggested that the match speed and impact forces were reduced because the players got fatigued due to the limited interchange rule. All these examples showed how the biomechanics information provides idea for designing preventive measures.

3.4 Evaluation of effectiveness

Biomechanics assessment is often conducted to evaluate the new preventive measures before it is introduced to the athletes. The measurement is the effect to eliminate the risk factors, the aetiology or the mechanism. For the ankle, cloth sport shoes were evaluated to be insufficient in providing lateral heel stability, thus, such shoes should not be introduced to court games (Fong et al., 2007b). Semi-rigid but not lace-up braces were found to be effective to resist dynamic forces ankle inversion (Ubell et al., 2003). High-top shoes were effective in reducing the amount and rate of inversion during a simulated inversion on an inversion platform (Ricard et al., 2000). Taping with lateral or medial subtalar-sling limited the strain on the anterior talofibular ligament and protected the subtalar ligaments from excessive loading (Wilkerson, 2002). For the knee, knee brace with a constraint to knee extension could decrease the knee flexion angle at landing, and thus may be useful to prevent ACL injuries in sports (Yu et al., 2004).

Finally, if deemed necessary, prospective study with the preventive measures implemented could be conducted. For example, randomized controlled trials demonstrated that balance training with wobble board is effective in improving static and dynamic balance, and reducing sports related injuries and recurrent ankle sprains among healthy adolescents (Emery et al., 2005). A three-year prospective study reported that soccer boots with cleat designs with lower torsional resistance could reduce the incidence rate of ACL injury in high school soccer players (Lambson et al., 1996). If a preventive measure is assessed to be biomechanically effective, or preferably clinical effective, it is ready to be implemented in injury prevention program for athletes.

4. Biomechanics for immediate evaluation of treatment

There are five main biomechanics tools which are often used in evaluating the biomechanical outcome of treatment in sports medicine – (1) muscle activity and functions, (2) joint loads, torques and kinetics, (3) motion and kinematics, (4) proprioception and kinaesthesia, and (5) sports performance. Muscle functions are widely investigated – hamstrings and quadriceps strength and activity were investigated to study ACL injury (Ramsey et al., 2003), while peroneal muscles reaction was investigated to study ATFL sprains (Karlsson et al., 1992). Joint kinetics, such as valgus torque at knee (Withrow et al., 2006) and supination torque at ankle (Markolf et al., 1989) are also often reported. Kinematics is the most widely employed tool for evaluation, especially the in-vivo knee kinematics in related to ACL injury and reconstruction. For example, Benoit and co-workers (2007) employed intracortical pins inserted on tibia and femur to study the tibia translation and rotation with respect to the femur. Andriacchi and co-workers (1998) from the Stanford University designed a Point Cluster Method, which consists of a cluster of about 25 skin-attached markers, to reduce artifacts introduced by skin movement in order to determine in vivo kinematics with such non-invasive method (Andriacchi and Dyrby, 2005; Dyrby and Andriacchi, 2004). Recently, Tashman and Anderst (2003) reported a method employing biplane radiographic and computer tomography imaging at 250-1000 Hz to locate tantalum spheres of 1.6 mm inserted to the distal femur and proximal tibia with a 10-250 micrometers accuracy. Such method allows investigation of knee kinematics with minimum invasive alternation. Proprioception, as measured as the accuracy for joint re-positioning, in either active or passive motion, is also adopted in evaluation the biomechanical outcome (Fu et al., 2005; Xu et al., 2004). Last but not the least, sports performance is also an important criterion when prescribing the treatments, as we do not wish that the performance is hindered by the treatments. Burks and co-workers (1991) investigated several commercially available ankle support devices and found different degree of drop of performance. Cordova and co-workers (2005) conducted a meta-analysis and found that increased ankle support reduces ankle eversion range, but also inhibits jumping and running performance. However, they suggested the benefit in injury prevention should outweigh the impairment of performance.

Treatment to sports injuries, either acute or chronic, can be operative or conservative, and they vary with the specific problem. For example, in ACL reconstruction, procedures vary because of different tunnel placement, graft selection, graft length and thickness, fixation method and even single-bundle or double-bundle approaches (Fu et al., 2000). Although numerous cadaver studies have been conducted before applying any new approaches in patients, the individual difference of each patient may lead to the decision for a patient-specific operative procedure (McGiffin et al., 1997). Therefore, intra-operative assessment may help surgeons to evaluate the immediate outcome during the operation. For ACL reconstruction, Bull and co-workers (2002) used an electromagnetic device for motion capturing for intra-operative measurement of knee kinematics during ACL reconstruction and found that abnormal anterior and rotational subluxation of an ACL deficient limb was abolished after the operation. Intra-operative investigation with navigation motion capture system revealed that knee stability in both anterior-posterior translational direction and rotational direction were restored after double-bundle ACL reconstruction (Ishibashi et al., 2005).

Conservative treatment can also be evaluated immediately with biomechanics analysis. For the knee, Ramsey and co-workers (2001) found that functional knee brace does not have significant effect in reducing anterior tibial translations in ACL deficient patients in maximal horizontal jump. They further investigated and found that functional knee brace improved proprioceptive feedback and increased hamstring and quadriceps activity during landing and running, thus, enhancing knee joint stability (Theoret and Lamontagne, 2006). This may add stability to ACL deficient knee. Swirtun and co-workers (2005) found that functional knee brace improved the sense of stability, but had no effect in quadriceps and hamstring muscle peak torque. For the ankle, Karlsson and Andreasson (1992) reported that ankle taping significantly improve the peroneus muscle reaction time in ankle with mechanical instability. All these biomechanics evaluations provide evidence for orthopaedics specialists to consider or re-consider the prescription to specific musculoskeletal problems.

5. Biomechanics for long-term outcome evaluation

Finally, biomechanics also serves the role to monitor long-term rehabilitation progress (Woo et al., 2004). It also serves as a referee to decide whether a rehabilitated athlete is ready to return to sports (Kvist, 2004). This is simply a series of regular biomechanics assessments with respect to time, to evaluate if certain biomechanics parameters are returning to or deviating from a desired standards or values. For the ankle, a ten-week ankle disk training with adhesive tape on the ankle enhances a two-week earlier correction of postural sway, probably due to the increased afferent input from the skin receptors by the traction of the adhesive tape (Matsusaka et al., 2001). For the knee, prolonged extensions at hip and knees in a jump-landing were found in ACL-reconstructed limb 33 months after surgery in an elite female basketball player, suggesting normal lower limb biomechanics was not sufficiently restored (Fong et al., 2006b). Prospective studies revealed that the abnormal tibial rotation in ACL deficient knee is not restored with a single-bundle reconstruction in running at one year after the operation (Tashman et al., 2004, 2007) and in stair walking, jump-landing and pivoting at two years after the operation (Ristanis et al., 2006). In rehabilitation after ACL reconstruction, a study showed that humans walk with normal kinematics patterns but altered joint torque and power patterns after a six-month accelerated rehabilitation intervention (DeVita et al., 1998). Therefore, these patients were assessed as not yet “rehabilitated” in terms of knee rotational stability.

The decision to return an injured or rehabilitated athlete to sports is empirical (Kvist, 2004). Biomechanics assessments on physical criteria provide an objective way to evaluate if an athlete is adequately rehabilitated (Podlog and Eklund, 2004), and is often awaited by physicians to make objective recommendation for return to sports (Morganti, 2003). For ACL patients, the concerns are the time to return to sport, the re-injury risk, the prevalence of the development of osteroarthritis, and lastly, the time to quit (Myklebust and Bahr, 2005). The objective biomechanics measurements include dynamic assessment of baseline limb strength, patient-reported outcomes, functional knee stability, bilateral limb symmetry with functional tasks, postural control, power, endurance, agility and technique with sport-specific tasks (Myer et al., 2006). For monitoring the rehabilitation progress of ACL patients, performance of gait and physical activities could help determining the recovery progress, i.e., normal gait was restored in 3-4 months after ACL reconstruction, but single-leg hopping, being a more challenging task, could only be restored 5 months post-operation (Button et al., 2005). However, there is still a lack of such approach in sports medicine, probably because of the lack of consensus to establish such controversial "standard criteria" for return to sports. Therefore, yet, physicians still rely on experience and personal judgement to advice if a patient could return to sports (Podlog and Eklund, 2004). The need of objective biomechanics assessment as criteria to determine return-to-sports should be addressed as a future research direction.

6. Conclusion

A new paradigm "Orthopaedic sport biomechanics" is proposed in this paper, for the better understanding of the role of biomechanics in preventing and managing sports injury. The clinical relevance is for the orthopaedics and biomechanics specialists to understand what they could contribute to injury prevention, objective assessment of immediate treatment outcome, and long-term monitoring of rehabilitation progress for making suggestion to return to sports. Related researches on sport-related knee and ankle injuries, with specific attention on anterior cruciate ligament (ACL) rupture and anterior talofibular ligament (ATFL) tear respectively, are highlighted for better elaboration of the new paradigm. This interdisciplinary synergy will become a fashion approach in preventing and managing sport-related injuries, and will help suggesting biomechanics assessments for determining object return-to-play guidelines, which is lacked in the current literature.

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Figure legends

Figure 1 – New paradigm of "Orthopaedic sport biomechanics" in preventing and managing sports injury, flowing counter-clockwise from "Sports Participation".

Figure(1)
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