CHAPTER II

LITERATURE REVIEWS

1. The junior sports athletes

The junior or adolescent population age ranges between 11-20 years old. This range can be separated into 3 periods: early adolescent (10-13 years old), middle adolescent (14-16 years old), and late adolescent (17-20 years old). The rate of development may vary for each individual and development may continue after 21 years until the complete maturation at 25 years (14). Usually, girls start and stop theses physical changes earlier about 2 years before boys do. Injury prevention strategies for young athletes should receive more attention because the variability in maturation rate of the adolescent greatly affects their neuromuscular system. The Sports Authority of Thailand limits the age range of the junior athletes to be less than 18 years old (15).

2. History and development of badminton

Regarding the history of badminton, there are no historic records to tell us about the exact origin of this game. However, many people believe badminton has its origins in ancient civilizations in Europe and Asia more than 2,000 years ago. Modern badminton came from a child's game called battledore and shuttlecock, in which two players hit a feathered shuttlecock back and forth with a simple wooden bat. It was a favorite game at the Badminton House in Gloucestershire, England, the home of the Duke of Beaufort, and in 1873 it became known as 'the Badminton game' among various guests who introduced it to other friends. This greatly increased the game's popularity in England and “Badminton” became its official name (16-18).

Badminton has almost a century of history in Thailand. In 1913 (Buddhist Era 2456), the first outdoor badminton court was built at Praya Nipatkullapong’s home and from there its popularity grew. Standard indoor badminton courts were built and over time as Thai players developed their mastery of the game to a highly competitive level. Currently, badminton is one of the most popular sports in Thailand. Many Thai badminton players are eligible for international competitions such as the Thomas Cup, the Uber Cup, and the Olympic games (16). Given this level of professionalism and popularity, it is important to attend to the movement technique of Thai badminton players, especially those at junior level, so that if improper movements should occur, there can be a prompt correction to prevent associated injuries and aid better development for the future elite athletes.

3. Simplified law of badminton

Badminton is a game that resembles both tennis and volleyball and involves the use of a net, lightweight rackets, and a shuttlecock. It is played by two or four players, either indoors or outdoors, on a marked-out area 13.40 meters (m) long by 5.18 m wide for the two-player game and 6.10 m wide for the four-player game. A net is fixed across the middle of the court, with the top edge of the net set to a height of 1.53 m from the ground at the posts. The players hit the shuttlecock back and forth over the net with the rackets. Only the serving side can win a point. A game is played to 15 points, except in women's singles, in which a game is played to 11 points (18).

4. Epidemiology of badminton injury

Although badminton injuries are not as frequent, they are more severe and are correlated with longer hospital times than other sports (1, 2). Previous studies reported the epidemiology badminton injuries in various ways. Yung et al (19), who retrospectively surveyed the injury rate on 44 Hong Kong elite badminton players in 2003, reported the overall injury incidence rate to be 5.04 per 1,000 players per hour. Elite senior players (age 21 – 28 years) had the highest incidence rate of recurrent injuries (4.58), while elite junior players (age 16 – 21 years) had the highest incidence rate of new injuries (3.10).

Hoy and coworkers (1) determined the epidemiology of badminton injuries during a 1 year period at Randers City Hospital, Denmark. The incidence of injuries among players younger than 18 years old was 28 per 1,000 players per year. Players between 18 and 25 years old had an injury incidence of 45 per 1,000 players per year, and for those over 25 years old the incidence was 42 per 1,000 players per year. Although most overall injuries occurred in men (58% versus 42% in women), girls had a higher injury rate among players younger than 18 years old.

Hensley and Paup (20) used questionnaire to survey the badminton injuries rate from 231 players, ranging from club players to international champions, in sanctioned badminton tournaments in the United States and Canada. They found that the incidence rates of the female and male badminton players were 0.14 and 0.09 injuries per person per year respectively.

Both competition (1, 19) and training (21) were reported as times common for badminton injury occurance. Most injuries occurred to the lower extremity (1, 2, 19-21), involving the knee and ankle, much like injuries of other racket sports with motions (5). Kroner et al (2) reported that with injuries to the joints and ligaments, the latter were in form of sprains and ruptures, and were often seen in players younger than 30 years old and almost always occurred at the ankle joint (66.9%), the knee joint (15.7%), and foot (11.0%) respectively. Yung and coworkers (19) found that most injuries in Hon Kong elite players occurred to the lower extremity such as thighs and knee joints. And for elite junior players who had the highest overall lower extremity injury rate, injuries to the knee were most common. According to Shariff et al (21), who reported the musculoskeletal injuries among Malaysian badminton players in the National Sports Institute Clinic, the common location of these lower extremity injuries was the knee (37.1%), followed by the ankle (28.3%) and thigh (13.2%). This finding was consistent with the studies in Thai badminton players. Piensajja (3) who surveyed the epidemiology of badminton injuries among recreational players in Chiang Mai province presented that most of these players (83%) reports injuries to some parts of the body with most (42%) of the injured players suffered knee injuries (3). Pirunsan and coworkers (4) reported the most injuries in junior badminton players also occur in the knees (25.6%), ankles (18.9%) and calf muscles (15.6%).

The main cause of badminton related injuries were intrinsic factors, such as muscle weakness, muscle imbalance, lack of flexibility, or the player's individual way of moving their body to retrieve the shuttle by jumps, lunges, and sudden changes in direction plus twisting actions or in the stroke motion itself (2, 5, 20). Previous studies reported that the most common mechanism of the injuries was overuse (2, 3, 21).

5. Anatomy of the knee

The knee is one of the most complex joints and is commonly injured during sports participation. It is a large synovial joint including two joints: the tibiofemoral joint and the patellofemoral joint (PFJ). The tibiofemoral joint, which is commonly known as the knee joint, function as a modified hinge joint. Because when it moves, it does not only bend and straightens (flexion and extension) but also entails a slight rotation in the motion. The tibia rotates laterally to the femur during the last few degrees of knee extension to produce the "locking" of the knee. This mechanism, known as the "screwing home", brings the knee into the closely packed (most stable) position of full extension (22).

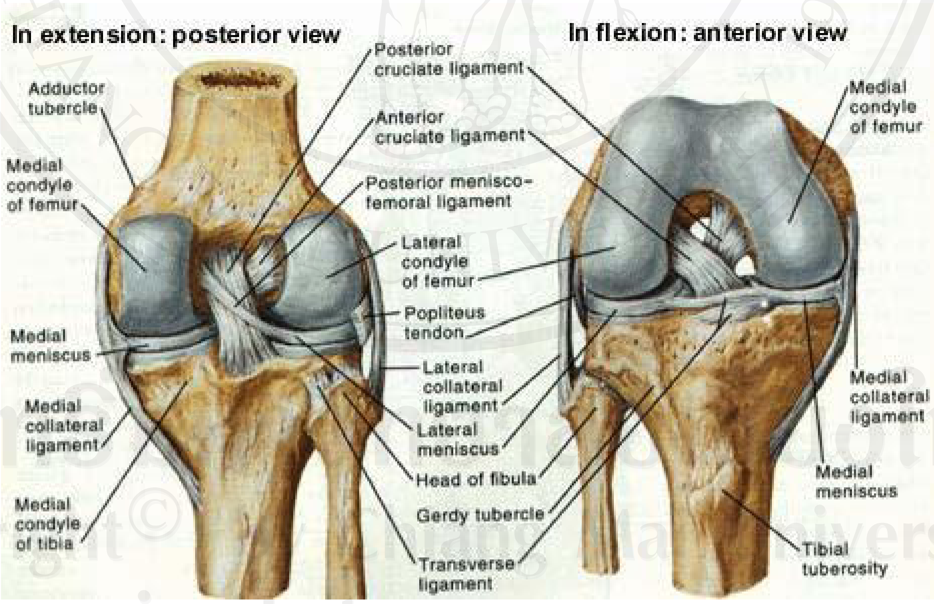

Figure 1. Right knee anatomy (23)

The knee joint also has a structure made of cartilage, which is called the meniscus. The meniscus, which fit in to the joint between the tibia and the femur, have an essential role as a shock absorber, buffering some of the force placed through the knee joint, and thus protecting the joint and allowing the bones to move freely.

There are also many bursas around the knee joint. A bursa is a little fluid sac that helps the muscle and tendon slide freely as the knee moves. The suprapatellar bursa, which is the largest bursa in the body, is located between the femur and quadriceps femoris tendon. Posteriorly, there are two other bursae: those between the lateral condyle of the femur and popiteal muscle (subpopiteal bursa) and between the medial head of the gastrocnemius and semimembranosus tendons (22).

Because the feature of the articular surface of the tibiofemoral joint contributes little stability to knee joint, the stabilizing role of the ligaments crossing the knee is more essential. Among the most important, and most often injured, are the cruciate ligaments and the collateral ligaments (22). The two cruciate ("cross") ligaments, anterior and posterior, are often referred to as the "crucial" ligaments, reflecting their importance in sporting activities. Their name relates to their attachment to the tibia. The weaker of two, the ACL, runs posteriorly and superiorly from its attachment, on the anterior portion of the intercondylar surface of the tibia, to attach at the posteromedial aspect of the lateral condyle of the femur. The primary role of the ACL is to prevent excessive anterior movement of the tibia relative to the femur. It also plays secondary role to limit valgus, varus, and tibia rotation (11). The shorter and stronger posterior cruciate ligament (PCL) extends from the posterior aspect of the tibia intercondylar area in a superior, anterior direction to attach at the anteromedial aspect of the medial condyle of the femur. The PCL prevents the posterior translation of the tibia on the femur.

The medial and lateral collateral ligament provide medial and lateral stability to the knee joint (prevent valgus and varus movement of the knee). The medial collateral ligament (MCL) extends from the medial epicondyle of the femur merge with the joint capsule and medial meniscus to the medial tibia. This means MCL injuries can occur with medial meniscus tears. Its role is preventing medially direction shear (knee valgus) and rotational forces acting on the knee. On the opposite side of the knee, the fibers of lateral collateral ligament (LCL) run from the lateral epichondyle of the femur to the head of the fibula, with no attachment to the lateral meniscus. The LCL serves to limit excessive laterally directed shear force (knee varus) acting on the knee (22, 24).

The knee muscles which cross the knee joint generate tension to produce knee movement and cooperate to enhance the knee's stability. They organize force in the lower limb and decelerate the body over the lower limb during running, landing, cutting, and stopping during sports activities. Principal muscles of knee control include the quadriceps, the hamstrings, the gastrocnemius, the gluteus medius and tensor fascia lata/iliotibial band, and the adductor (7).

The patella is a triangular bone generally known as kneecap. It located between the quadriceps tendon and its attachment on the tibia tuberosity, which gives it the mechanical advantage of the knee extensor mechanism (increase the angle of pull of the patellar tendon on the tibia). The patella also offers some protection for the anterior aspect of the knee. The articulation of the patella with the femur forms the

PFJ. The PFJ experiences great loads when the knee is in flexed position and thus is predisposed to injuries (24).

6. Biomechanics of the knee

6.1 Kinematics

Kinematics defines the range of motion and describes the surface motion of a joint in three planes: frontal (coronal or longitudinal), sagittal, and transverse (horizontal). Clinical measurements of joint range of motion (ROM) define the anatomical position as a zero position for measurement. Gross measurements can be made with a goniometer, but more specific measurements require the use of more precise methods such as electrogoniometry, cinematography, or optoelectric techniques (25).

In the tibiofemeral joint, motion takes place in all three planes, but the ROM is most present in the sagittal plane. The motion from full extension to full flexion of the knee is from 0º to approximately 140º. Motions in the transverse plane, internal and external rotation, are affected on the position of the knee joint in the sagittal plane. In full extension, the knee joint is in a close packed position and rotation motion is almost completely eliminated. The range of rotation increases as the knee is more flexed. At 90º of knee flexion, maximal external rotation ranges from 0º to approximately 45º and internal rotation ranges from 0º to approximately 30º. Similarly affected by the degrees of knee flexion, the motions in the frontal plane include valgus and varus. A close packed position limits almost all motion in the frontal plane. Valgus and varus increase with knee flexion up to 30º and they touch an maximum range approximately 10º to 20º (25, 26). Thus many knee ligament injuries, which are produced from the force in the medial or lateral direction, often occur in slightly bent knee positions.

During flexion/extension movements the patella glides superiorly and inferiorly against the distal end of the femur almost in vertical direction as much as 8 centimeters (22). It also experiences medial and lateral displacement as the tibia is rotated laterally and medially, respectively. The quadriceps tendon, which attaches to the patella, produces the net force acting on the patella. Mistracking of the patella during knee flexion/extension can be terribly painful and requires medical attention.

6.2 <u>Kinetics</u>

Kinetics analysis allows one to resolve the size of the moment and force on the joint produced by body weight, muscle action, soft tissue resistance, and externally applied load in any position and to verify which actions produce excessively high momentum or force (25).

For the force acting on the tibiofemoral joints, both compression and shear forces act on these joints during daily and sports activities. Weight-bearing and tension development in the muscles crossing the knee contribute to these forces, with compression dominating when the knee is fully extended. As knee flexion occurs and the angle at the joint increases to 90º degrees, the shear force produced by weight bearing increases. Shear force at the knee, which may cause the femur to displace anteriorly on the tibia plateaus, must be resisted by the ligaments and other supportive structures crossing the knee. Because these structures can be stretched or even ruptured under such stress, activities like deep knee bends and full squats that require load bearing during deep knee flexion are risk to injury (22).

On the one part of forces acting on the PFJ, compressive force at this joint has been found to be half the body weight during a normal gait, increasing to over 3 times body weight during stair climbing. The squat exercise, commonly known for being particularly stressful on the knee complex, produces a PFJ reaction force about 7.6 times body weight (22). In conclusion, activities such as extreme knee bends produce a large shear force at the tibiofemoral joint and more compressive force at the PFJ. The knee ligaments are the primary stabilizers for all motion of the knee, and along with the miniscus, joint capsule, and muscles around the knee, they produce knee stability.

7. Knee Injury

Because the knee is positioned between the body's two longest levers, the femur and tibia, a large amount of torque and force can be developed at the knee in sports activities. To understand more about knee injuries in badminton activities, the mechanisms of injury, risk factors of knee injury, and type of knee injuries commonly presented in sports motions such as cruciate ligament sprain, collateral ligament sprain, meniscus injury, and knee extensor disorders will be extensively reviewed.

7.1 <u>Definition and mechanism of injury</u>

Whiting and Zernicke (24) describe the definition of 'injury' as the damage caused by physical trauma and sustained by tissue of the body. Injuries can occur when a single overload exceeds a tissue's maximum tolerance. Sports injuries may be categorized as acute or overuse injuries, depending on the mechanism of the injury and the onset of symptoms. Use is normal functional loading, whereas overuse is repeated overloading. Many injuries, like tendonitis and carpal tunnel syndrome, are called overuse injuries because they result from repeated overload with deficient recovery time. Overuse injuries can be represented as conditions noted by an etiology of repeat force application. These injuries are chronic injuries and may also be referred to as cumulative trauma disorders or repetitive stress syndromes. The causes of these injuries are usually divided into extrinsic factors (such as unsuitable training, surface, shoes, equipment and environmental conditions) and intrinsic factors (such as malalignment, leg length difference, muscle imbalance, muscle weakness, lack of flexibility, and body composition). In contrast, injuries resulting from a single or a few loading incidents are called acute injuries. Acute injuries might be due to an extrinsic cause (such as a direct knock from contact with another player or equipment) or an intrinsic cause (such as a ligament sprain or muscle tear while performing an extreme and improper movement).

7.2 Type of knee injuries commonly present in sports activities

Knee joint stability primary depends on a static passive system of support from its ligament and capsular structure, rather than from an active dynamic system from the surrounding muscles. Bone and meniscus provide some increase in stability via their shape and natural stability when these structures are in a closed pack position.

The knee structures that more often affect from badminton players' injuries are such as knee muscles (hamstrings and quadriceps), collateral ligament, cruciate ligament, meniscus, patellar tendon, and PFJ (5, 21). Thus next part is a review of the common injuries in badminton players. These include cruciate ligament injury, collateral ligament injury, meniscus injury, and knee extensor disorders that may present in badminton players.

7.2.1. Cruciate ligament injury

The growing participation in exercise and sports in recent years has led to an increased incidence of cruciate ligaments injuries. According to Majewski et al (27), who documented the knee injuries in sports participants over a 10-year period in Switzerland, found that ACL injury is one of the most common sports player injuries. It presented 45.38 % of all knee ligaments injury cases and 20.34 % of all internal knee injury cases involving surgery treatment. There are two types of ACL injuries: contact and non-contact. Over two thirds (70%) of all reported ACL injuries are non-contact, while the remainder implicate contact from outside of the body force (i.e. an opposite player or another object on the field/court). The mechanisms of non-contact ACL injuries typically occur when engaging in the following movements: a one-step/stop deceleration, a rapid cutting movement, sudden change of direction, or a landing following a jump with insufficient knee and hip flexion (24, 28). Non-contact ACL injuries usually occur during a deceleration maneuver combined with a change of direction while the foot has contact with the ground. While the foot contact in closed-chain with the ground and pronated, the tibia is in an internally rotated position, and knee is slightly bent (0º - 20º flexion). If the player attempts to change direction, the result is an excessive force of torsion that can produce sprain or rupture the ACL (11). In addition, the ACL injuries sometimes occur due to knee hyperextension with internal tibia rotation mainly observed in gymnastics and basketball players when landing from jump (24).

Although its prevalence is lower than that of ACL injury, another commonly injured cruciate ligament is the PCL (22, 24). The PCL is the primary restrictor to the posterior drawer, and secondary restraint to external, valgus, and varus rotation (22, 29). There are many mechanisms of PCL failure. Most commonly, PCL injury occurs when knee flexed 90 degrees with force impact, moves the tibia posterior to the femur. Forced knee flexion with the foot either plantarflexed or dorsiflexed can also result in PCL injury. Unusual mechanisms of PCL injury are sudden and violent hyperextensions of the knee. This mechanism usually presents PCL injury along with ACL damage. The final mechanism is rapid weight shift from one foot to another while rotating the body quickly on a minimally flexed knee. This causes internal rotation and anterior translation of the femur and results in PCL damage (24).

7.2.2. Collateral ligament injury

Injury to the MCL is quite common, involving the LCL at lower frequency (24, 27, 29). Both injuries result from sudden and powerful valgus or varus loading. The MCL injury results from impact to the knee's lateral aspect or valgus loading while the foot is contact with the ground and the knee is flexed 25º – 30 º (24, 29). Patients usually experience MCL failure along with ACL injuries (which is the secondary restraint on valgus rotation of the tibia) and lateral meniscus injuries (because the mechanism of injury typically opens the medial side and compresses the lateral side (29). MCL injuries sometimes occur with medial meniscus tears because it merges with the joint capsule and medial meniscus to the medial tibia (24). Conversely, impact force on the medial side of the knee cause tensile loading of the knee's lateral aspect and produces LCL injuries. LCL injuries usually occur with a severe, high-energy, direct varus stress on the knee.

7.2.3. Meniscus injury

Acute meniscus tears occur when the shear stress generated within the knee in flexion or extension combines with femoral rotation during weight bearing (24, 29). For example, when an athlete with foot planted on the ground, attempts a rapid change of direction, internal femoral rotation on a fixed tibia cause posterior displacement of the medial meniscus. The medial meniscus attachment to the medial joint capsule and MCL decrease its mobility, thus increasing risk of injury compared with the more mobile lateral meniscus (24, 27, 29).

7.2.4. Knee extensor disorders

Disturbance of normal patellofemoral function often leads to injuries from fracture of the patellar to osteochondral damage of the patellofemoral with persisting PFJ pain. Injuries to the knee extensor mechanism could result from direct trauma, indirect trauma, or chronic overuse. Two such terms are used in referring to patellofemoral pathology: jumper's knee and chondromalacia patella.

The first term refers to tendon pain of the knee extensor mechanism developed through repeated jumping and useful to identify the location and condition of the involved tissue (i.e. quadriceps tendonitis, patellar tendonitis, opophysitis of the tibia tuberosity, or Osgood-Schlatter disease) in medical clinic (24).

The second term, chondromalacia patella, specifically describes the degeneration of the cartilage on the undersurface of the patella (24). The chondromalacia patella is now thought to be relate to overuse and often occur secondary to other mechanisms in both traumatic (i.e. patellar fracture) and chronic (i.e. patellar malalignment, chronic subluxation, phathological patella tracking) events that induce pain in the anterior knee.

7.3 <u>Risk factors related to knee injury</u>

The risk factors of knee injuries are from external and internal factors. The external factors are the causes from outside the body while the internal factors are from inside the body. An injury can be the result of a single factor or the combination of many risk factors, with the latter more common in sports.

7.3.1. Extrinsic risk factors

1) <u>Level of competition</u>

The injury incidences are lower during in training than in competition, which is more aggressive stress for the athlete (9, 10, 13). Hootman et al (13) surveyed 16 years of National Collegiate Athletic Association (NCAA) injury data in 15 sports and found that the rate of competition injuries was 3.5 times higher than the rate of training. Similarly, Arendt et al (28) revealed that both basketball and soccer players had the greater ACL injury in competition than in training sessions. However, both competition (1, 19) and training (21) were reported as time commonly get badminton injury.

2) <u>Skill level</u>

Several studies have examined the relationship between skill level and injury; however, the findings are contrary. Some previous studies have shown that a higher injury rate was reported in the athletes with low skill level, while the others reported in athletes with high skill level. Low skill level groups may have the same number of injuries as higher skill level groups, but show a higher incidence rate based on less exposure to sport. Alternatively, higher skill level groups may play at a more aggressive intensity than lower skill level thereby increasing the risk of injury (9).

3) Playing surface and shoes type

Injury frequencies were reported to be different for varying surface in several sports (10). Several researchers thought that the lower extremity injury in racquet sports may reflect harder court surface. High friction between the shoes and playing surface and low shock absorption shoes may increase the risk of injury to the knees and ankles (5, 30).

7.3.2. Intrinsic risk factors

1) Age

Tissue degenerative change can induce injuries incidence in older players. Higher injury rate has been reported with age increased in badminton, squash, and tennis players (1, 5). The studies showed players aged over 25 years had the highest injury rates. To compare female and male, there was higher injury rate in female than in male for aged under 18 years, contrast with the other age groups. Most ACL injury was found in female athletes aged 15 – 19 years (10). The young athletes showed these higher injuries due to the effect of the lack of physical maturity.

2) Sex

As the participation of women in sports continues growing, lower limb injuries in female athletes, such as knee pain or ankle sprain, are present at high rates in sport medicine clinics. Gender was also reported to be one of the factors contributed to knee injury. Several researches relate typical female anatomic features, such as an increased quadriceps angle (Q-angle), increased femoral anteversion, and a smaller diameter of the ACL to the higher knee injury rates of female athletes (7-9, 11, 12). These factors may have a direct impact when the body is dynamically moving and may induce injuries. ACL injury was found two to four times more often in females compared to males particularly in soccer and basketball players (28). This is because of the differences of hormonal, anatomical, and movement biomechanics factors.

2.1) Hormones: Estrogen plays an important role in ACL strength. The level of estrogen in menstrual cycle affects on fibroblast proliferation and type 1 collagen indicating ligament strength (31). The increasing estrogen induces the reduction of fibroblast proliferation and type 1 collagen. Thus, the ACL injury is often reported in preovulatory phase or before the onset of menses (7-11, 28).

2.2) Anatomical alignment: Lower limb alignment can induce injuries. Previous studies revealed that increasing of anterior pelvic tilt, femoral anteversion, tibia torsion, subtalar pronation, and Q-angle were the anatomical risk factors for ACL injury and anterior knee pain (7-11, 28). A wider pelvis in the female are associated with a gain in Q-angle (an angle between a line from the ASIS to the patella center and a line from patella center to the tibia tuberosity) and produce an increased valgus angle on the knee. In addition, the size of the intercondylar notch of the femur and the real diameter of the ACL itself are smaller that tend to have more non-contact ACL injuries in the female than male athletes (32).

2.3) Biomechanics: The common non-contact ACL tear involves a deceleration before change of direction or landing with foot contact and slightly bent knee. The results from several biomechanical studies showed that the movement of the cutting and/or landing in female is different from male athletes. Compare to male, the kinematics and kinetics analysis of lower limb joints in female volleyball players in stimulated landing, showed less hip and knee flexion angles when landing. And female volleyball players applied higher ground reaction force than male player during landing (33). This finding is similar to the study of Schmitz et al (34) who found gender differences in sagittal plane kinematics. An electromyographic (EMG) analysis of knee muscles during jump landing showed that the hamstrings activity was firing lower in female than in male at 15º, 20º, and 25º of knee flexion angles (35). Thus, the lower knee flexion angle and less hamstring activity in female athletes may induce the higher non-contact ACL injury because of allowing anterior tibia translation on the femur (33-35). Some studies were not only found the motion different in sagittal plane but also found in the frontal and transverse plane between female and male (36-39). Knee valgus with internal or external rotation commonly reported in female athletes with high risk of ACL injury (7-11, 40-42).

3) Muscle strength, imbalance, and activation patterns

Muscle strength, imbalance, and activation patterns can be the risk factor of knee injury. The quadriceps muscle acts as an antagonist to the ACL and it increases the anterior shear force on the tibia, whereas, the hamstrings muscle acts as an agonist to the ACL and it prevents the excessive anterior translation of the tibia on the femur. If the hamstrings shows weakness or a delay in contraction time when versus the quadriceps, the ACL may have increased risk of injury (11). Female showed significantly lower quadriceps and hamstrings muscle strength than male, when the muscle strength is normalized for body weight (43-45). The hamstrings/quadriceps ratio (H/Q ratio) has attracted a great deal of interest and was used as an indicator of normal balance between the flexor (hamstrings) and the extensor (quadriceps) function in the knee (43, 46, 47). A low H/Q ratio has been suggested to be a contributing factor to knee injuries such as ACL tears (43) and overuse knee injuries (48).

Additionally, some female athletes seem to have different coactivation patterns between quadriceps and hamstrings than males. The coactivation of the hamstrings with quadriceps is essential to advance the dynamic component of joint stability. The female athletes tend to have quadriceps dominant pattern or contract their quadriceps first and reply to anterior tibia translation, whereas the male athletes preferred to contract their hamstrings first. This quadriceps dominant pattern can produce more strain on the ACL than the synchronous cocontraction of hamstrings and quadriceps muscle or that of contracting hamstrings before quadriceps (8).

4) Body size

The effects of height, weight, lean muscle mass, body fat content, and body mass index (BMI) on knee injury is still in conclusive. Both increasing and decreasing of these variables may relate to the increasing of forces action on the body structures (9).

5) Limb girth

Limb circumference or limb girth relates to the maximal force that muscle can produce. In the field test, limb girth is measured by the physiological cross sectional area of muscle (9).

6) Flexibility

Flexibility is indicated by joint laxity and muscle flexibility. Some studies showed that knee injury related to increased of joint laxity and muscle tightness (8, 9). Recent study stated that only increasing of muscle tightness produced knee injury (43).

7) Previous injury and inadequate rehabilitation

Previous knee injury, muscle weakness, muscle imbalance and incomplete tissue recovery may induce the reduction of hamstrings and quadriceps co-contraction. Thus, the stress can be increased on knee ligaments and meniscus.

8) Aerobic fitness

The aerobic fitness is the integration of the musculoskeletal, the cardiovascular, and pulmonary system. Low aerobic fitness can be a risk of knee injury due to fatigue. The reduction of force resulted from decreasing in muscles recruitment patterns may induce knee instability while fatigue is occurred.

8. Biomechanical analysis of knee joint in badminton movements

During competition, badminton player requires the performance of work in the nature of sprints, stops and starts, jumps, leaps, lunges, rapid changes of direction, twists and turns and a variety of strokes. Awkward techniques to approach or return the shuttle cock may be associated with the injury of badminton players. The lower part of the body, especially knee joint, was more often injured compared with the upper part of the body; however, the studies of kinematics of the lower limb motion during badminton tasks is still lacking.

Most of the previous studies related to badminton player's motion have been focused on the upper extremity movement. A study of Tang et al (49) in 1994, three-dimensional (3D) cinematographical was used to analyze the forearm and hand during forehand smash. Huang et al (50), kinematically analyzed three badminton backhand overhead strokes (drop, clear and smash techniques) in eight Taiwanese male subjects. Tsai and coworkers (51) compared the performance of the smash and the jump smash between Taiwanese elite players and collegiate players with a 3D model.

Most previous researchers investigated the knee movements during other sports tasks that might relate to knee injury especially ACL injury. The video analysis study of Cochrane and coworkers (52), who investigated the causes of the 34 ACL injuries in Australian football league over the period from 1992 to 1998, reported that most of ACL injuries presented in non-contact injury during side stepping, landing, landing and stepping, stopping or slowing, and crossover cutting. The knee in the valgus, varus, internal and external rotation positions were observed during these non-contact ACL injuries occurred. However, knee positions in valgus and internal rotate were mostly presented in these knee injuries. Additionally, most of non-contact injuries occurred at foot contact with extended knee or bended knee less than 30º. VDO analysis is a comfortable tool which can provide the mechanism of sports injury on-field situation; nevertheless, it has limitation to give accurate joint biomechanics. Hence, the 3D motion analysis laboratory could give us more accurate joint kinematics data during perform these risky ACL injury movements such as cutting and landing.

Two typical techniques are often performed during badminton play including the jump smash and net lift, place badminton players into greater risk for knee injury. The jump smash produces more stress on the knee joint while players landing from jump, whereas the net lift shot requires deep lunge and might contribute excessive force on both the patellofemoral and tibiofemoral joints.

8.1 Biomechanical analysis of knee joint in sports involving jumping

Jump smash

Badminton jump smash involves propel jumping and landing technique in vertical direction similar to vertical jumping in others sports such as volleyball and basketball. Previously, the ground reaction forces which are absorbed by the body during landing in badminton game were not reported; however, these loads reaching 3 – 14 times body weight have been measured for landing action in many sports (8). Combine with more loads transfer from ground reaction forces, an awkward landing techniques as a badly knee joint position in any dimensions during landing could relate to the knee injury in any sports athletes (8, 10, 40, 41).

Several studies compared the knee kinematics data between female and male during landing movement. Salci et al (33) compared the lower extremity kinematics and kinetics data between male and female volleyball players during landing on both feet in laboratory setup. The six cameras were used to capture the landing task and the reflective markers were placed on the anatomical landmark of both legs. Their coordination in flame were used to calculate the joint angles. The significant differences were found only in sagittal plane that female players showed less hip and knee flexion angles when landing from jump compared to males. Similarly to the study by Lephart and others (45) in 2002, who estimate kinematics and strength variables of the knee in healthy collegiate female basketball, volleyball, and soccer players compared with matched males during single-leg landing and forward hop landing task. During performed single-leg and forward hop landing, the females showed lower knee flexion and knee internal rotation than males. Weaker thigh muscles (hamstrings and quadriceps) were presented in females as less peak torque to body weight at 60º/sec compared to males. In contrast, the study of Nagano et al (39) in 2007 and Kernozek et al (53) in 2005, who analyzed the 3D kinematics of the knee during single-leg landing, found significant differences in females' knee joint kinematics in transverse (higher internal rotation of tibia) (39) and frontal plane (higher valgus knee) (53) compared to male. Most of researchers conclude that the different knee joint motions that occurred in females (less knee flexion, knee valgus, or tibia internal rotation) may lead to higher knee injury rate, such as ACL tears, compared to males.

8.2 <u>Biomechanical analysis of knee joint in sports involving lunging</u>

Net lift shot

Front court stroke to return the shuttle from the opponent such as net lift or underarm clear requires rapid stretching of the leg and forward bending (lunging) of the knee. Because the players must transfer more weight to the front leg, apply more knee bend, and initiate sudden stop movement and/or return to the ready position, injuries of the knee are related to this task. In the current literature there are no studies of 3D kinematics regarding the lunging movement pattern of the lower limbs during badminton. The study of Escamilla and coworkers (54) in 2008 compared the patellofermoral compressive force and stress during the forward and side lunge with and without a stride. They found that the patellofemoral force and stress, which were calculated from a biomechanical model of the knee, increasing along knee flexion increased and decreasing during knee flexion decreased. The side lunge and the forward lunge produce the similar patellofemoral force and stress excepted during knee flexion between 80º to 90º were showed higher force loading in side lunge than forward lunge. When adding a stride, which is perform stepping and return to starting position, the patellofemoral force and stress were presented greater than lunging without a stride between 10º to 50º of knee flexion. This study showed only the knee angle in sagittal plane related with the force acting on the PFJ as the subject performed a lunging exercise. Therefore, the lunging with sports movement such as the badminton footwork requires additional attention.