A BIOMECHANICAL ANALYSIS OF THE KNEE JOINT DURING POWER SNATCH

by

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ABSTRACT

This study focuses on the biomechanics of the knee joint which is one of the most frequently injured joint among weightlifters. Most of the techniques in snatch event are associated to knee flexion especially during squatting phases. The purpose of the study was to compare the range of motion (ROM) of the knee joint and barbell acceleration during one Repetition Maximum (1RM) and 50% of 1RM power snatch, and evaluate the knee joint reaction force (JRF) during 50% of 1RM power snatch. 25 state-level weightlifters were recruited voluntarily for the study. Standard 1RM power snatch test was analyzed using two-dimensional (2D) kinematic method. Next, the knee joint ROM, barbell acceleration and knee JRF for 50% of 1RM power snatch were analyzed using three-dimensional (3D) kinematic method. The demographic result showed that physical evaluation of the athletes was in fair category. The Paired t-test showed that there was a significant difference of the knee joint ROM between 50% and 1-RM power snatch. The barbell accelerated faster during acceleration 50% of 1RM power snatch compared to 1RM power snatch (P = 0.044) particularly during second pull phase. Lastly, descriptive statistics of the knee joint reaction force (JRF) of weightlifters during 50% of 1RM power snatch that normalized to the bodyweight were 0.33 ± 0.20 N.m/kg.m for male weightlifters and 0.75 ± 1.68N.m/kg.m for female weightlifters. Overall, the knee range of motion and barbell acceleration decreased as the load of the barbell increased. The knee JRF of weightlifters during 50% of 1RM power snatch was within the normal range of knee JRF during squatting.

Keywords: biomechanics, knee joint, weightlifting, power snatch

ABSTRAK

Kajian ini memberi tumpuan kepada biomekanik sendi lutut yang merupakan salah satu kecederaan yang kerap dalam kalangan atlet angkat berat. Kebanyakan teknik dalam acara "*snatch*" dikaitkan dengan akhiran lutut terutamanya ketika fasa mencangkung. Tujuan kajian ini adalah untuk membandingkan pelbagai gerakan sendi lutut mengikut 1 pengulangan maksimum (1RM) dan 50% daripada 1RM, untuk membandingkan pecutan "*barbell*" dalam 1 pengulangan maximum dan 50% daripada 1RM, dan untuk mengukur dan menganalisis daya tindak balas sendi lutut semasa 50% daripada 1RM. 25 atlet angkat berat peringkat negeri telah diambil secara sukarela untuk kajian ini. Ujian 1RM "*power snatch*" dianalisis menggunakan kaedah dua-dimensi (2D) kinematik. Seterusnya, gerakan sendi lutut, pecutan "*barbell*" dan daya tindak balas lutut untuk 50% daripada 1RM dianalisis dengan menggunakan kaedah tiga-dimensi (3D) kinematik. Keputusan data demografi menunjukan penilaian fizikal keseluruhan atlet berada dalam keadaan yang wajar. Ujian "*Paired-t*" menunjukkan terdapat perbezaan yang signifikan dari gerakan sendi lutut antara 50% dan 1-RM "*power snatch*". Pecutan "*barbell*" lebih cepat semasa pecutan 50% daripada 1RM "*power snatch*" berbanding dengan 1RM "*power snatch*" (P = 0.044) terutamanya semasa fasa tarik kedua. Akhir sekali, statistik deskriptif daya tindak balas lutut daripada atlet angkat berat dalam 50% daripada 1RM "*power snatch*" yang dinormalkan kepada berat badan ialah 0.33 ± 0.20 N.m/kg.m untuk atlet angkat berat lelaki dan 0.75 ± 1.68 N.m/kg.m untuk atlet angkat berat wanita. Keseluruhannya, gerakan sendi lutut dan pecutan "*barbell*" menurun apabila beban "*barbell*" meningkat. Daya tindak balas lutut atlet angkat berat dalam 50% daripada 1RM "*power* *snatch*" adalah dalam julat normal daya tindak balas lutut semasa mencangkung.

Kata kunci: biomekanik, sendi lutut, angkat berat, "*power snatch*"

CHAPTER 1

INTRODUCTION

1.1 Background

The sport of weightlifting has been in the Olympic Games since its introduction in 1896. It becomes increasingly popular around the world with growing international participation. Weightlifting is one of power sport which required dynamic strength. The aim of the Olympic weightlifting competition is to lift higher weights successfully and the key to a successful lift is the synchronization and perfection of the system that consists of the body and barbell (Storey & Smith, 2012). The whole-body lift is performed in snatch and clean and jerk competition.

The competitive weightlifting consists of eight body weight categories for men and seven body weight categories for women. Since 1998, the body weight categories are ≤56kg, ≤62kg, ≤69kg, ≤77kg, ≤85kg, ≤94kg, ≤105kg and ≥105kg for men; and ≤48kg, ≤53kg, ≤58kg, ≤63kg, ≤69kg, ≤75kg and ≥75kg for women (Storey & Smith, 2012). Two hours before the start of a competition session, the weightlifter must weigh-in within an hour window. The competition total which is the sum of the highest recorded weight in snatch and clean and jerk will determine the athlete's placing within their respective body weight class.

The snatch is a series of high intensity muscle contractions of whole-body movements. The snatch consists of lifting the weighted barbell from the floor to an overhead position in one continuous movement. The aim of snatch is to accelerate the barbell vertically to an adequate height for the weightlifters to move underneath it with support from the extended arms. The snatch combines strength, balance, speed, mental concentration and courage.

There are six phases in snatch: 1) first pull, 2) transition phase, 3) second pull, 4) turnover phase, 5) catch phase and 6) recovery phase. The first pull is when the lifter extends their knees to lift the loaded barbell off the platform until bar has cleared at the knee height. A transition phase is when the trunk moved to a near vertical position when the knee are re-bent and moved under the barbell (Enoka, 1979). It is also called double-knee bend that give the advantage to the lifter to a stretch-shortening cycle (Stone et al., 2006). Next, the lifter extends their hip, knees and ankles to accelerate the barbell maximally by simultaneously shrugging the shoulders in second pull phase. The ranges of the vertical velocity of the barbell during second pull are between 1.6 5m/sec and 2.28 m/sec (Akkus, 2012). Then, the turnover phase begin when the lifter pull their body underneath the barbell when the barbell rises in a vertical plane to approximately 62-78% of the lifters height (Chiu et al., 2010). The catch phase is when the lifter drop under the bar with an extended arm in full squat position until the lifter stands. Lastly, the lifter stand in upright position and hold the barbell overhead, this phase is referred to as the recovery phase. The duration of a successful lift that start from the first pull until the referee signal is ~3-5 seconds. Each athlete is allowed to make three attempts in snatch competition.

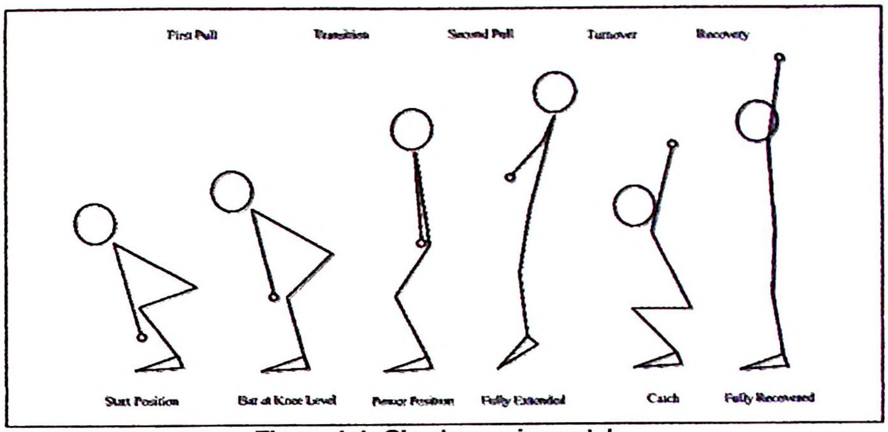

Figure 1.1: Six phases in snatch.

Movement of the barbell is determined by the power and force applied by the weightlifter. In snatch event, the knee joint plays a significant role in generating power and transmitting the force through the kinetic chain to lift the weight. Knee joint is the largest and most complex synovial joint in the human body. The forces and moments of force around this joint produce torques of such magnitude that injuries ensue (Nicholas, 1970). Many injuries occurred due to overloading the knee joint (Nicholas, 1970). Furthermore, a typical problem for many athletes is the increased value of knee joint reaction force during weightlifting movements. In the snatch, the hip extensors play a major role in the lower limb kinetic chain to produce the highest power demands. However, without sufficient power from hip, the knee extensor would have to do more work. By doing false movement technique, the lifter is prone to knee injury. Therefore, the correction of the snatch techniques helps to reduce the knee injury (Weide, 1989).

Furthermore, acute tendon and ligament ruptures of the knee joint may occurduring resistant training. Ligament ruptures seem related to inappropriate movement of a joint (Lavallee & Balam, 2010). For example, the wrong foot placement during squat may cause lateral ankle sprain and medial collateral ligament injury at the knee. Besides, repetitive stress on tissue that has insufficent time or recuperative ability resulted in chronic injury (Lavallee & Balam, 2010). Overuse injury occurs when the weightlifter tries to increase their lifting too fast during training. More frequently injured site in weightlifting is patellar tendon due to the deep loaded knee flexion that occurred during squat in snatch (Lavallee & Balam, 2010). Over the years of intense training, weightlifters are at high risk of developing patellofemoral osteoarthritis and patellar tendinitis (Kujala et al., 1995).

Therefore, biomechanics researches were conducted to gain insight into the internal structure of kinetic chain during weightlifting. In order to analyze the effects of the weights on the knee joint, it is necessary to assess the related kinematic and kinetic changes. The barbell trajectory has been extensively studied in biomechanical analysis of weightlifting (Haff et al., 2003). During weightlifting movements, the joint motions such as the position of the body and the displacement of the feet determined the bar trajectories. However, it was difficult to improve a snatch technique by instructing the weightlifters to change the joint angles or the joint angular velocities. An easier approach is monitoring the trajectory of a barbell to evaluate their performance.

However, to our knowledge, no studies have been done comparing the knee joint reaction force, range of motion and barbell acceleration in 1RM and 50% of 1RM tests. This is particularly important because the variation of snatch technique can alter movement patterns and barbell velocity, resulting in different specific adaptations. Besides, these biomechanical factors may help the athletes to understand the many aspects of the Olympic lifts that will optimize their performance.

1.2 Objective of the Study

This study embarks on the following objectives:

1. To compare the knee joint range of motion following 1RM and 50% 1RM power snatch.
2. To compare the barbell acceleration following 1RM and 50% of 1RM power snatch at second pull phase.
3. To measure and analyze the knee joint reaction force of weightlifters during 50% of 1RM power snatch.

1.3 Hypothesis

Null hypothesis:

1. There is no difference of the range of motion of the knee joint during 1RM and 50% 1RM power snatch.
2. There is no difference of the barbell acceleration during 1RM and 50% 1RM power snatch at second pull phase.
3. There is no difference of the knee joint reaction force of weightlifters during 50% of 1RM power snatch.

Alternate hypothesis:

1. There is difference of the range of motion of the knee joint during 1RM and 50% 1RM power snatch.
2. There is difference of the barbell acceleration during 1RM and 50% 1RM power snatch at second pull phase.
3. There is difference of the knee joint reaction force of weightlifters during 50% of 1RM power snatch.

1.4 Significance of the Study

The analysis is important in providing better understanding about weightlifting. The findings can be applied to improve the snatch techniques and reduce the risk of knee injury.

1.5 Operational Definitions:

Power Snatch: One coordinated, continuous movement executed with speed. The grip should be wide enough to allow partial squat with the bar at arm length over head.

2-Dimension (2D) Kinematic: For 2D kinematic, the analysis was carried out for one day or one session only with three attempts. The lifters were required to complete lift with 100% of perceived maximum resistance.

3-Dimension (3D) Kinematic: For 3D kinematic, the analysis was carried out for one session only. The lifters were attached with 37 markers (lower limb only) and they were required to complete lift 50% of 1 Repetition Maximum.

Young male and female subjects: A group of male and female best-state level weightlifters from Kelantan National Sport Council, aged from 13 to 18 years old were recruited.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction of Weightlifting

2.1.1 History of weightlifting

Weightlifting can trace its beginnings to more than 4000 years ago. Michael et al. (2006) found that evidence for both strength training and strength contests can be found in the illustrations of weightlifting and strength movements on the tomb of the Egyptian Prince Baghti dating from approximately 2040 BC. Resistance training and contests of strength or power were quite popular in ancient Greece at least as early as 557 BC and that exhibitions and strength contests were likely included in other ancient games and gained popularity in the modern era.

Weightlifting sport in the present day requires not only great strength but also exceptional power, speed of movement and flexibility. In mid 1800s, modern weightlifting was traced when several clubs devoted to weightlifting and general strength training began to spring up in Europe especially in Austria and Germany. The first World Weightlifting Championships were held in London in March 1891. United States was a world leader in weightlifting producing several world and Olympic champions (Fair, 1999).

Men's weightlifting was included in the first modern Olympics as a part of track and field in 1896. Its own international federation was formed in 1905 and it recognized by the International Olympic Committee (IOC) in 1914. At the 1920 Antwerp Games, weightlifting became a permanent fixture in the Olympics. During the early 1980s, women's weightlifting increased in popularity especially in the United States and China. In 1987, first women's world championships were held in Daytona Beach, Florida. Women's were first included as part of the Olympics weightlifting program during the 2000 Games in Sydney, Australia. In addition, both junior (12-20 years), open men's and women's competition in most countries weightlifting were held at the local, regional, national and international level.

2.1.2 Snatch

In weightlifting competitions, weightlifters compete on combined (total) lifted weight for the clean and jerk and the snatch. The snatch is a barbell lifted overhead in one singular movement. Snatch lifts requires a multifactor performance including technique, power, explosive strength and flexibility. Isaka et al. (1996) stated that snatch can be broken down into a sequence of phases characterized by the posture of the weightlifter relative to the bar position. It consists 6 phases of pulling the bar from the floor to the overhead position. The phases include the first pull, the transition, the second pull and the catch (Stone et al., 2006).

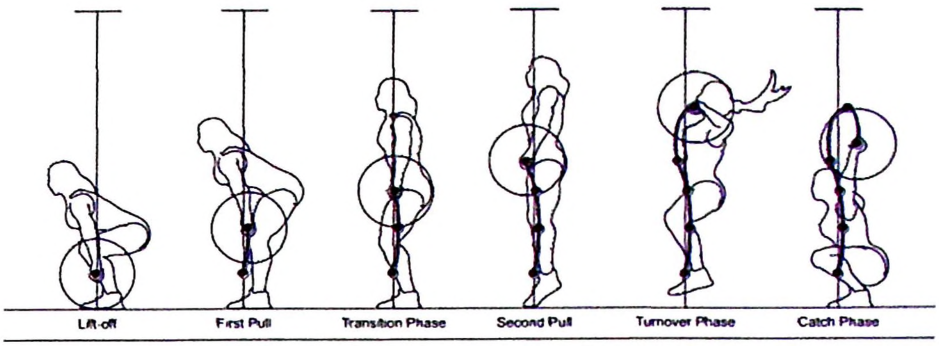

Figure 2.1: The snatch phase.

To succeed in a lift of the snatch, support the barbell over the head and transmit physical output effectively to the barbell. Garhammer (1980) stated that the barbell must lift over the head in less than 2 seconds. To improve the snatch technique, weightlifters use training exercise and the exercise must be specific to maximize the training effect. Squat is the most used exercise for the strength and conditioning (Escamilla, 2001). The exercise is an integral component in competitive sports like weightlifting to strengthen the lower-body muscles.

2.2 Musculoskeletal Injury in Weightlifting

As weightlifting becomes increasingly popular, safety is a growing concern. There is no exception having injury in weightlifting. In weightlifting, existing literature indicates that most injuries occur at the shoulder, back and the knee. Calhoon & Andrew (1999) found that most acute and chronic injuries include the strains, tendinitis and sprains of back, knee and shoulder. In general, the injury rates of weightlifting are similar with other sports.

One of the most injury sites in weightlifting is shoulder. The risk of shoulder injury may due to flexing the shoulder into an extreme overhead position. As a result, a weightlifters reported that the shoulder joint do not have instability only 4.0% (Gross, 1993). It is prone to instability from the dynamic power movements and the techniques used. Thus, missed lifts in weightlifting sometimes involve dropping the weight behind the lifter and can make the shoulder in extreme external rotation and flexion. Shoulder in vulnerable situation may increase the rate of shoulder injury. Weightlifter should note the skill, flexibility, and strength to prevent the problems that can affect the shoulder.

Another potential injury site in weightlifting is back. In weightlifting, trunk musculature serves as a stabilizer and primary movers for both upper and lower extremities depending on the phase of the lift. Calhoon et al. (1999) stated that the risk of back injury in weightlifting will occur when the load is applied. Common back injury is spondylolysis. It is a degenerative condition where the vertebrae develop stress fractures (Alexander, 1985). Rossi & Dragoni (1994) reported that back injury in athletes is 13.49% greater than general population. Furthermore, Kulund et al. (1978) stated that low back pain is small problem in weightlifters, while Granhed & Morelli (1988) stated that retired wrestlers more suffer from chronic low back pain than retired weightlifters.

The previous reports of spondylolysis, it appears in weightlifting competition before 1972 during clean and press lift (Figure 2). Extremely lordotic positions occur during the pressing phase of the lift while the weightlifter was holding very heavy weights overhead (Stone, 1994). The current lifts (snatch and clean and jerk) do not emphasize a lordotic position as the former competitive pressing motion. In Calhoon et al. (1999) studies reported that there is no spondylolysis appears in weightlifters. Hence, low back region is most common serious injury that found in the athletes.

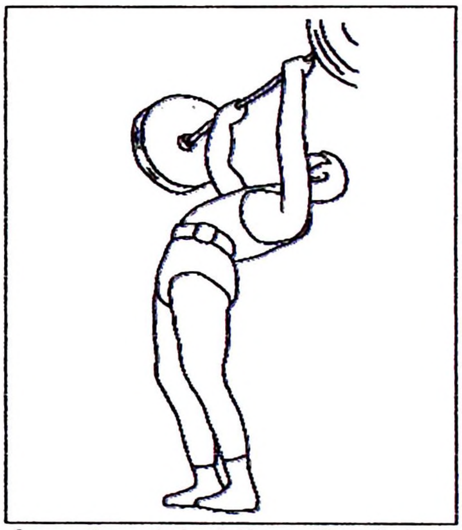

Figure 2.2: An example of an extremely lordotic position during the pressing motionof the clean and press lift. The lift was discontinued from competition in 1972.

The knee is the most injured joints in weightlifting (DeHaven & Lintner, 1986). Isear et al. (1997) found that the interaction of the hamstrings and quadriceps contractions that serves as a protective mechanism. The hamstrings provide internal and external rotation restraint at the knee joint. From a biomechanics standpoint, the hamstring will provide a posteriorly directed force along with the quadriceps to stabilize the knee as well as to facilitate movement during squat.

In addition, high knee forces during weightlifting movements are typical. Figure 3 illustrate the typical range of motion for the knee during snatch lifts. Calhoon (1999) study stated that knee injuries are mainly chronic inflammatory problems but not the traumatic stability problems. Besides, Kujala et al. (1995) study indicated that the weightlifter is high risk at patellofemoral osteoarthritis. It may due to repeated stresses placed to those joints when training and competition over years during performing the same motion. In addition, patellar tendon frequently mentioned as an injury site in quadriceps muscle due to the deep loaded knee in the snatch (Lavallee & Balam, 2010). The strain on the knee as the lifter sits and then rises from the deep squat in the Olympic lift is enormous (Tucker, 1990). When the calf and thigh contact, it can causes over stretching of the knee ligaments in any full squat technique. The injuries may result in long-term damage. In summary, the most frequent types of injuries were strains and tendinitis. Nevertheless, majority of injuries were acute occurrences then followed by chronic injuries.

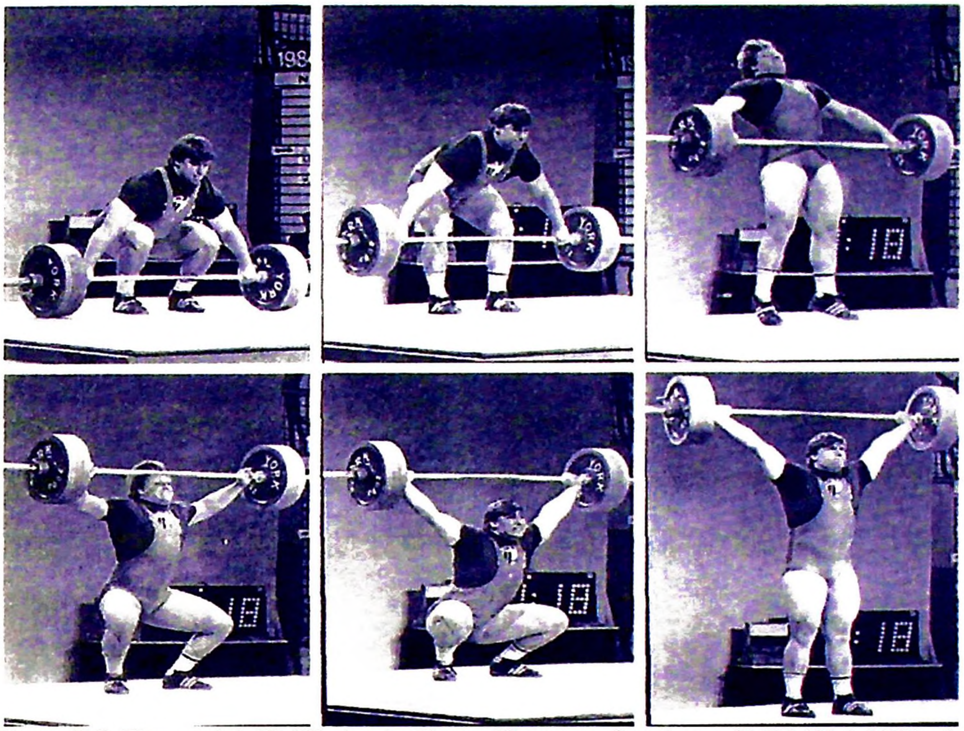

Figure 2.3: The snatch lift (Photos by Bruce Klemens, Courtesy of USA Weightlifting).

2.3 Biomechanical Analysis in Weightlifting

2.3.1 Barbell acceleration

Barbell acceleration can influence the outcome of a snatch attempt. Studies have specifically focused on the path of barbell in relation to body position, barbell velocity, mechanical work and power output. Gourgoulis et al. (2000) noted that in their studies, there is no discussion made regarding the interpretation of the barbell acceleration graph and table and barbell acceleration report is limited to only three studies even though the biomechanics of weightlifting have been a well-studied subject.

In the present study, the peak barbell acceleration during the second pull phase has been focused. To being pulled up the barbell to desired height to catch is a critical part of the lift in the second pull phase (Stone et al., 2006). Furthermore, the body produces the force to accelerate the barbell to an upward direction when a barbell increases its rate of velocity. The measurement of acceleration can be valuable for weightlifters to examine the intensities change the peak barbell acceleration. As conclusion, acceleration is directly proportional to force production.

Next, a common variable used to describe and analyze the performance of Olympic lifters is power output. External mechanical power output may provide the information of how much power can produce at the level either the barbell or the lifter-barbell system. Cormie et al. (2007) stated that the production of peak mechanical power output is increased during submaximal loads. Hip and knee internal joint powers at 85% of 1RM are significantly correlated with external peak power output (Garhammer, 1980). The correlation indicates that knee and ankle joint power output is partially related at high loads of barbell mechanical power output.

Furthermore, more power output produced during the second pull phase. Hakkinen et al. (1984) found that there was significantly different in average duration of the drop-under times between men elite and district-level lifters as the load increased. Bartonietz (1996) noted that the power position adopted at the transition phase will affect the force generated during the explosive leg extension in the second pull. During the second pull, elite women weightlifters consistently produce more power output (74%) compare to men than during the total pull (63%)

have been noted by Garhammer (1998). As conclusion, examining the power production during these phases provides insights regarding the biomechanical factors contributing to success in weightlifting.

2.3.2 Trajectory

Bar trajectory is a function on how the weightlifter moves the bar. It explains the position of the bar movement as a mark of performance. Bar trajectory during weightlifting movements is related to the position of the body during the snatch affects both the path that the bar takes during the lift and the subsequent displacement of the feet as the lifter drops under the bar in to the catch position. The joint motion of a lifter will influence the barbell trajectory during the snatch. Vorobyev (1978) proposed that there have three main types of bar trajectories, shown in Figure 2.4.

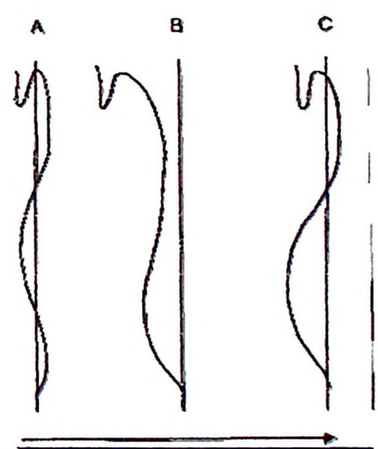

Figure 2.4: Proposed variations in bar.

Many of elite Olympic weightlifters display a backward displacement of the feet during the drop-under phase. This is because during the drop-under phase, it requires the lifter to displace the feet backward to bring the center of gravity under the barbell. Many successful weightlifters have been demonstrated the type-B trajectories. Most of the medalist's at the 1996 Olympic Games use the type-B trajectories. Hiskia (1997) found that from the 669 snatches sampled in international competition, only 42.9% showed the type-B trajectories. Meanwhile, sample in international competition from 1978 to 1984 were of the type-B trajectories at 45% of the lifts (Garhammer, 1998). In summary, which ever the weightlifters produced the trajectory is depend on the training history and morphology of the lifters.

Anthropometric factors of the lifter must be considered to get the proper bar trajectory. Rearward displacement of the bar for smaller weightlifters is large (7-12cm) compared with larger lifters. Stone et al. (1998) indicate that lighter lifters prevent themselves from being pulled forward by the bar weight with they must stay on their heels longer. These lifters use their body mass as a "counterweight". Besides, lighter lifters at the elite level, they exhibit type-B trajectories more than heavier lifters. Pulling type-B trajectory and rearward foot displacement is a natural trait in some lifters technique and can be taught a proper technique by coaches.

Previous studies of the snatch technique in competition have concerned with the analysis of the trajectory of the barbell and the angular kinematics of the body in the sagittal plane using only one camera. Barbas & Fabian (1989) stated that inadequate precision in measurement are the main problem of recording the movement from a single side using only one camera. Baumann et al. (1988) found that the problem can be successfully solved through 3-dimensional cameras with two or more positioned cameras. Baumann et al. stated that during the first pull and transition phase, the lifters pulled the barbell towards their body. Thus, vertical displacement of the barbell was greater also in the first pull but the power output greater in the second pull.

Moreover, an easier approach to evaluate the lifter performance is to monitoring the trajectory of the barbell. The lifters are difficult to change their joint angles or joint angular velocities to improve the snatch technique by instructing. Chiu, Wang & Cheng (2010) found that a barbell pulled more toward the lifter when starting to lift the barbell off the platform. A barbell moves less horizontal displacement and velocity after pushed away from a lifter. The successful snatch performance is keeping the bar close to a vertical reference line from the starting position of the bar.

2.3.3 Knee joint reaction forces

Weightlifting has high joint reaction forces. The joint reaction force is the representation of the adjacent body segment's action upon the segment under investigation. It is derived from the net force that is transmitted from one segment to the other. The net force may represent many different forces such as muscles, ligaments and bone contacts. A joint reaction forces when the knee is slowly extended from 90° of flexion to full extension approximately 50% of the body weight. Collins (1994) found that joint reaction forces are greater in activities like vertical jumping and weightlifting. The tensile strength of the cruciate ligaments are failure limit of around 2 kN for the ACL of young healthy males was evaluated by Chandrashekar et al. (2006) and 4.5 kN for the PCL was evaluated by Amis et al. (2003). The values of this range are potentially being borne by the cruciate ligaments.

The joint reaction forces shift from the medial to the lateral tibial plateau during the gait cycle. Kettlekamp & Jacobs (1972) stated that the contact area approximately 50% larger in medial tibial plateau rather than lateral tibial plateau. The larger surface area of medial tibial plateau and their thickness allow it to more easily maintain the higher forces that imposed on it. Joint reaction forces are sustained by the menisci in a normal knee (Seedhom & coworkers, 1974). In a normal human knee, the wide area of the tibial plateau is distributed by the stresses. The stresses are not distributed if the menisci are removed but there are limited to a contact area in the center of the plateau.

In addition, the patella rises from intercondylar groove when the knee is extended. It produces the significant anterior displacement of the tendon. The length of the lever arm slightly diminished when the knee extension beyond 45°. The magnitude of the muscle forces acting on a joint directly affects the magnitude of the joint reaction force during dynamic activities, hence, the greater the muscle forces, the greater the joint reaction force.

Other than that, in the patellofemoral joint, the force in quadriceps muscle is increase during knee flexion. When the center of gravity shifts away from the center of rotation, it's greatly increasing the flexion moments to be counter balanced by the quadriceps muscle force. During the activities that require greater flexion, the joint reaction force was much greater. Reilly & Martens (1972) found that the force reach 2.5 to 3 times body weight during the knee bends to 90°. The knee flexion also influences the patellofemoral joint reaction force with affecting the angle between the patellar tendon force and the quadriceps muscle force. The patellar tendon force higher than the quadriceps muscle force (Figure 2.5).

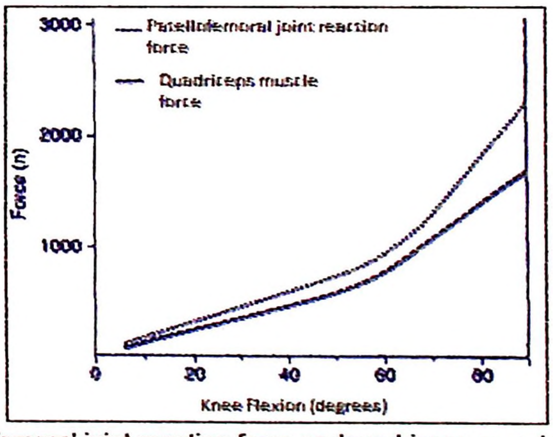

Figure 2.5: Patellofemoral joint reaction force andquadriceps muscle force during knee bend to 90°.

2.4 Musculoskeletal Modeling

The biomechanical problems in which the direct measurement of key variables is difficult or impossible to analyze can be solved using the musculoskeletal modeling. The musculoskeletal modeling will provide the insights regarding muscle and joint interaction around the knee. Many studies have sought to quantify hip and knee forces through musculoskeletal modeling techniques and measurement. In contrast, there are fewer musculoskeletal modeling studies that have sought to understand the loading of the hip and knee joints during more dynamic movements with faster execution speeds. Nisell & Mizrahi (1988) stated that biomechanical models have limiting assumptions and not accurately capture the nature of the joint loading. Besides, Southgate et al. (2012) noted that the model may underestimate the joint loading if the musculoskeletal model more favorable geometry than the actual subject. It is important in future work to understand the effect of changes in subject-specific detail. Thus, complexity is a key issue in modeling. Increase complex models are not always advantageous, as they can be more labor intensive to implement and interpret.

Two types of biomechanical analysis is two-dimensional (2D) kinematic and three-dimensional (3D) kinematic. The most prevalent method in weightlifting analysis is two-dimensional (2D) kinematic. It is used to analyze the body technique such as body posture, position and angle. It provides the immediate feedback by video. The 2D kinematic only used single camera. Byers, Wu & Gervais (2008) stated that the video camera can be record the specific bony landmarks of the lifter and one side of the barbell in the sagittal plane. 2D kinematic can explore the snatch lifts in addition to increase knowledge about snatch technique during competitions.

Next, another method in weightlifting analysis used recently is three-dimensional (3D) kinematic. It start with the triangulation method (Figure 2.6 & 2.7) that involved minimum of 2 phase-locked cameras with 1 on each side of the platform placed at 45° diagonally angle from a distance of 9-20m. The 3D motion capture has been improved. The angular displacements of all joints in the body together with the bar may obtained with involves the multiple infrared cameras capture of a frame rate minimum at 120 Hz to get the information (Kipp, Harris & Sabick, 2011). Akkus (2012) stated that the 3D motion analysis systems provide more accuracy in digitizing bar and bony landmarks of the lifter in establishing bar and joint kinematics. As a result, the 3D kinematic might allow more variables related to the bar such as bar displacement, trajectory and successful lifts to be investigated rather than 2D kinematic.

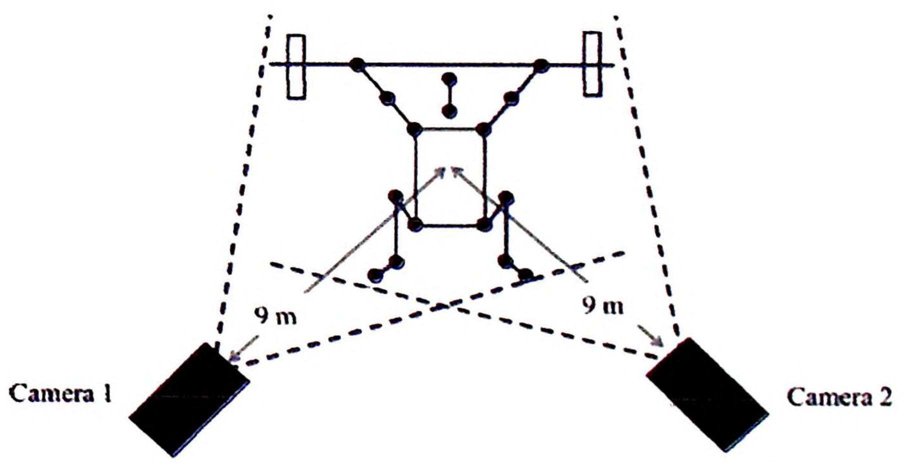

Figure 2.6: Traditional 2-camera setup for acquiring 3D kinematic data.

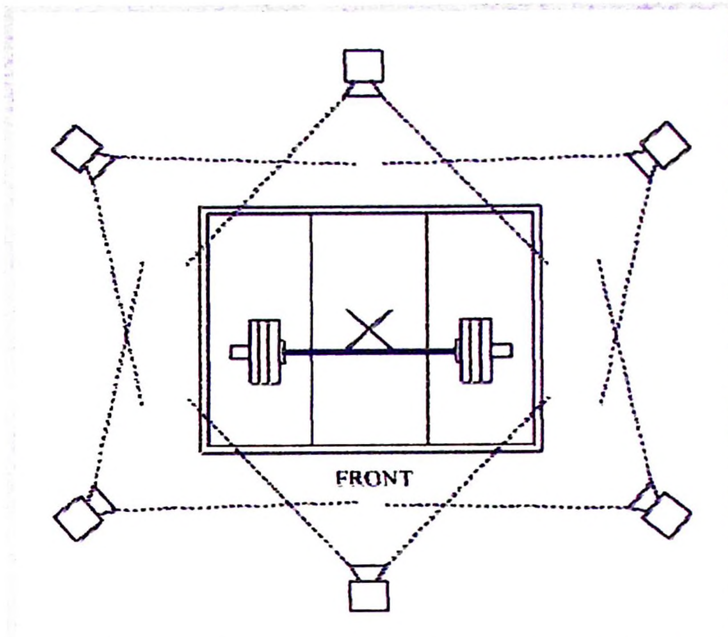

Figure 2.7: Six-camera setup for a 3D motion analysis system.

Tibiofemoral joint can be obtained in 3D kinematic analysis through roentgen stereophotogrammetric analysis (RSA). Brandsson, Karlsson & Sward (2002) stated that the exposure to radiation and invasive nature of the procedure is limited even though the RSA may provide a direct measurement of bony motion in vivo. There is six degree of freedom (Figure 8) in three-dimensional (3D) kinematic analysis to study the tibiofemoral joint which are three rotations (internal/external, abduction/adduction, flexion/extension) and three translations (anterior/posterior drawer, medial/lateral shift, distraction/compression). Lafortune et al. (1992) found that the skin and soft tissue movement will affect the accuracy of the measurement. The researcher must use goniometers attached to intracortical pins then inserted into tibia and femur to overcome these problems (Ishii, Terajima & Terashima, 1997).

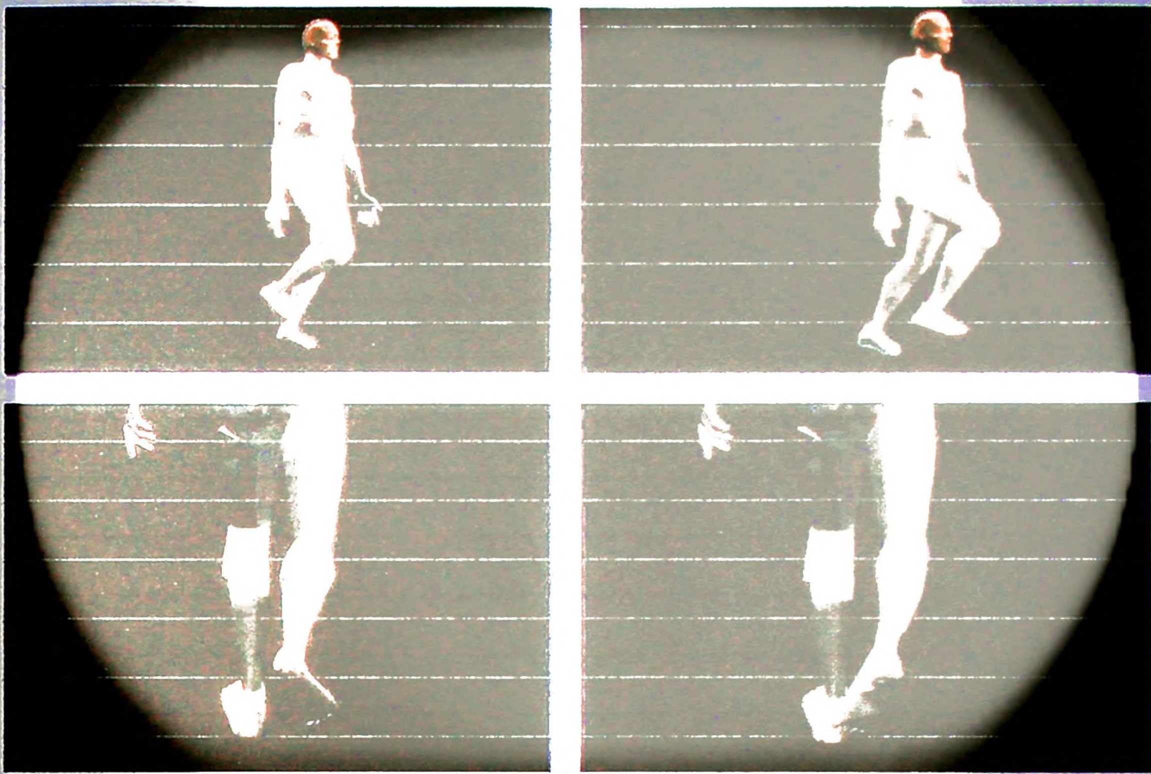

Figure 2.8: Variables evaluated with 3D kinematics. Top panels: flexion/extension, **bottom panels: external/internal rotation.**

Mainly, video cameras and opto-electronic digitizers are used when conducting the 3D kinematic analysis. The markers are placed on the subject to perform a task. Place of the markers on specific anatomic bony landmarks (Figure 2.9) are depending on the biomechanical model used (Davis et al., 1991). During the task, the position of the markers is recorded and the signal converted into a digital format for computer processing.