Orthopedic injuries in water-skiing

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ORTHOPEDIC INJURIES IN WATER-SKIING

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Abbreviations

ACL = anterior cruciate ligament

ALB = anterolateral bundle (of the PCL)

AMB = anteromedial bundle (of the ACL)

AP = anteroposterior

ASIS = anterior superior iliac spine

BPTB= bone-patellar tendon-bone

DDX = differential Diagnosis

ECM = extracellular Matrix

LCL = lateral collateral ligament

MCL = medial collateral ligament

PCL = posterior cruciate ligament

PLB = posterolateral bundle (of the ACL)

PLC = posterolateral corner

PMB = posteromedial bundle (of the PCL)

ROM = range of Motion

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Summary

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Summary:

As a traditional water sport, water-skiing is a high-risk sport, like alpine skiing or soccer. In the introductory part of this thesis, the anatomy of the knee will be defined. Then the functional properties of the knee and its ligaments will be explained, including knee movements, the stability of the knee and the biomechanics of the knees ligaments. This knowledge will help the reader understand the content of the scientific part of this paper. Considering the ligamentous injuries, we focus on ACL and PCL injuries.

Water-skiing is a 3-event sport and every discipline involves different movement patterns that may lead to variable injury patterns due to the diverse cutting, pivoting and deceleration movements. As our study will reveal, the most dangerous discipline is Jumping. Here, the high speed of the boat and the skier himself aggravate the impact onto the water during a crash. Knee injuries caused by water-skiing show a high association with a prolonged season on the water, possibly due to overuse or fatigue of the ligaments and muscles supporting the joint. After treating a ligamentous injury, either conservatively or surgically, the knees ROM can be limited and pain may still be present. Those two restrictions will influence the skiers' performance. It may even force him or her to quit the sport, which, fortunately, rarely happens. For the injured skier it is essential to undergo proper treatment and rehabilitation, so that the knees strength returns to its pre-injury level. If the joint does not manage to reach full strength, it can be due to structural changes of the implanted graft, wrong placement of the graft, or falsely executed rehabilitation program. The former two will cause weakness of the ligament itself, and the latter will result in weaker muscles.

The aim of this study was to identify and obtain as much information from professional water-skiers as needed to point out any possible preventative measures, as well as any association between a specific factor or training pattern and injury occurrence.

Key words: water-skiing, high-risk sport, knee injury, ACL, PCL, disciplines, prolonged season, ROM, knee strength, preventative measures

Sažetak

Naslov: Ortopedske ozljede tijekom skijanja na vodi

Autor: Kim Haas

Sažetak:

Skijanje na vodi je jedan od tradicionalnih sportova na vodi, a smatra se visoko rizičnim odmah do skijanja i nogometa. U početnom dijelu definira se anatomija koljena, a nakon toga funkcionalne karakteristike koljena i ligamenata. Opisani su pokreti i stabilnost koljena te biomehanika ligamenata koljena. Ovo znanje će pomoći čitatelju da razumije sadržaj znanstvenog dijela ovog rada. S obzirom na ozljede ligamenta, usredotočit ćemo se na ACL i PCL ozljede. Skijanje na vodi je sport s 3 događaja, a svaka disciplina uključuje različite uzorke kretanja koji mogu dovesti do različitih ozljeda. Kao što će naša studija otkriti, najopasnija disciplina je skakanje. Velika brzina broda i samog skijaša pogoršavaju utjecaj udarca koljena na vodu tijekom sudara. Ozljede koljena uzrokovane skijanjem na vodi pokazuju visoku povezanost s produljenom sezonom; ukoliko je duža od 8 mjeseci (godišnje), usko je povezana s većom pojavom ozljeda koljena. Jedan od mogućih razloga je posljedica pretjeranog korištenja ili umora ligamenta i mišića koji podupiru zglob. Nakon liječenja ozljede ligamenata koljena, konzervativno ili kirurški, njegov ROM može biti ograničen te bol i dalje može biti prisutna. Te dvije restrikcije mogu utjecati na izvođenje skijaša, te bi moglo prisiliti osobu da napusti sport, što se na sreću, rijetko događa. Za ozljeđenog skijaša suštinski je bitno da se podvrgne odgovarajućem liječenju i rehabilitaciji, tako da povrijeđeno koljeno može postići razinu snage prije ozljede. Ako se to ne dogodi, to bi moglo biti posljedica strukturnih promjena implantiranog grafta ili pogrešno postavljanog, kao i nezadovoljavajuća rehabilitacija (prekratka ili nije pravilno izvedena). Prvo može uzrokovati slabost ligamenata, a drugo može rezultirati oslabljenim mišićima.

Cilj ovog istraživanja bio je identificirati i dobiti što više podataka od profesionalnih vodenih skijaša kako bi se ukazalo na moguće preventivne mjere, kao i svaku povezanost između određenog faktora ili uzorka treninga i pojave ozljeda.

Ključne riječi: skijanje na vodi, visoko rizični sport, PKL, SKL, discipline, produljena sezone, ROM, snaga koljena, preventivne mjere

1. Anatomy of the knee

The knee, the largest synovial joint in our body, is a hinge-joint, allowing flexion, extension and additional subtle rotational movements. Being such a large joint makes it very vulnerable to traumatic or degenerative events. The high-energy forces that regularly act on it, are vastly influencing those events.[1(p.634), 2(p.575)]

The knee joint is formed by three bones, the distal femur, the proximal tibia and the patella. It is also called a "compound joint", that is made up of two condyloid and one sellar joint. The two tibiofemoral articulations, medial and lateral, are the condyloid joints. Their articulations are fairly unstable and depend on the surrounding ligaments and muscles for adequate stability. The sellar or patellofemoral joint lies between the condyloid joints and is formed by the femur and the patella. Articular cartilage coats all these surfaces.[1(p.634), 3(p.201), 4(p.630)]

The so-called "Q angle" is an important tool to evaluate the alignment of the femur and the tibia. It clarifies if there is any valgus or varus force acting on the knee by the positioning of the two bones. The angle is measured by using two lines. The first one starts at the ASIS and ends at the central patella. The other line is connecting the central patella to the tibial tubercle. Usually the Q angle is wider in females than in males because of the anatomical differences in the pelvic structure. For its evaluation, the patient's knee and hip are extended, and the quadriceps muscle is relaxed. The normal Q angle values are about 14° (+/-3) for men and about 17° (+/-3) for women.[5] There are certain factors increasing the Q angle, for instance genu valgum or increased femoral anteversion. If the angle is not in its usual range, there is a higher risk for patellar subluxation or luxation.[5, 3(p.212)]

1.1. Knee Joint Capsule

The joint capsule of the knee is made up of two parts:

a.) the fibrous capsule (externally)
b.) synovial membrane (internally)

ad. a.)

The fibrous layer is thin and partially incomplete. It's attached to the femur, proximally to the condyles, and it encases the condyles and the intercondylar fossa superiorly and posteriorly. The inferior attachment is the tibial plateau except where the popliteal tendon crosses the bone because the tendon passes through an opening of the fibrous capsule located posteriorly to the lateral tibial condyle. Due to this, the tendon can leave the joint capsule and attach to the tibia. Anteriorly the capsule is continuous with the quadriceps tendon, patella, and patellar ligament, meaning there is no fibrous layer in the anterior region.[1(p.363), 2(p.578)]

ad. b.)

The synovial membrane is vast and coats all areas of the articular cavity that are not lined by articular cartilage. It attaches peripherally to the articular cartilage at the femoral and tibial condyles, the patella's posterior portion, and the edges of the menisci. One if its essential functions is to separate the two cruciate ligaments from the articular cavity. This is accomplished by the membrane expanding into the intercondylar region and forming the "median infrapatellar synovial fold". The infrapatellar fat pad is separating the patellar ligament from the synovial membrane on the anterior aspect of the knee joint. There are fat pads on both sides of the patellar ligament placed internally to the fibrous layer. They are lined on their inner surface with fat-filled lateral and medial alar folds, which are formed by the synovial membrane. The suprapatellar bursa, which is lined by synovial membrane, is the superior elongation of the joint cavity. It is located deep to the vastus intermedius.[1(p.636), 2(p.577)]

1.2. Bones of the knee joint

The distal femur

The medial and lateral condyles of the distal femur are two convex structures that articulate with the proximal head of the tibia and the patella. The articular surfaces of the condyles are round posteriorly and flat inferiorly. Anteriorly they form a V-shaped depression that makes space for the patella, and on the posterior aspect the two condyles are separated by the intercondylar fossa. There are two facets on the walls of this fossa making up the superior attachment points for the cruciate ligaments. The large oval facet, where the proximal end of the PCL is fixed, is located on the lateral surface of the medial condyle. The small oval facet, where the ACL attaches, is part of the medial surface of the lateral condyle. The collateral ligaments of the joint attach at the so-called femoral epicondyles. These are bony elevations on the non-articular outer surfaces of the condyles. Around them are several muscle attachment points located. The gastrocnemius muscle attaches to the upper facet while the popliteus muscle attaches to the lower facet. The groove lying between those two facets is where the tendon of the popliteus muscle is situated.[1(p.518), 2(p.556-8)]

The proximal tibia

As the distal femur, the proximal tibia has a medial and a lateral condyle, but these are concave. They are separated on their superior articular surfaces by an intercondylar fossa. The two condyles and the intercondylar region make up the “tibial plateau” which articulates with the distal femur. The intercondylar region is the attachment point of the cruciate ligaments and menisci. Anteriorly, the region is home to three facets to which the anterior horn of the medial meniscus, the ACL, and the anterior horn of the lateral meniscus are attached. Posteriorly, there are three more facets where the posterior horn of the lateral meniscus, the posterior horn of the medial meniscus and the posterior cruciate ligaments are attach to. On the anterior surface of the proximal tibial shaft, inferiorly to the condyles, lies the tibial tuberosity. The patellar tendon attaches here.[1(p.520-21), 2(p.558-60), 3(p.204)]

The patella

On inspection this bone is the most prominent and exposed part of the knee joint. It is the largest sesamoid bone in the body. Its major function is to act as a fulcrum for the quadriceps muscle and increase its mechanical strength by doing so. This is needed for knee extension. Additionally, the patella covers and protects the anterior surface of the joint. The triangular-shaped structure is held in its position by the quadriceps tendon, and the patellar ligament, which is the distal extension of this muscle tendon. The patella’s posterior surface has two facets, articulating with the V-shaped depression of the femur, as mentioned above.[1(p.547), 2(p.558), 3(p. 201)]

1.3. Muscles for the knee joint

All the included muscles are part of the anterior, medial or posterior compartment of the thigh. They are subdivided into two groups:

a.) Knee extensors
b.) Knee flexors

The extensors are all part of the anterior compartment and the flexors are all part of the posterior compartment with two exceptions: the Gracilis muscle (medial compartment) and the Sartorius muscle (anterior compartment).

ad. a.) The extensors include the following muscles: quadriceps femoris muscle, including rectus femoris, vastus lateralis, vastus intermedius and vastus medialis and the articularis genus.

ad. b.) The flexors include the following muscles: biceps femoris, semitendinosus, semimembranosus, which are grouped together as the hamstring muscles, the gastrocnemius and the plantaris which together form the tibialis anterior muscle, the popliteus and the gracilis muscle.[1(p.570,643), 2(p561, 562, 565, 568)]

1.4. Ligaments of the knee

The main function of a ligament is to connect bone to bone and to maintain the integrity of the knee joint. They are viscoelastic structures. Damage to ligaments happens if the strain impacting on them is higher than 4%, causing microscopic failure, or it is 8-10%, at which point macroscopic failure occurs. This will be discussed in further detail in the chapter of Biomechanics of the knee ligaments.[6,7]

There are 2 subdivisions of ligaments of the knee:

a.) Extracapsular ligaments
b.) Intracapsular ligaments[1(p.636)]

ad a.)
These include the patellar ligament, the fibular/ or lateral collateral ligament (LCL), the tibial/ or medial collateral ligament (MCL), the oblique popliteal ligament, the patellofemoral ligament and the arcuate popliteal ligament.

The *patellar ligament*, or patellar tendon, is a very compact fibrous band forming the distal extension of the quadriceps femoris tendon. It extends from the patellar apex to the tibial tuberosity, therefore connecting patella and tibia. On its sides the medial and lateral patellar retinaculae join this ligament.[1(p.636)]

The *medial collateral ligament* is the one of the most commonly injured ligaments of the joint. This ligament has a broad and flat appearance. Some of the ligaments fibers are fixed to the medial meniscus. It’s proximally attached to the medial femoral epicondyle just below the adductor tubercle. It descends obliquely to reach the medial margin of the tibia and attach to it inferior to the pes anserinus. If the proximal part of the MCL is somehow sprained, the prominence at the medial epicondyle may be increased due to haemorrhage or oedema. It has the function to protect the knee from valgus forces.[1(p.636), 2(p.579), 3(p.206)]

The *LCL* (= lateral collateral ligament) is proximally attached to the lateral femoral epicondyle, just above the popliteus tendon attachment. Then it courses posterolateral to reach its distal attachment point, the lateral surface of the fibular head. None of its fibers are attached to the meniscus. The LCL protects the knee joint from varus forces acting on it. Visualization of the fibular head is best at 90° flexion of the knee. If the patients' legs form a figure-four position in which the varus stress pulls the lateral collateral ligament taut and makes it visible.[1(p.636), 2(p.579), 3(p.206)]

The *oblique popliteal ligament,* located posteriorly to the knee joints' articular surfaces, contributes to the formation of the popliteal fossa and reinforces the joint capsule. It arises distally on the posterior aspect of the tibial head and travels superolaterally until it reaches the lateral femoral condyle.[1(p.636)]

The *arcuate popliteal ligament* is another extracapsular ligament that attaches inferiorly to the posterior aspect of the tibia head. Its special characteristic is that it is Y-shaped and has two proximal attachment points. The medial fibers of the ligament fuse with the oblique popliteal ligament and the lateral ones attach to the lateral femoral epicondyle joining the gastrocnemius muscle. Its function is to strengthen the joint capsule and help the knee joint to resist posterolateral disc.[1(p.636)]

The patellofemoral ligament, is the most important medial static stabilizer of the patellofemoral joint. Its anterior part intertwines with the vastus medialis obliquus muscle to work together for medial stabilization. In concert these two structures move the patella medially during flexion.[8, 9]

ad b.)

"The two cruciate ligaments cross each other in the sagittal plane." [2(p.579)] "The anterior cruciate ligament crosses lateral to the posterior cruciate ligament as they pass through the intercondylar region." [2(p.579)] Both cruciate ligaments span from the intercondylar region of the tibia to the intercondylar fossa of the femur. They are not lined by the synovial membrane; therefore, they are outside the articular cavity, but they are enclosed by fibrous membrane. During medial rotation of the knee joint these two structures block any rotation more than 10° because they wind around each other. During lateral rotation, on the other hand, they unwind and let the joint rotate up to 60°, and during 90° flexion up to 90°. The lateral rotation of the knee joint is then stopped by the LCL. The pivoting point for rotational movements of the knee is the chiasm. The two cruciate ligaments are responsible to maintain the contact between the knee joints articular surfaces during flexion.[1(p.639-42)]

The *anterior cruciate ligament* is the weaker of the two and originates at the anteromedial tibial plateau. Proximally it is attached to the medial aspect of the lateral femoral condyle and distally to the anteromedial tibial plateau.[1(p.642)] The ligament measures about 33 mm in length and 11 mm in width.[10,11] The ligamentous structure is a lot broader on its insertion than mid-substance. It has an anteromedial bundle (AMB) and a posterolateral bundle (PLB) which names derive from their tibial insertions. The AMB is the major protector against anterior translation of the tibia on the femur and it is taut during flexion while the PLB tightens when the knee joint is in extension and is responsible to act during rotational movements.[12(p.209), 13] It has a maximal tensile load of 2160 Newton but due to aging the ACL loses strength and is then injured easier.[14]

The *posterior cruciate ligament*, or PCL, is resisting the posterior translation of the proximal tibia when the knee is flexed more than 30°.[15] It spans from the anterolateral area of the medial femoral condyle to its distal insertion on the posterior tibia in the fovea between the two tibial plateaus and is covered by its own synovial layer.[16, 17] Anatomically it is consisting of two bundles like the anterior cruciate ligament but the PCL's bundles are inseparable. There is the ALB, which is larger and taut during 90° flexion of the knee, and the PMB, which tightens during extension.[18] These two bundles act co-dominantly during all range of motions.[19] The ligament receives some contribution from the so-called meniscofemoral ligaments which will be explained below. Additionally, the PCL acts as a secondary restraint to varus and/or valgus stress, as well as a resistor to external tibial rotation.[1(p.642),]

The *transverse ligament* is intracapsular and located within the anterior aspect of the joint. It holds the menisci together by attaching to both of their anterior edges, therefore joining them.[1(p.642), 20]

The *meniscofemoral ligaments* (anterior, Humphrey; posterior, Wrisberg) are variable in distribution. They originate from the posterior horn of the lateral meniscus and insert into the PCL." If there are posteriorly directed forces acting on the knee joint during 90° flexion, the meniscofemoral ligaments add as much as 28% of resistance. [18]

1.5. Menisci

The menisci lie between the articular surfaces of the knee joint, the tibial and femoral condyles. The medial meniscus is C-shaped, and the lateral is rounder in shape. Anteriorly they are connected to each other by the transverse intermenisceal ligament. The menisci are fibrocartilaginous and viscoelastic structures that are primarily built by the fibrochondrocytes, which have the main function of creating and maintaining the ECM. The extracellular matrix is built up mostly by water and a small percentage of collagen fibers, elastin, proteoglycans and glycoproteins. The minimally present elastin is very important for the recovery after deformation of the meniscus and it differentiates the menisci from non-elastic articular cartilage. The collagen fibers are mostly type I fibers.

The meniscus is divided into three zones: a.) “red zone”

b.) “red- white zone”

c.) “white zone”

Their subdivision relies on the blood supply of the areas. These areas are starting with the “red zone” peripherally and ending with the “white zone” centrally. The outer third is vascular, thus “red”, and receives its nutrition by the attached joint capsule from the so-called perimenisceal plexus which is formed by the geniculate arteries, medial, lateral and middle one. The “white zone” is the most central area of the meniscus and is avascular. The synovial fluid supplies this part with nutrients by diffusion. In between these two zones lies the “red-white zone” which is variable in its nutritional state. These zones are determining the healing state of the meniscus. The outer portion has a good blood supply hence it will heal quite nicely, in comparison to the inner portion which is avascular and has poor healing capabilities. Usually in menisceal injuries, surgical suturing is only performed if the injury is located within the red zone, to support its healing process. This is especially useful in young individuals. In the other two areas repair is of no use due to their low blood supply. The nervous supply of the menisci derives from diverse branches, including femoral nerve branches, the terminal obturator branches and the posterior articular branch of the tibial nerve. The menisci’s functions are very diverse: contribute to load transmission, increase articular conformity, act as shock absorbers and lubricate the knee joint during movements. In case of an absent meniscus the two articular surfaces of the knee joint would be in direct contact and would show faster degenerative changes over time.[1(p.642), 21(p.103-105), 22(p.24-26), 23]

1.6. Blood supply and innervation of the knee joint

The blood supply of the knee joint is coming from the periarticular genicular anastomotic network. It is made up by “the genicular branches of the femoral, popliteal, and anterior and posterior recurrent branches of the anterior tibial recurrent and circumflex fibular arteries.” [1(p.642-43)] “The middle genicular branches of the popliteal artery penetrate the fibrous layer of the joint capsule and supply cruciate ligaments, synovial membrane, and peripheral margins of the menisci." [1(p.642-43)]

The innervation of the medial aspect of the joint is by articular branches from the obturator and saphenous nerves. The anterior, posterior, and lateral areas of the knee joint are innervated by articular branches from the femoral, tibial, and common fibular nerves.[1(p.642-43), 2(p.581)]

1.7. Bursae surrounding the knee joint

There are many bursae located around this joint. The actual function of a bursa, a thin fluid-filled sac, is to enable smooth movements of the joint and to reduce friction. They are especially needed in areas where there are tendons or muscles moving across a bony surface, as in the knee joint. Around the knee some of the bursae communicate with the joint cavity. The four communicating bursae are: suprapatellar bursa which communicates with the articular cavity, the popliteus bursa, anserine bursa, and gastrocnemius bursa. There are some more bursae which are the noncommunicating ones like the subcutaneous prepatellar and infrapatellar bursae.[1(p.643), 2(p.577)]

2. Knee movements

The knee has an average range of flexion of 0 – 140°, with some additional degrees of hyperflexion. This range highly depends on the muscular state around the patients' knee. If an athlete has a lot of muscle mass surrounding the joint, the range will be diminished, but if the athlete is doing sports like ballet or gymnastics the range could be increased. The knee joint is mostly able to move around the sagittal plane, but varus and valgus rotation around the frontal plane are possible as well.[21(p.23)] "Also, it facilitates the medial rotation at the end of the knee flexion and the lateral rotation at the terminal extension of the knee both at the transverse plane." [24(p.2)] The movements of the sagittal plane would be flexion, with a ROM of 130 to 135°, and extension with about 0 to 10° of hyperextension. The range of motion of the knee is influenced by several factors including age, weight, and previous pathology. The so-called "screw-home mechanism" stands for the external tibial rotation that is necessary for the last 10 to 15° of extension of the knee joint. Internal and external tibial rotation will reach about 10° in each direction. Any type of injury to the knee joint will affect its ROM.[25(p.234)] The muscles which initiate movements are called the agonists, and the resistors are the antagonists. There are different types of muscle fibers. The type 1 myofibers (also called "red fibers") are slow and show great resistance against fatigue, while the type 2A are fast fibers with intermediate resistance and the type 2B are fast fibers as well, but they are easily fatigable. Type 2 fibers are also called “white fibers”. Any sportsman has an individual set-up of these fibers due to the regular training they chose. A sprinter would have mostly type 2 fibers, but a marathon runner would have more type 1 fibers.[21(p.109-10)] According to their sports needs they adapt their workouts to this. In water-skiing the person would need a higher ratio of fast-acting type 2 muscle fibers since all the movements are happening in a short amount of time.

The examiner always tests active and passive movements of the knee. First the patient will flex the knee actively and after that the examiner helps to flex it passively. The same goes for extension. During those movements one hand of the examiner is resting on the patella, to feel for patellofemoral crepitus. Flexion and extension of the knee are always compared with the contralateral limb.[21(p.23)]

3. Stability of the knee

The most stable position of the knee is the erect, extended one, since the knee is capable of “locking”. The surrounding muscle tendons and ligaments are taut, creating a splinting effect for the knee joint and reducing the usage of muscle energy.[1(p.634), 2(p.576)]

An unstable knee is a very complex issue since most affected people are young active athletes or physically inactive elderly. The knee joints structure itself gives a certain amount of stability to it, by the shape of the condyles and the menisci. The hinge-joint is surrounded by primary stabilisers, the ligaments, and secondary stabilisers, the muscles. If these structures would not be present, the femur and the tibia would lie loosely on each other.[24(p.1-2)] During knee movements, the surrounding ligaments are very vulnerable, that is why the musculature around the joint will contract and reinforce the movements to prevent ligamentous injury. The major ligamentous stabiliser is the ACL, being responsible for about 85% of the knees stability. This explains why it is the most commonly injured ligament of the knee joint.[14] The musculature around the knee has two main functions, mobilisation and stabilisation.[24(p.3)] The better trained the muscles are, the better the joints stability is. That is why conditioning and training of the muscles can have a large impact on injury prevention and is also important in knee rehabilitation. The major muscular stabilisers of the joint, the quadriceps femoris and the hamstrings, are therefore strengthened by specific exercises.[12(p.214)]

The primary stabilisers, the ligaments, as well as the secondary ones, the musculature, will both benefit from conditioning, which we will further discussed in the scientific part of this paper. The main four primary stabilisers are the anterior and posterior cruciate ligaments, which hold the joint together during anterior and posterior movement, and the medial and lateral collateral ligaments, which resist valgus and varus angulations.[25, 26] (see Table 1.) The stability of the knees medial side is additionally handled by the medial capsuloligamentous complex. It is built like a three-layered sleeve which protects the joint from valgus loads and gives the joint abduction stability during movements.[22(p.39)]

Table 1.- Ligamentous structures stabilising the knee joint

Structure	Stability	Origin	Insertion	Function
ACL	Anterior-posterior	Lateral femoral condyle (posteromedial aspect)	Anterior tibial plateau	limits anterior translation of the tibia, resists hyperextension & internal rotation
PCL	Posterior-anterior	Medial femoral condyle (anterolateral aspect)	Posterior tibial plateau	Limits posterior translation of tibia & internal rotation
MCL	Valgus	Medial epicondyle of femur	Proximal tibia	Limits valgus stress & external rotation
LCL	Varus	Lateral epicondyle of femur	Fibular head	Limits varus stress & external rotation

modified by [24(p.5-6)]

Often the words laxity, instability and disability are used synonymously, which is incorrect. Therefore, we will define those three important words for the knee joint.

- Laxity = joint moves excessively within the constraints of its ligaments
- Instability = inability to maintain a single leg stance due to joint subluxation from pathological laxity
- Disability = instability is interfering with the required function of the knee.[27]

Knee instability is caused either by direct or indirect trauma, degenerative changes or overuse. The traumatic event most commonly involves a “noncontact” mechanism like twisting, jumping, and sudden deceleration. Important for the examiner is the direction of instability which is either in one plane, rotatory or combined. In multi-ligamentous knee injuries, the combined instability is most common. They are anterolateral/anteromedial, anterolateral/posterolateral, or anteromedial/posteromedial.[21(p.24), 25, 26]

Instabilities in one plane may be medial, lateral, anterior or posterior. These can occur in isolation or combined. Posterior instability is caused by a damaged PCL or other posterior structures. The anterior instability is due to ACL rupture. Rotatory instability is subdivided into anteromedial, anterolateral, posteromedial and posterolateral. ACL rupture may cause anterolateral instability, and PCL rupture combined with MCL injury will result in posteromedial instability. This can be demonstrated by the examiner during internal rotation looking for the posterior sag.[21(p.24-25)]

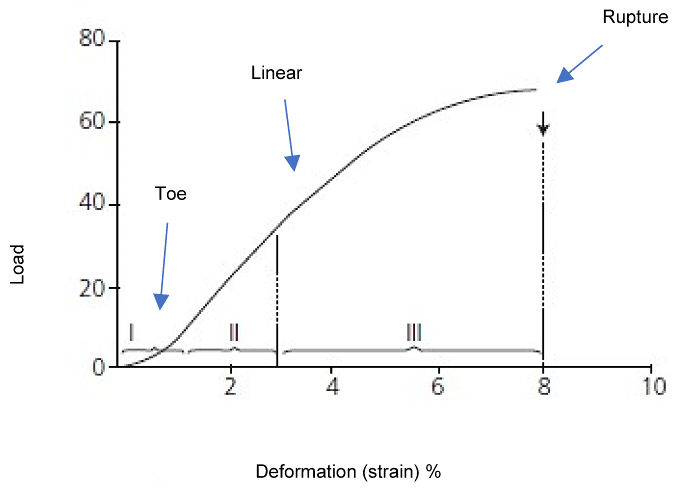
It is important to differentiate between acute and chronic instability. In a chronic state the patient will have some mechanical symptoms such as catching, giving way, locking, or clicking, especially when twisting the joint while in an acute state the patient will often present with pain and the other symptoms depending on the structures that are injured.[26]

4. Biomechanics of the ligaments of the knee

As viscoelastic, passive structures, ligaments have an impact on the joints stability by avoiding unwanted joint motions during statics and dynamics. These white bands are made of cells, mostly fibroblasts and extracellular matrix, containing water, ground substance, collagen and elastin.[28, 29, 30] In comparison to tendons, ligaments have a higher content of elastin, making them more flexible during motion. The elastin content of the ACL is about 5% and of the PCL it is 7.3%, while the dry weight content of collagen type I. is about 60%.[31] This elastin content also allows the ligament to deform and return to its resting shape when forces stop acting on it which is called “recoil”. Recoil means that the potential energy stored in the object, coming from its deformation, is used to bring it back into its original state. But since ligaments are viscoelastic, and not purely elastic structures, there is an additional fact to know about this process.[21(p.179)] “Viscoelasticity” means that a ligament has elastic solid and viscous fluid properties. Viscous material dissipates the deforming energy, so not all the energy acting during deformation of a ligament can be used for its recoil, but a certain amount of energy dissipates. The loading phase of a ligament therefore represents with more energy than the unloading phase. This is defined as “mechanical hysteresis”. Another property of viscoelastic structures is “creep”. It is the continuing deformation caused by a constant force acting on it. and by slowly increasing the strain on the object. If the viscoelastic structure is held at a constant elongation, the stress acting on it will be less with time, it will undergo “stress relaxation”.[21(p.181)]

The ligaments collagen type I. fibers are not only unidirectionally ordered, enhancing its rigidity against loads acting in various directions. Those collagen fibers appear wavy in the relaxed state. As soon as a load acts on a ligament the fibers initially straighten out, they are pulled taut, and are then increasing the tension afterwards. If the tension force is released during this process, the ligament returns to its original length by recoil, as described above. A ligaments response to loading is rate- and time-dependent.[28, 29, 30, 32] Microscopic damage will appear if there is tensile load added on the tissue, reaching the so-called “yield point”. After this the tissue will present with plastic deformation or retention and cannot return to its original length. If the structure is given sufficient rest, it is capable to recover.[28,30] Rupture of the ligament will happen when it is unable to withstand the applied stress and reaches its ultimate tensile strength.[33] For the ACL to rupture, 2000N are necessary and for the PCL even more.[34(p.60)]
Normal loading for ligaments reaches 25% to 33% of maximum. The usual deformation during activity is around 2 – 5%.[35] If this value is higher than 4%, the ligament will undergo damage as shown by the stress- strain curve, described by Butler et al. 1979; Oakes 1981.[36,37]
(Figure 1.)

Figure 1. Stress-Strain Curve



modified by [36,37] and [21(p.112)]

The “toe” region (I.) presents the physiological strain range of 3-4%, but it can be up to about 19% in the cruciate ligaments. This is due to their intrinsic macro-spiralling of their collagen fibre bundles. During this concave toe region, the collagen flattens the “crimp”. No irreversible micro- or macroscopic tissue damage occurs.
The “linear” region (II. and III.) stands for pathological irreversible elongation of the ligament. The process inducing this elongation involves damages of the intermolecular cross-links. Structural failure can occur following those cross-links disruptions due to further increasing the load. The early portion of this region, II., symbolizes grade 1 or mild ligament tears. These include 0-50% of the fibres. The latter part, III., on the other hand, symbolizes grade 2 tears, involving 50-80% of the fibres. In grade 2 injuries there is joint laxity present when examined.
The region of “rupture” represents the surpassing of the yield or failure point. Beyond this point, occurring at a strain of 10-20%, complete ligament rupture occurs.[34(p.58-59),36,37]
Basically, injury to a ligament happens as soon as the applied force exceeds its physiological tolerance or reparative skills. The result would be a macro- or microtrauma. Macrotrauma, e.g. ACL rupture, is induced by sudden, extreme stress overwhelming the ligaments adaptive properties. Microtrauma is caused by smaller forces that start structural disruptions at a rate outweighing the ligaments reparative abilities. Therefore, the structure will be weaker and more prone for further macroscopic trauma.[38,39,40]
The shape and size of a ligament are major influencers of their capacity, so a larger structure can bear bigger loads. This explains why ligaments rupture at different parts, and not at the same. A ligaments’ response to loading is measured by rate or time. In the case of higher rates of loading, there is more intense elongation of the structure before it fails, compared to lower rates. If the load is repetitive or cyclical, the ligaments strain response may change. It will present with greater elongation.[28,30,41] Systemic exercise impacts ligaments by making them become stronger and stiffer. This increased exposure to load may even increase their size. Immobilization, on the other hand, results in their loss of strength and stiffness. It also reduces the collagen turnover and may lead to reduced cross-sectional area, if long-term. In this case, ligaments may not be able to withstand loads that they usually tolerate.[28,30,41,42,43,44,45] If compared with control ligaments, immobilized ones have trouble handling loads even after 12 months of reconditioning.[46] Also fatigued ligaments may injure faster due to repeated stress. Many repetitions of loading may set a ligament to rupture at a lower stress level than its ultimate tensile strength.[47,48] Aging presents in those structures as reduced tensile capacity due to downsizing their diameter and their water content which will result in a weaker ligament in older subjects compared to the younger ones. The collagen turnover in older ligaments decreases as well.[49,50,51,52,53]

The secondary effect of ligamentous injuries, Grade II or III sprains as well as complete rupture, is abnormal joint motion. This may cause disintegration of articular cartilage or subchondral bone. The physicians goal of treatment is to minimize secondary damage and its end results. Ligamentous injuries may be due to intrinsic or extrinsic factors, or a combination of the two. They can happen acutely or chronically.[47] A ligaments weakest area at low loading rates is the insertion site, also called the "ligament-bone junction", but at higher loading rates the ligament itself will fail, mid-substance. [21(p.113)] A ligaments blood supply derives from their insertion sites and flows uniformly and diffusely, but it is sparse. Their healing will be slow since the metabolic rate is low, and they are relatively avascular, meaning their oxygen consumption is a lot lower than that of skeletal muscles.[21(p.111), 54]

5. Imaging of the knee joint

Later we will go into detail about the specific imaging of ACL or PCL in the chapters regarding these two structures. Now we will focus on a more general approach. The "standard imaging" includes:

- AP views of both knees, while bearing weight
- AP and lateral views of the involved view and the
- patella view. [4(p.633)]

The so-called "clinical decision rules" of the knee are used in attempt to make diagnosis and prognosis more accurate. Both help the clinician to diagnose knee fractures easier. The Ottawa knee decision rules are there to define indications for radiography of the knee. They are divided into indications and exclusion criteria. (see Table 2.)

Table 2.- Indications and exclusion criteria of Ottawa knee decision rules

Indications	**Exclusion Criteria**
1. Patient older than 55 years of age	1. Age younger than 18 years
2. Tenderness at the head of the fibula	2. Isolated superficial skin injuries
3. Isolated tenderness of the patella	3. Injuries more than 7 days old, recent injuries being re-evaluated
4. Inability to flex knee to 90°	4. Patients with altered levels of consciousness
5. Inability to weight bear four steps immediately after the injury and in the emergency department	5. Paraplegia or multiple injuries

quoted and modified from [55; 56,57]

5.1. Diagnostic Arthroscopy of the knee

Diagnostic Arthroscopy is used as an additional tool to assess many types of knee injuries, including ligamentous injuries, after taking the patients history, physical examination and imaging. It is most commonly performed under local anaesthesia since it relates to less morbidities than general or regional anaesthesia. The advantages of regional or general anaesthesia are keeping the patient more comfortable if the procedure may take longer than expected or if a tourniquet is used. Another positive aspect of regional anaesthesia is better pain control post-operatively.

In diagnostic arthroscopy the intraarticular structures are directly visualized and assessed to plan further treatment. When ligaments are injured, this procedure is very useful because it determines if the damage is at the insertion site or intrasubstance. Tears of the cruciate ligaments will be either partial or complete. The information the examiner gains with a diagnostic arthroscopy can be helpful in further treatment planning.[4(p.630-32)]

Prior to every diagnostic arthroscopy of the knee are a detailed physical examination and standard imaging, as described above.[4(p.633)]

Before starting the procedure by introducing the portals, the important landmarks can be marked (i.e.: patella, patellar tendon, medial and lateral joint line, tibial tubercle), which would reduce the risk of injuries caused by wrong placement. The marking should be done while the knee is flexed, since it is more difficult in an extended position.[4(p.636)] Under evaluation during diagnostic arthroscopy are the synovium, the conditions of the tibiofemoral and patellofemoral articular cartilages, the menisci and the capsuloligamentous structures. It is important to exclude any loose bodies. This structural assessment is executed by the two “standard portals”, the anterolateral and anteromedial. All the findings should be documented photographically and verbally.

Follow-up protocols suggest that after the diagnostic arthroscopy, the patient removes the bandages after 24 hours and puts band-aids on the incision sites. These should be kept dry for 48 hours. The patient is instructed to do certain home exercises to increase ROM, and do quadriceps strengthening exercises. If the patient is not compliant enough for the home workout, formal physical therapy is advisable. The patient returns after 7 days post-surgery for suture removal. If he or she experiences any increasing pain with increasing ROM or persistent draining after the surgery, he or she should contact the surgeon because of the risk of possible postoperative infection. Without any complications the patient can return to work within a few days and start with sports activities within 3-6 weeks post-surgery.[4(p.655-66)]

6. ACL

6.1. Differential Diagnosis

Differential diagnoses of an ACL tear include PCL injury, meniscal injury, patellar dislocation, and osteochondral fracture. To differentiate all of them thorough physical examination is necessary.[12(p.211)]

6.2. Epidemiology

Injuries of the anterior cruciate ligament are very common and very well studied nowadays. The rupture of the ACL is often associated with damage to other structures of the joint, like the menisci, subchondral bone or articular cartilage.[58,59] They may happen isolated or with combined multi-ligamentous injuries, like in a dislocated knee. Mostly young and active people are affected. Female athletes are 2 to 8 times more prone to injure their ACL due to different neuromuscular adaptions and biomechanical landing techniques during sport activities. 70% of all ACL tears in females happen due to sporting activities, most commonly at soccer or skiing. Most of the ACL injuries are induced by noncontact mechanisms, showing why the landing techniques are so important.[60,61,62] Another risk factor for damaging this ligament is a person’s occupation. Heavy laborers or professional athletes are more likely to have overuse or degenerative changes at the knee joint because of their repetitive stress exposure leading to further injuries.[55(p.232)]

6.3. History & Physical Examination

A thorough history taking is of high importance. The goal is to find out the patient’s tissue injury complex, meaning the tissue damage, and their clinical symptom complex, including all the presenting symptoms.[63] A patient with an ACL tear would describe a history of sudden non-contact deceleration, pivoting or cutting movement with the foot fixed, non-contact hyperextension or an anterior blow to the tibia causing contact hyperextension of the joint.[60, 64] The knee might give way or shift and show immediate intraarticular effusion that is not only visible but also palpable.[25, 55(p.239)] The “locking knee mechanism” happens if the symptoms worsen during knee extension, making it impossible to achieve optimum normal extension. This mechanism is there to avoid any unnecessary pain by restricting the angle of extension. Some of the patients may hear or feel a “pop” during the mechanism of injury and the inability to continue with the activity.[55(p.236-37, 239), 21(p.807)] During activity, sharp pain, superficial or deep, is very typical for ligamentous injuries while at rest it would be relieved or milder. The pain may also be present due to the joint effusion. Symptoms of ACL tears are intermittent, they improve during resting, unloading and conservative treatment. If the pain is resistant to those tools, surgical treatment may be indicated. [55(p.235), 12(p.208)]

To summarize all the symptoms of ACL rupture, also called the “clinical symptom complex”: pain, acute intraarticular effusion, instability or “giving way” of the knee, inability to bear weight or continue with sporting activity, hearing or feeling a pop during the moment of injury, “locking knee mechanism” and therefore loss of ROM.[6(p.22-23), 21(p.22,23), 34(p.146)]

After all the questioning, the examiner looks at the knees general appearance, the patients gait and alignment. Inspection, palpation, testing the ROM and the neurovascular supply are the first step. When the knee is acutely injured, the range of motion can be limited due to swelling and pain, but other possible diagnoses for those limitations should be considered and excluded. [21(p.23, 807)] In any knee examination, no matter what injury is suspected, the examiner assesses if there is any effusion present. The prominence of the patella can be affected by excessive fluid accumulation in its surrounding area. The effusion is most commonly due to oedema or haemorrhage in the knee joint and results in a reduced prominence of the bone. By examining the patella for its orientation, the examiner can check if there is any rotational malalignment in the inspected limb. The patient is placed in an upright standing position with the feet together facing the examiner. Usually the patellae should face directly forward in their coronal plane but if they don't, there is further examination necessary.[1(p.547), 2(p.558), 3(p. 201)]

The typical acute effusion of an ACL injury appears within hours.[21(p.22)] The "patellar tap" is an examination technique to estimate the level of effusion in the knee joint or if there is even any present. If it is positive it indicates an extensive effusion. For executing this test, the knee is fully extended, and the examiner gently taps on the patella, by which "the patella engages with the trochlea and the femoral epicondyles." [21(p.23)] The so-called "bulge test" is used to determine mild or moderate effusion. [21(p.23)] A symptom specific evaluation assesses if there are any knee extension deficits and continues with a thorough ligamentous examination, always comparing the affected knee with the contralateral uninjured one. At first the examiner checks if there is any varus or valgus translation present, indicating an injury of the medial or lateral collateral ligament. The tests used for evaluating the state of the ACL are the Lachman test, anterior drawer test and the pivot shift test.[12(p.211), 21(p.807), 55(p.232-242)]

Lachman test

It is the most sensitive and reliable test for evaluating the ACL. The patient is in a supine position and the knee is at 20 - 30° flexion without any rotation. The examiner applies with one hand anterior stress to the tibia while the other hand holds the femur in position. If the ACL is intact, it should prevent anterior excursion on the femur and the endpoint should be firm. A positive Lachman test includes anterior laxity and a soft endpoint, which are both graded. (see Table 3.) The so-called "endpoint" is indefinite in the case of an injured ACL. Comparison to the healthy knee of the patient helps to distinguish the translation and the endpoint from their normal state. Swelling and stiffness during the acute state of the injury may make the evaluation of the endpoint more difficult.[3(p.230-31), 12(p.209 – 211), 21(p.807-8)]

Table 3.- Grading of the Lachman test

Normal	**No or little translation, between 1 – 2mm, a firm endpoint**
Grade I. (mild)	microscopic tears stretch the ACL which don't affect its ability to support the knee joint. The endpoint is firm and the displacement is < 5 mm
Grade II. (moderate)	there is partial rupture of the ACL affecting the stability of the knee joint moderately. It might give out during walking or standing. Displacement is between 5 – 10 mm
Grade III. (severe)	complete rupture of the ligament either at the middle or at its attachment site to the bone, which makes the joint unstable. Displacement is 10 mm and more

modified from [3(p.230-31), 21(p.807-8)]

Anterior Drawer test

The patient is placed on the examination table in a supine position with the hip flexed at 45° and the knee at 90°. While sitting on the patient's feet, fixating them, the examiner grasps the tibia just below the joint line and pulls it forward to evaluate the translation. If the test is positive, there is increased tibial excursion and a soft endpoint. A false positive may happen due to interpreting this test wrong. Before performing it, the examiner would have to check if there is any posterior sag of the tibia present. This would indicate an injury of the PCL, not the ACL.[12(p.209-11)] Difficulties of this test include that patients in the acute state of knee injury might not be able to perform a 90° flexion of the knee as pain or swelling would prevent them to do so. Relaxation of the patient's extremity may be problematic and due to that the hamstrings may cover up any abnormal tibial translation by not being able to fully relaxing.[3(p.229-30)] This test is the least sensitive of the three tests used for evaluating the ACL.[55(p.571)]

Pivot Shift test

With this test the examiner assesses the rotational stability of the knee joint. Mild physiologic pivot shift is possible in hyperextension of some patients because of excessive elongation of the ACL. It is very rarely performed during the normal physical examination due to pain and guarding. Usually it is executed while putting the patient under general anaesthesia. It is a highly sensitive and specific test. Performance of this test involves slight abduction of the hip, while the examiner applies valgus stress and internal rotational force to the extended knee. If the ACL is torn, the tibia will anteriorly subluxate. As soon as the examiner flexes the knee to 20 degrees, the tibia will reduce, inducing the “pivot shift”. Since this is a dynamic test, it is difficult to grade it, but grading would be according to the degrees of the shift. Grade I. is also called pivot glide, grade II. is called shift, and grade III. is called transiently locked out. In a grade III. case, the subluxation is severe and spontaneous reduction is not possible. The knee is “stuck” between 20° – 30° flexion and can only be reduced manually by the examiner.[3(p.231-32), 12(p.209-11), 21(p.807-8)]

6.4. Imaging of the ACL

First, plain radiographs, AP and 30° lateral view, are being used to rule out any associated fractures of the knee joint area. These kind of fractures, as the tibial eminence fracture, may mimic ligamentous injuries, or they are pathognomonic for ACL injury, like the so-called “Segond fracture” (lateral capsular avulsion). The tibial spine avulsion fracture most commonly occurs in skeletally immature patients. To diagnose damage at the patellofemoral articulation more accurately two special views are used, the Merchant view and the “sunrise” view which give us a better look at the bony structures of this area. If images show that the physes are not fused yet, it will affect the approach of surgical treatment.[4(p.657), 12(p.211), 22(p.4-5)] To evaluate for malalignment, a long leg standing AP view is used. [65(p.213)]

The gold standard to diagnose ligamentous injuries of the knee joint is the MRI. It is more than 90% sensitive for diagnosing ACL injury.[66] The MRI additionally displays the menisci, chondral injuries and bone bruises. In an acutely injured ACL, there is a pathognomonic bone bruise present. It is located at the posterior third of the lateral tibial plateau and the middle third of the lateral femoral condyle. Since the ACL is made up by two bundles, it is important to assess both and check for any additional injuries to menisci, other ligaments or the articular cartilage. This is crucial to creating a proper treatment plan.[12(p.211), 21(p.808-9)]

6.5. Treatment

The treatment of the anterior cruciate ligament is influenced by many different variables, such as the patients age, the activity level, the degree of laxity, possibly present associated injuries and future expectations of the patient regarding their knee, like in professional athletes. A patient’s choice of treatment is highly dependent on the his or her activity status. A highly active patient, like a professional athlete, is advised to undergo surgical reconstruction to reach their pre-injury activity level, but inactive patients may benefit more from conservative treatment involving rehabilitation and follow-ups. If there is recurrent instability present, these patients also receive the operative treatment.[12(p.213)] If there is any associated injury like a meniscal tear, fixed by meniscal repair, the ACL reconstruction is inevitable since the risk of repair-failure of the meniscus without an intact ACL is too large. Also, in patients with 2 major ligaments injured, the patient must undergo surgery since patients do not tolerate this major instability.[26, 67] The goal of treating a deficient ACL is to prevent secondary injuries and late degenerative changes, such as arthritis or osteoarthritis of the knee. For active patients, such as athletes, it is highly recommended to undergo surgery to be able to reach their pre-injury level of injury.[12(p. 213), 21(p.809), 26, 68]

The sport activities of the ACL-deficient patient can be graded by their risk. Level 3 include low risk activities, level 2 involve intermediate risk by pivoting movements, level 1 are high-risk. In Table 4. are some examples of those activities.[26]

Table 4. List of risky activities for ACL-deficient patients

Level 3 (low risk)	**Level 2 (intermediate risk)**	**Level 1 (high risk)**
Cycling	Tennis	High-level skiing
Swimming	Golf	Football
Stair climbing	Skiing	Basketball

modified from [26]

6.5.1. Non-Operative Treatment

This type of treatment relies on indirect healing of the ligaments and the formation of scar tissue. The issue with this process is that the original large collagen fibrils which were present pre-injury are not replaced post-injury. The material forming the scar tissue has poorer properties. Even in ACL reconstruction (explained in Chapter 6.5.2., p.22-23), in which an auto- or allograft tendon is used as a scaffold, the large collagen fibrils are not replaced. This may cause the ACL reconstruction to fail.[34(p.62)]

In most ACL-deficient patients, the knee shows signs of recurrent instability, preventing the person to reach his or her pre-injury level of activity. The ACL-deficient knee is at higher risk to develop meniscal tears, chondral injuries or late degenerative changes. Initially a patient with an isolated ACL rupture will unload their joint from weight-bearing by using crutches and avoid high energy cutting movements. The range of motion will be protected by using a brace, which is initially locked in extension. The brace will be adapted daily to enhance the ROM of the knee joint by adjusting the degree of extension and flexion of the machinery. It is used post-surgically as well. Non-operative treatment should also include physical therapy, such as strengthening of the quadriceps and the hamstrings. Straight-ahead activities like biking are allowed, as well as swimming.[12(p.213), 69-71]

Rehabilitation is commonly used before surgically reconstructing the ACL as well. This pre-surgical muscle strengthening can positively affect the outcome of the reconstruction and reduce post-surgical rehabilitation time. This pre-surgical rehabilitations' purpose is to gain a better or even full range of motion and increase the strength of the quadriceps and hamstrings muscles.[21(p.809)]

6.5.2. Operative treatment

Unlike for other ligaments, for the ACL a direct suture repair is not an option because of its poor healing ability after that procedure. There are two different categories being considered as operative treatment:

a. Treatment depending on immobilization,
b. Treatment including early mobilization of the knee joint.

The first category involves placing an external fixator to immobilize the knee joint for about 6-8 weeks. A study by Taylor et al. has shown that prolonged immobilization, longer than 6 weeks, presents with severe stiffness and pain.[72] This is the reason why surgical reconstruction, allowing early mobilization after the procedure, is the gold standard for ACL ruptures nowadays. After it, the patient can be as active as before the injury. Early mobilization is defined as movement induced on day 1, or up to week 4 post-surgically, depending on the patient's post-surgical state.[73(p.690)] An ACL reconstruction during the immediate post-injury period is not recommended because it results in a higher incidence of knee stiffness and arthrofibrosis. Pre-surgically it is important that the swelling partly subsides, and that the inflammatory state in the area is reduced. Before the operative intervention, the joint should have a minimal ROM of 5 to 90 degrees, additionally to the subsiding inflammation as mentioned above. That may take a few days.[4(p.657)] Often the ACL reconstruction is wrongly called "ACL repair", but as previously mentioned it is not possible to "repair" this ligament.[22(p.56)] Three main factors influencing the outcome of the reconstruction include the surgical technique with the correct tunnel placement, the timing of the surgery and the post-surgical rehabilitation.[21(p.809)] To reconstruct the ACL, a tissue graft, for which multiple choices are available, is used. It can be either an autograft or an allograft or a synthetic (also called "prosthetic) graft. All of them present with different advantages and disadvantages, making it easy to compare them during treatment planning. Autogenous grafts are the first choice for an ACL reconstruction.[26] Allografts work similarly, but they heal slower and carry the risk of possibly transmitting diseases, so they are mostly used if there is no autograft available or if the patient is of older age, has a multi-ligamentous injury or is a revision case.[12(p.213), 26, 74] All the variable grafts are introduced via an intra-articular or extra-articular approach. Currently the intra-articular reconstruction is more commonly performed, using arthroscopic assistance. For this reason, we will focus on those procedures. The implanted tissue must be properly placed, set taut, and fixed to avoid any future complications.

The diverse autogenous tissues used as grafts include:

- the patellar tendon graft (BPTP)
- the iliotibial band
- the semitendinosus and gracilis muscle tendon
- quadriceps tendon graft

No matter what graft is chosen, it is passed through newly drilled tunnels, located at the ACL's tibial insertion site and its femoral origin. They are called "tibial tunnel" and "femoral tunnel".[12(p.213), 26]

Patellar tendon autograft

The BPTB, which stands for bone-patellar tendon-bone, technique is the most classical choice of the diverse autografts. It remains to be the gold standard for ACL reconstruction in athletes because there is supposedly better long-term stability according to recent studies.[73(p.698)] For this graft the surgeon harvests one third of the tendon en bloc, including also its bony attachments to the patellar apex and tibial tuberosity. Those attachment areas function as the reattachment parts for the fixation to the native ACL origin and insertion. Its advantages are the ability to re-vascularize, to withstand higher energy before failing and being characterized by greater stiffness than other graft options.[75] Its mean strength is 168% of the native ACL.[14,76] The results of using an autogenous B-PT-B are mostly very good according to the surgeons.[26] Complications of this procedure include a patellar fracture or incorrect tunnel placement, which are avoidable by a careful procedure, patellar tendinitis, which is usually short-lived and anterior knee pain, which is more pronounced in this procedure than in the hamstring reconstruction.[26]

Hamstring tendon autograft

The hamstring autografts gain more and more popularity nowadays.[12(p.213)] Its mean strength is 240% of the native ACL and 138% of the patellar tendon autograft.[77] The grafts stiffness characteristics seem to be more like the normal ACL than the patellar tendon grafts.[26] The hamstring autograft can be either double- or quadruple-stranded. The double-stranded graft involves only the semitendinosus tendon and is not used very often since its long-term clinical outcome has been reported worse than in the BPTB. The quadruple-stranded version, involving the semitendinosus and the gracilis tendons, on the other hand showed the same long-term outcomes compared to the BPTB graft.[78,79,80] The graft harvested has the advantage of a large cross-sectional area maximizing revascularization, but it is more difficult to fixate and the tendon to bone healing is lacking, compared to the BPTB autograft.[81-83] Complications occurring after this kind of graft include possible loss of fixation,[83,84] the hamstring could be continuously weak,[85,86] expansion of the tunnel[87] or possible graft failure in an early stage.[88] This type of graft is a better choice for skeletally immature patients, since harvesting the patellar tendon would risk damage to the tibial apophysis.[26]

Allografts

They are most commonly used in multi-ligamentous injuries or for revision surgery.[55(p.57)] Cadaveric allografts that are options for an ACL reconstruction include patellar tendon, quadriceps tendon, hamstring tendons or the Achilles tendon.[21(p.571)] In the case of using the patellar tendon or the Achilles tendon, a bone plug can be additionally harvested for better fixation.[55(p.57)] The advantages of allografts would be the lack of any donor site morbidity and a less invasive approach resulting in quicker return to function. There is also a decreased risk of arthrofibrosis.[89] But as mentioned earlier there are many Con's including the limited number of available donors, possible spread of disease via the graft, delayed incorporation, an immune response to the tissue by the host or even failure of the graft.[90,91] The allografts are a lot weaker than the autografts because of the sterilization process they must go through. The usage of gamma radiation decreases its strength by 26% and stiffness by 12%.[55(p.571)] Compared to an autograft, the allograft has been proven to have a three times higher failure rate in ACL reconstruction.[92]

Synthetic ACL graft

Nowadays the usage of a prosthetic ACL graft is largely obsolete because of their increased risk of infection, the formation of intra-articular debris and possible re-rupture.[74]

Double-bundle reconstruction

The double bundle technique involves both functional ACL bundles, the AMB and the PLB, not only the anteromedial bundle as in all the single-bundle techniques described above. For this reason, it is a more complex procedure.[12(p.214)] Tendons that may be used for this technique include the semitendinosus tendon or gracilis tendon. Working on both bundles may improve the outcome of the joints rotational stability as well as restoring normal knee kinematics.[12(p.214), 93] Often young high-performance athletes, who go back to activities involving translational and rotational stress to the knee joint, show persistent pain and instability after a single- bundle reconstruction. They have residual laxity during tibial rotation.[94] For them a double-bundle reconstruction could be the solution, but this procedure is still under evaluation since clinical outcome studies describing and confirming its advantages are sparse.[21(p.811)]

6.5.3. Post-operative management & Rehabilitation

The wounds will be covered by elastic compressive bandages, the knee will be cooled with ice, and post-op radiographs will be taken. Monitoring of the vasculature and the innervation of the lower extremity is of high importance to avoid missing any damage to them, caused by the treatment. The wounds from the surgery should be kept dry for at least 48 hours. Suture removal is usually scheduled on day 7 post-surgically. If any sign of infection, like persistent drainage, is present, the patient should immediately inform the surgeon to be examined. [4(p.655-656)]

The patients knee is post-surgically placed into a hinged knee brace for about 6 weeks. This brace is locked into full knee extension in the beginning and is adapted daily to enhance the knees ROM. The immediate passive motion with the brace starts at about 0° to 45° flexion and increases for about 10° each day.[21(p.810)] Joint motion will support the healing process.[12(p.214)] Crutches are used to support weight bearing for the first month after surgery. After 8-12 weeks the patient can return to light activities such as cycling or swimming, depending on the physical state of the operated joint. After 6 months the patient may resume with sport activities, except any high-risk sports which are allowed after 9-12 months.[21(p.810), 65(p.219-20)]

Rehabilitation after ACL reconstruction is a complex path for the patient. Its goal is to restore full ROM, reduce swelling, keep the patellar mobility at its normal level and stop or limit anterior knee pain. To reach those goals, it is important to take the process of ligamentation and graft maturation into account. This involves gradual transformation of the tissue including necrosis, revascularization and collagen formation and remodelling.[12(p.214), 55(p.572)] In a study that evaluated the patellar tendon graft, they observed the changes in quantitative collagen fibrils. It was proven that the original large-diameter fibrils of the autograft will be removed and replaced by small-diameter fibrils (< 7.5 nm). The smaller ones are less well-packed and less well-oriented. Hence the tensile strength was reduced in the patellar tendon graft showing more small-diameter fibrils than large ones. This was observed by Parry et al. (1978) and Shadwick (1990). In conclusion these findings revealed that all the ACL grafts show a lower tensile strength than the original ACL due to that remodelling of the fibrils.[95,96]

Those studies underline the importance of conditioning the musculature around the knee as part of rehabilitation after ACL reconstruction. The phase, during which the muscle training starts, is the so-called remodelling phases (Phase 3 and 4) and will be introduced as soon as there are no functional limitations of the joint present anymore. The patient usually receives a home-exercise program or is referred to formal physical therapy. Strengthening exercises involve mostly the quadriceps, which unfortunately atrophy quickly during immobilization and after surgery, and the hamstrings. Isometric exercises that are “closed chain” (= foot-planted) are the first choice during the early part of this phase of rehabilitation. The goal is to regain 80% of quadriceps strength and 90% of hamstrings strength before the patients starts to be fully active again.[12(p.214-15), 55(p.572)] The exercises help re-train the muscles and correct the possible contributing factors that resulted in the ACL injury. During Phase 4 the patient should introduce sporting activities again, until he or she reaches their pre-injury state. [55(p.572)]

Before the remodelling phases the patient undergoes the inflammatory phase (Phase 1) and the reparative phase (Phase 2) of rehabilitation. During Phase 1 the most important goals are to improve healing and to decrease the inflammatory state. The patient will receive anti-inflammatory medication, as well as ice for cooling the knee joint. Additional modalities besides icing include electrical stimulation of the quadriceps muscle for re-education, and ultrasound. Phase 2 focuses on restoring the range of motion of the affected knee. Swelling should be minimized and full extension should be achieved. This phase progresses as the pain allows. Modalities and medication are used as individually needed. In all three phases the patient should work on their lower leg flexibility using special exercises to do so. In all three phases the patient should work on their lower leg flexibility using special exercises to do so. This will avoid any future limitations of ROM. [55(p.572)]

6.6. Complications:

The most commonly found complications of ACL injuries, even after treatment, are pain, restricted motion and recurrent instability. All other complications are divided into:

- injury-related or
- treatment-related.[97]

The goal of any ACL reconstruction is to improve the knee kinematics to its pre-injury state. In this chapter we will mostly focus on treatment-related complications.

Flexion Contracture

Loss of motion is often produced by flexion contracture. Flexion contracture is common and often overlooked. It can be caused by arthrofibrosis, cyclops lesion, incorrect graft positioning or tensioning, or improper post-surgical bracing of the knee. A cyclops lesion (= a type of arthrofibrosis, which is explained next), classically located in the anterior part of the intercondylar notch right behind Hoffa's fat pad, occurs when the remnant of the native ACL hypertrophies on the tibia and blocks full knee extension. It may cause additional anterior knee pain. The cyclops lesion occurs about 4-6 months after ACL reconstruction and can be diagnosed and treated via arthroscopy.[12(p.214)] To assess a flexion contracture, the patient is placed in a prone position, and heel heights of both extremities are compared with each other. 1 degree of flexion contracture stands for 1cm difference in heel height. For treatment the patient is placed in a supine position, because then the leverage for stretching is much higher. The patient will now extend their knees and weights are hung to stretch the posterior capsule. This should be done twice daily for about 20 minutes. To make this exercise more comfortable for the patient, he or she is advised to recline, so that the hamstrings can relax. Prior this treatment usage of pain medication is recommended.[73(p.700-01)] Abnormal graft handling, like wrong positioning will cause limited motion, loss of motion, or even graft failure. If the graft is placed too anterior, it limits flexion, if it is too posterior, it limits terminal extension. This shows how proper placement is of high importance for a good outcome.[12(p.214)]

Arthrofibrosis

Arthrofibrosis is one of the complications that causes painful ROM limitations. It is characterised by excessive postoperative fibrous tissue formation, synovial hyperplasia, and inflammation around the ACL graft.[98] It is well visualized in the sagittal plane, on MRI images. Always distinguish arthrofibrosis from scar tissue in Hoffa's fat pad, which derives from the portals used during arthroscopic reconstruction of the ACL.[22(p.65-66)]

Post-surgical Pain

Following surgical treatment, limited motion, as described above, and pain, are more frequent issues than instability. Pain may range from mild or occasional to disabling and constant and it needs proper attention. In the case of severe pain, the knee may be non-functional despite its normal ROM or stability. Limited motion and disabling pain often occur together. Many studies have been done about pain following knee dislocation surgery, but their results are highly variable. Yeh et. Al for instance reported up to 25% of the patients having pain while Richter et al had results showing 68% of patients presenting with pain.[73(p.705), 99-103] Pain may be also due to an impinged graft, introduced by inadequate graft positioning. (see Chapter "ACL graft impingement" below)

Recurrent rupture of the ACL

A complete ACL graft rupture can be detected nicely by the MRI while partial tears are not as easily visualized. There are several secondary signs present in a full-thickness rupture which include anterior tibial translation, specific bone contusions and buckling of the PCL.[104] It is important to differentiate between ACL graft rupture and ACL graft elongation since anterior tibial translation or PCL buckling can present in elongation as well. In this case, the fibers are stretched, but still intact and cause knee instability.[22(p.64)] A partial tear presents with the disruption of the fiber continuity while replacing it with fluid in the injured place. Focal graft thinning may be another sign of partial rupture, as well as laxity of the ACL graft. The best way to image partial graft tears is by the MR arthrography. Partial damage to the graft is often presenting together with graft impingement.[105]

ACL graft impingement

ACL graft impingement is mostly due to mal-positioning of the tunnels which leads to an inadequate course of the graft. This impingement results in limited ROM and pain, especially during extension. Other causes of impingement include osteophytes or protruding fixation devices. If impingement is repetitive it can be associated with graft rupture or elongation.[22 (p.64), 106]

Tunnel widening

Tunnel widening is a multifactorial, mechanical and biological, complication of ACL reconstructions. It occurs more often after hamstring graft placement than with BPTB reconstruction.[107] The normal tunnel width is about 10mm, but this diameter may change since it is a dynamic and not a static value. The diameter may increase during the first 6 weeks post-operatively but remains stable for the following 1.5 years post-surgically and sometimes decreases 3 years after the reconstruction. If a tunnel widens, it can cause the graft to fail or exaggerate its laxity.[22(p.69), 108]

Vascular or nerve damage

An important complication, which is mostly injury-induced, is damage or even rupture of the popliteal artery and/or vein. Patients with multi-ligamentous injuries are the ones presenting more often with this, as well as nerve injuries. The rupture of the popliteal artery or vein would have disastrous effects resulting in possible amputation, since the collateral vasculature around the knee is not able to profuse the lower extremity adequately on its own.[109-112] To avoid this devastating fate, examiners use the so-called "selective arteriography" as a primary screening tool in any patient that shows signs of vascular damage after knee dislocation.[112] Nerve injury, affecting either the peroneal nerve or the tibial nerve, may be due to injury or treatment. There is very poor prognosis if the patient suffers a complete injury of the nerve.[110, 113, 114]

6.7. Outcome

The long-term success rate of surgical ACL reconstruction is between 82-95% after ACL reconstruction.[55(p.572)] The operative treatment, in comparison with the non-operative treatment, for ACL injuries is proven to be more effective in improving the patients motion, stability and return to work or sporting activities. (Surgical Treatment for Ortho & trauma p.705) From 1994 until today many outcome studies were evaluating the improvement of the mean arc of motion. Comparing more current studies with earlier ones, they discovered that the mean arc of motion was 106 degrees and is now 121 degrees. This shows a major development due to immediate motion rehabilitation programs rather than including an immobilization period. Over the years the progression in surgical techniques also had a major positive impact on the outcome of surgical treatment of ACL injuries.[73(p.705)] Failures of ACL reconstructions are more common in cases with multi-ligamentous injuries in comparison with isolated ACL injuries.[73(p.707)]

Pain is an important outcome measure since it can lower the outcome scores. It can vary from mild occasional pain to severe constant pain. Studies have shown that the outcomes of acutely treated patients showed better results, than those of patients receiving delayed care. There haven't been many specific studies to present a connection between chronic pain and the timing of surgery up to now, so there is still the possibility to gain new knowledge concerning this in the future.[101, 115]

Returning to work post-operatively can be a burden to many patients. Some of them will never return to their former job but will settle with a less demanding occupation. When the results of seven outcome studies were combined, they demonstrated that 93% of those patients could return to their job, but 31% had to change to a lighter form of work.[99, 103, 115-119]

Functional outcome is often measured with the total scores of IKDC (International Knee Documentation Committee) or the Lysholm scores. (Clinical Outcomes after Anterior Cruciate Ligament Reconstruction Article) If there is any knee impairment, the IKDC score is a tool to evaluate any improvement or deterioration of the knee joints function, symptoms or activity level. Therefore, it is useful in patients with ligament injuries.[120] The Lysholm score, on the other hand, is very specific for knee ligament surgery outcomes and focuses on instability.[121]

7. PCL

7.1. Epidemiology

PCL injuries are less common than ACL ruptures, accounting for 15-20% of all ligament injuries of the knee joint and accounting for only 3% of all knee injuries.[97, 122] They most often occur as part of multi-ligamentous injury and not isolated. The associated injured structures in PCL injuries, oftentimes occurring with grade III., are: PLC (62%), ACL (46%) and MCL (31%).[123,125] In the past, there were not many studies about this ligament but nowadays it becomes increasingly recognized. Over the past years, the knowledge of the PCL's anatomy and biomechanics increased immensely, leading to better PCL management. Studies have shown that many untreated PCL patients developed knee arthrosis later in life.[20] In comparison to ACL injuries, the PCL is affected more often in trauma, like motor vehicle injuries due to the dashboard impact, than in sports. The best-known causes for PCL tears in sports are a fall in hyperflexion, or a sudden impact hyperextending the knee. Males (97%) are far more commonly affected by PCL injuries than females (73%).[125]

7.2. History & Physical Examination

While the ACL is injured by active mechanisms, the PCL is impacted by passive external forces, applied to the knee. To damage it, a high-energy force is necessary, since it is the strongest ligament of the four primary stabilisers.[55(p.604)] The high-energy stress will most often injure some other structures first, because they are less capable of withstanding such forces, and only after that affect the PCL (multi-ligamentous injury). Peri-articular fractures of the knee occurring concomitantly can cause the examiner to suspect the ligaments' injury in about 60% of the time, which was described by Kim *et al.* Rarely the PCL is injured in isolation. A patient with a PCL tear would have a history of a force posteriorly displacing the tibia either by collision (dashboard type injury) or by fall.[34(p.60),126] As mentioned above in sports the injuries to the PCL occur due to a fall onto the flexed knee (possibly with the foot in plantar flexion), but it can be also damaged by a combination of knee dislocation or rotation with some varus or valgus translation.[125,127] If the athlete falls onto the flexed knee, it allows the PCL to rupture in isolation, while all the other possible movements to injure it, usually cause other damages as well. Instability in an isolated rupture is not as bad as in combined injuries.[26] In 70% of the cases, PCL damage develops at its tibial attachment.[55(p.604)]

Typical symptoms of PCL injuries include mild to moderate pain and effusion, limited ROM, stiffness, instability and giving way. Rarely the patient hears or feels a "pop" while the injury happens, compared to the ACL injury during which many of them encounter it. Prior knee, hip or ankle injuries may predispose the knee joint to further injuries.[55(p.604)]

After taking the patients history, the examiner inspects the knee for any effusion or abnormalities of the bones. The gait and the lower limb alignment are inspected as well.[65(p.231)]

Then the examiner continues with the knees physical examination including the specific PCL tests, like the posterior sag sign, Godfrey's test, posterior drawer test, quadriceps active test and the dial test. If the knee lacks the PCL, posterior translation is most pronounced during 90° flexion, but least pronounced in full extension.[128]

Additionally, rotational tests are important since their positivity may suggest a combined PCL and PLC injury when the external rotation is increased at 30° and 90° flexion of the knee.[3(p.233-35), 22(p.11)] Also valgus and varus tests are performed to assess any associated MCL or LCL injury.[129]

Godfrey's test

It determines if the "dropback phenomenon" is present in the affected knee. The patient lies in a supine position and flexes the knees and hips to 90° while the examiner holds the patient's legs to support them. Gravity, acting as a posteriorly directed force, will cause visible posterior subluxation of the tibia with respect to the femur, if the PCL is damaged.[3(p.234)]

Posterior drawer test

This is the most accurate test used in determining PCL injury, with a sensitivity of 90% and a specificity of 99%.[126, 130]

The patient is placed in the same position as for the anterior drawer test, supine with the hip flexed at 40° and the knee at 90°. Without any manipulation of the knee by the examiner, gravity may show the "posterior sag sign" or "dropback phenomenon" in this position. The best way to visualize this abnormality is by looking at both knees in profile, seeing that the patella seems more prominent and the tibia less prominent if compared to the non-affected knee. During the acute state of PCL injury this may not be visible due to swelling.[3(p.233-34)] The examiner must be careful to recognise the "sag sign" if any ACL injury is suspected, because it only appears in PCL injury and could lead to a false-positive anterior drawer. This would cause a mix-up of those two injuries.[12(p.211)] To do the test, the examiner sits on the patient's feet to fixate them and exerts with his hand a posterior force to the proximal tibia. A positive test presents with posterior translation of the tibia with respect to the femur. The endpoint in PCL injuries is most often firm, even in complete rupture, which differentiates PCL from ACL injury. During ACL examination the Lachman test may show positive anteroposterior translation but a firm anterior endpoint. The explanation for this is that by applying this test on a PCL injured the knee, the examiner reduces the subluxed tibia to the normal position, which would seem like anterior translation. This is important to avoid any mix-up of these two injuries.[3(p.234), 26]

To grade any posterior laxity of the knee joint, it should be compared with the uninjured knee. The grading involves the positioning of the proximal tibia and the distal femur. (Table 5.)

If grade III. is present, combined injury, involving the PLC, is commonly present. In those cases, treatment has to be planned accordingly not only reconstructing the PCL but also the PLC. If the combination is not recognized, treatment with only PCL reconstruction is prone to fail, studies concluded.[128, 131]

Table 5. Grading of Posterior Laxity of the knee

Normal	at 90° flexion of the knee, the proximal tibia is placed about 10mm anteriorly to the femoral epicondyles.
Grade I. (mild)	Step-off is still felt but not visible because the prominence of the tibia is reduced from the normal 10 mm to 5 mm microscopic tears stretch the PCL which don't affect its ability to support the knee joint. Displacement is < 5 mm
Grade II. (moderate)	The proximal tibia and the femoral epicondyles are on the same level, there is no prominence present. partial rupture of the PCL, mild to moderate instability of the knee, may give out during walking or standing. Displacement is between 5 – 10 mm

Grade III. (severe)	The proximal tibia is now placed posterior to the femoral epicondyles. Positive “sag sign” and no endpoint. Complete tear of the PCL either at the middle or at its attachment site to the bone, the joint unstable, displacement is > 10 mm

modified by [3(p.234), 22(p.10), 26, 55(p.604)]

The quadriceps active test

In a supine position the patient flexes both knees at 90° while the foot is on the examination table. The patient is asked to contract the quadriceps muscle by sliding the foot distally while the examiner hold pressure against it. The test is positive if this quadriceps contraction reduces the proximal tibia anteriorly to its normal position.[3(p.234-35), 26]

Dial test

This test is helpful in evaluating the presence of a combined injury including the PLC.[22(p.11)]

7.3. Imaging of the PCL

If there is any suspicion of PCL injury due to the history or physical examination, imaging is there to confirm the diagnosis. First, plain radiographs are taken to rule out any avulsion fractures or tibial plateau fractures as well as posterior tibial subluxation or posterior tibial sag.[22(p.11)] The used views include: AP, lateral, “sunrise” and tunnel views.[132]
Long leg alignment films are there to exclude any varus malalignments of the limbs axis, if suspected. To differentiate a partial from a total tear, the examiner will order stress radiographs, where the single-leg kneeling technique is the most useful to determine any posterior tibial instability.[133]

The first choice to diagnose PCL tears is the MRI, which shows a 100% sensitivity and a 97% specificity for the acute state but can be less accurate for chronic PCL injuries. Unfortunately, 28% of chronic PCL damages appear normal on the MRI.[134-138]
The MRI is additionally able to show any associated injuries to other knee ligaments, the menisci or articular cartilage. To establish the correct treatment plan for the patient it is very important to know if the PCL is isolated or associated with other injuries around the knee.

7.4. Treatment

The main factor to figure out before deciding on the treatment plan for PCL injury is if the damage is of acute or chronic nature and if it is isolated or combined. Usually isolated PCL damage is treated conservatively, but if there is an additional menisceal injury, it would indicate operative treatment, as would any other combined injury. Chronic PCL tears are only addressed surgically, if the patient shows any symptoms like problems with deceleration, or if the tibia displaces more than 8 mm posteriorly or if the injury is combined.[129, 139-140]
The traditional treatment algorithm for PCL injuries was conservative with bracing and physical therapy, but nowadays it is changing towards surgical intervention.[22(p.9)]

7.4.1. Non-Operative treatment

The PCL has the intrinsic property to heal and may do so in a lax position.[141, 142] Conservative management is used if an acute isolated PCL tear is translating posteriorly for less than 10 mm. This would include grade I. and II. PCL injuries. The treatment involves bracing and aggressive rehabilitation. The brace is worn to compensate the posterior sag of the tibia to create a better knee position for the ligaments healing process. The patient wears a brace and immobilizes the knee for 2-4 weeks. The physical therapy includes muscle strengthening addressing the quadriceps muscle. Meanwhile using the hamstrings should be avoided to minimize any posterior tibial displacement during rehabilitation.[65(p.228,280),128, 131, 143-145] This strengthening program is used until the knee is fully stable and the affected quadriceps reaches about 90% strength of the contralateral one. Then the athlete may continue with his or her sporting activities.[127] Follow-ups should be regular to exclude overlooking any combined instabilities. In any grade III. injury, surgical reconstruction is the first choice, since it can often involve damages to other structures surrounding the PCL.[146]

7.4.2. Operative treatment

Usually it is used if the posterior translation is more than 10 mm, if symptoms don't subside by conservative treatment approach, or if the patient is an athlete and requests the best stability possible. If there are any degenerative changes present, surgical treatment is not indicated.[26]
The operative approach is mostly arthroscopically and includes either a single- or double-bundle technique by using an auto- or allograft.[129] Recently, some studies have shown that reconstructing both bundles of the PCL will reinstate its function and make ROM better than reconstructing only the anterolateral bundle.[147, 148] Every arthroscopic PCL reconstruction is supported by intraoperative radiographs to ensure correct placement of tunnels and graft. In

any acute combined injury, it is advised to operate early, at 2-3 weeks post-injury, since this may improve the healing and reduce the stiffness.[149]

Single-bundle reconstruction

A single bundle technique reconstructs the ALB and affects the kinematics of the knee between the first 0° to 60° flexion.[19] The type of fixation of the graft is of high importance. Either the surgeon uses a transtibial tunnel technique or the tibial inlay-technique.[150] Each of these techniques has pros and cons. The transtibial tunnel approach has the disadvantage of the so-called “killer turn” which can cause graft abrasion and final graft failure. Meanwhile the tibial inlay technique avoids the “killer turn” by using a bone plug and fixating the graft at the tibia with a screw or anchor.[151, 152] The choice of the technique is still controversial, since no study showed the evidence that the inlay approach has a smaller failure rate than the transtibial tunnel technique. Both of those single-bundle techniques improve knee stability but both don’t manage to bring it back to the pre-injury state.[153-155]
The grafts commonly used for a single-bundle reconstruction are either the BPTB autograft or the Achilles tendon allograft. There is no evidence of any difference in failure rate between those two graft choices.[156]

Double-bundle reconstruction

It is an alternative to the single-bundle technique and may restore normal knee kinematics, not only for the first 0 – 60° of flexion.[19] For this procedure two femoral tunnel technique is used and an allograft or autograft is placed. Tibial inlay- technique is also possible.[153, 157] Comparing both techniques there is not much difference because both show good clinical outcomes.[155]

7.4.3. Post-Operative Management & Rehabilitation

The healing of a PCL graft takes twice as long as ACL healing which underlines the importance of proper rehabilitation.[129] After surgery the knee should be immobilized in full extension for a period of 2-4 weeks. Early on the patient is advised to do some passive flexion exercises, which help minimizing hamstring action. The patient must avoid any posterior subluxation and hamstring usage while progressively increasing weight-bearing, and improving the strength of the quadriceps. Due to this there will be no stress on the graft, while continuously restoring ROM.
Full activity of the patient is usually accomplished after 9 – 12 months of rehabilitation, when full strength of quadriceps and hamstring muscles is reached. [21(p.812)]

7.5. Complications

Most complications of PCL injuries affect the knees ROM. Often an associated PLC injury is overlooked and causes residual posterior laxity, presenting as posterior tibial displacement of more than 4 mm. If the post-surgical immobilization period is too long, flexion loss can occur.[158] Wrong placement or tension of the graft can affect the ROM as well, limiting it.[127] Injuries to the popliteal artery or the saphenous nerve may sometimes occur during surgery.[158] Complications may also occur due to falsely diagnosing a PCL tear as an ACL injury and treating it that way. The examiner may perform a false positive anterior drawer test and give the wrong diagnosis. This occurs fairly common.[12(p.209-11)]

7.6. Outcome

Any isolated PCL injury should be first treated conservatively and only operated if there is no improvement or no subsiding of the symptoms. If the PCL is injured in a combination with other structures, surgery is advised. The outcome of conservative treatment is very variable, which was concluded by Boynton et al in 1996.[159] They found out that some patients would experience extensive symptoms while others were asymptomatic. A different study, evaluating the transtibial double-bundle technique showed that those patients were able to return to sporting activities, moderate and strenuous, with mild posterior laxity.[160] Usually a tear of the PCL occurs at the bone attachment site, which makes the results of the reconstruction a lot better than the mid-substance ACL tear repair results. The fixation of the ruptured ligament is much easier to handle if the injury is at the attachment site and it shows more stability than mid-substance repairs. But in total there is still a lack of long-term studies about PCL injuries and treatment.

8. Background

Water-skiing is a traditional water sport, which, if done professionally, exposes the human body to extremely high external forces. In this 3-event sport it is still uncertain which factors are most influential for knee injury prevention, since there haven't been many studies about this sport.

In a study by Hostetler S.G. et al. it was found that with a percentage of 36.3% of all injuries, strains or sprains were the leading injury diagnoses of this sport, mostly affecting the lower extremity.[161]

Nearly every professional water-skier, who participated in our observational study, had encountered an injury by this sport. In the study we focus on injuries of the knee joint, specifically the ACL and PCL.

9. Hypothesis

The prevalence of knee injuries in water-skiing is close to that of variable other high-risk sporting activities. Evaluating the regular training pattern, as well as the injury pattern of professional water-skiers may help to make preventative measures more precise to avoid that athletes injure themselves. Analysing the treatment choices including their post-treatment complications as pain, instability or decreased mobility can help determine the best options for managing any water-skiing induced injury.

10. Methods & Materials

The survey used for this study was created by a former water-skier, who wanted to gain a better understanding of the knee injury patterns in water-skiing and how they could be prevented. The survey was composed on the 2nd of December 2017 on a web page called "www.umfrageonline.com" and was activated for a duration of about one month, until the 12th of January 2018. It was sent to around 300 active or former water-skiers. The distribution was accomplished by sending a link with a short description of what the survey is about and how the personal data will be handled. A few of former team mates supported the spread of those messages worldwide to achieve a broader response.

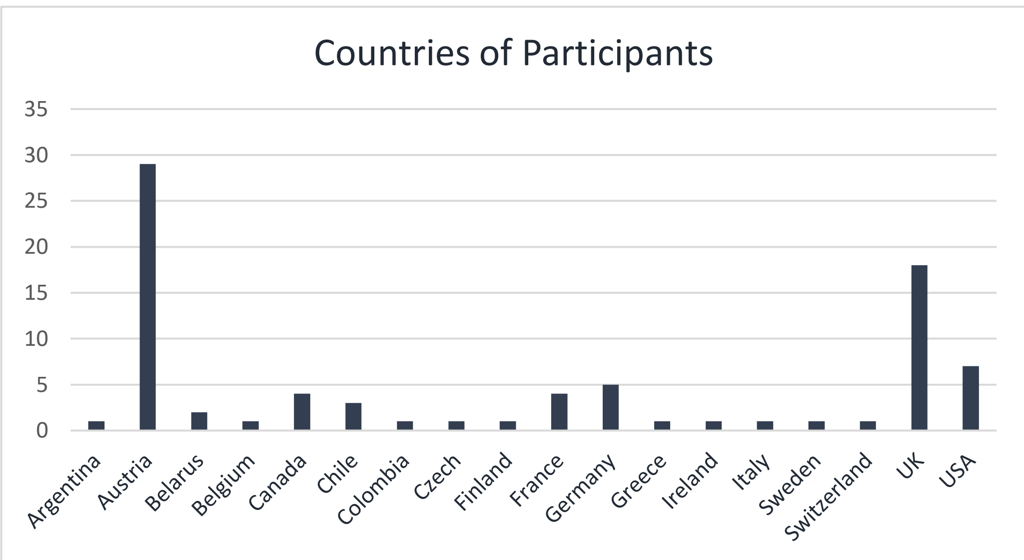
In total, 82 participants completed the survey. The questionnaire focused on the regular training habits of the individual skier, as well as the history of knee injuries, especially ACL or PCL damage, and which discipline caused the injury. Some specific questions involved season length, additional training, as well as stretching, besides the time on the water. The study also included the treatment choice and the post-treatment state of each participant, who injured the knee. You can see the full questionnaire attached at the end of this paper. (see Chapter 14 p.51)

For statistical calculations and views, Microsoft Office Excel was used. Additionally, “vassarstats.net” was utilized to establish Pearson Chi-Square, as well as p. If the p value was < 0.05, it would indicate that the null hypothesis was not true, presenting therefore a difference between exposure and no-exposure. For the discussions of this study several other studies about sports injuries, mentioned in the book “Rehabilitation of Sports Injuries: Scientific Basis”, volume X of the encyclopaedia of sports medicine, edited by Walter R. Frontera, were used for comparison.

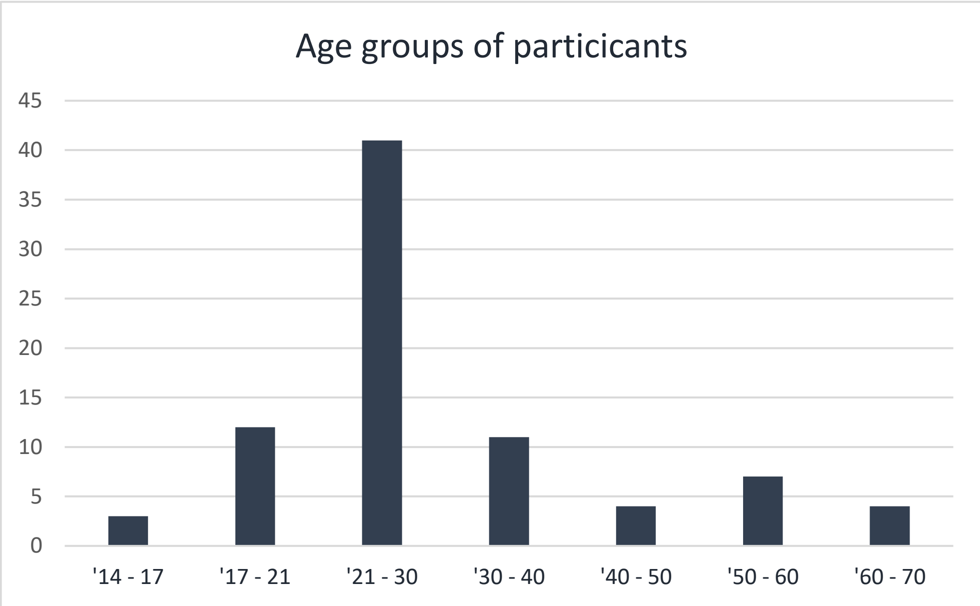
11. Results

A total of 82 surveys were completed. All the pro- or advanced water-skiers, that participated, were from diverse countries, as well as variable age groups. (see Graph 1 and 2) Most individuals in the study were from Austria, the UK and the USA. The major participating age group was between 21 and 30 years of age.

Graph 1.- Illustration of the participants’ home countries

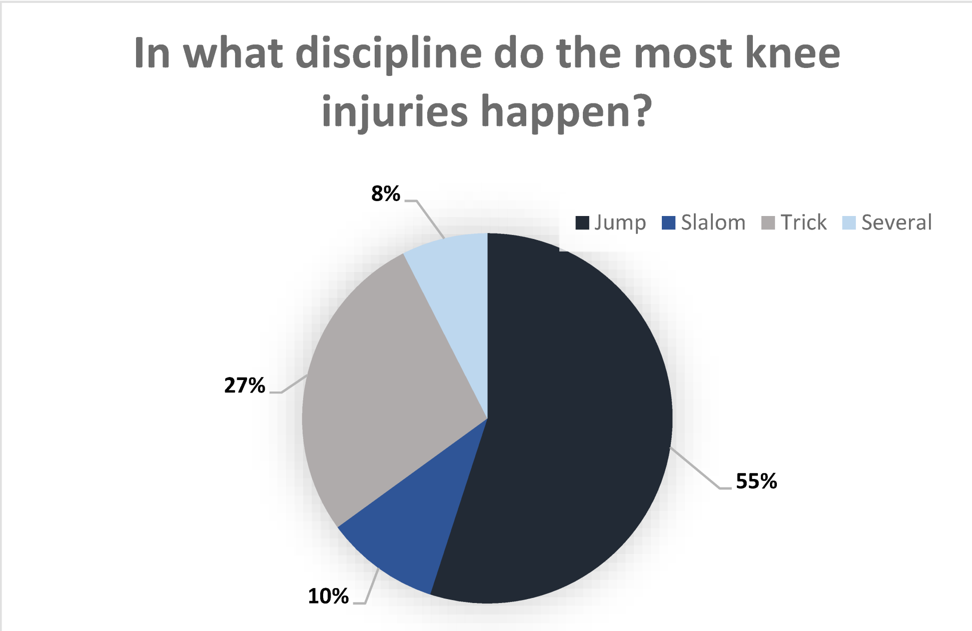


Graph 2- Age groups of the participants



An interesting fact was that of all 82 participating water-skiers, 75 (91 %) already have injured themselves during this sport, while only 7 of them (9 %) have not. Of all the affected athletes, the knee was injured in 41 (50% of all participants), while the other 34 individuals had different injuries. Most knee injuries were obtained during the discipline “Jump” (55%), followed by “Trick” (27%). Slalom showed by far less occurrences with only 10%. (see Graph 3.) This can be explained by the fact that the speed that the skier accomplishes is a lot higher in Jump than in the other two disciplines. Also, the consequences of any mistakes by the athlete, are higher which will be explained in the discussion. A faulty landing technique can impact the knee acutely as well as over time. Trick presented with a high percentage of knee injuries because it demands many diverse motions of the knee joint. Most participants encountered their injury as an adolescent between 14 and 17 years of age (16 participants) and with an age between 18 and 21 years (12 participants). The reason that a lot less injuries occurred later is that a lot of water-skiers end their professional career after turning 21 or a bit before that. This is on one hand connected to them starting college, on the other hand connected to any other change in life leaving less room for this sport and changing their focus of interest. Also, most people in this study were from the age group of 21-30 years (see Graph 2), which could be influencing the final distribution of the most common age group during which the knee injury happened. Maybe, if older people would have participated, this result would have shifted. Many participants who injured their knee, damaged it recurrently. With 12 participants showing recurrence, it presents a fairly high percentage of all knee injured participants (28,6%).

Graph 3.- Disciplines causing most knee injuries

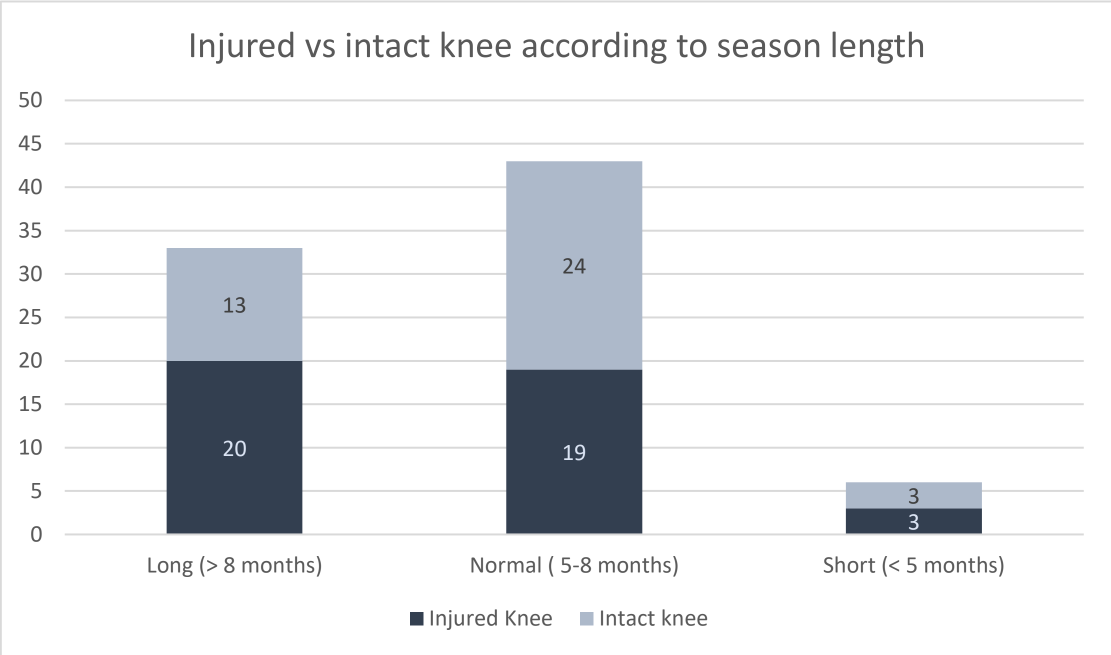


The study also pointed out the connection between any knee injury and the length of the athletes' season on the water. (Season length definition in Table 6.) In total 43 participants were in the normal range of season length, while 6 enjoyed a shorter season and 33 were active longer than 8 months on the water, each year.

Table 6.- Season length definition

Short	**< 5 months**
Normal	5 – 8 months
Long	> 8 months

Graph 4.- Comparison of knee injury vs intact knee according to the skiers' season length



As we can see on Graph 4. a longer season is associated with a higher possibility of knee injury, since out of 33 skiers, 20 injured their knee. This might be due to overuse or fatigue of the joint, which will be discussed later. In the other two groups, normal and short season, the possibility of injury is lower.

Regular stretching, or doing Yoga or Pilates didn't show any significant association with knee injuries in water-skiing. (see Table 7.) The calculated values demonstrated that the null hypothesis is true, meaning that there is no difference between the athletes who do stretch or do Yoga/ Pilates or those who don't.

Table 7.- Calculations of Chi Square Pearson and p for Stretching and Yoga or Pilates

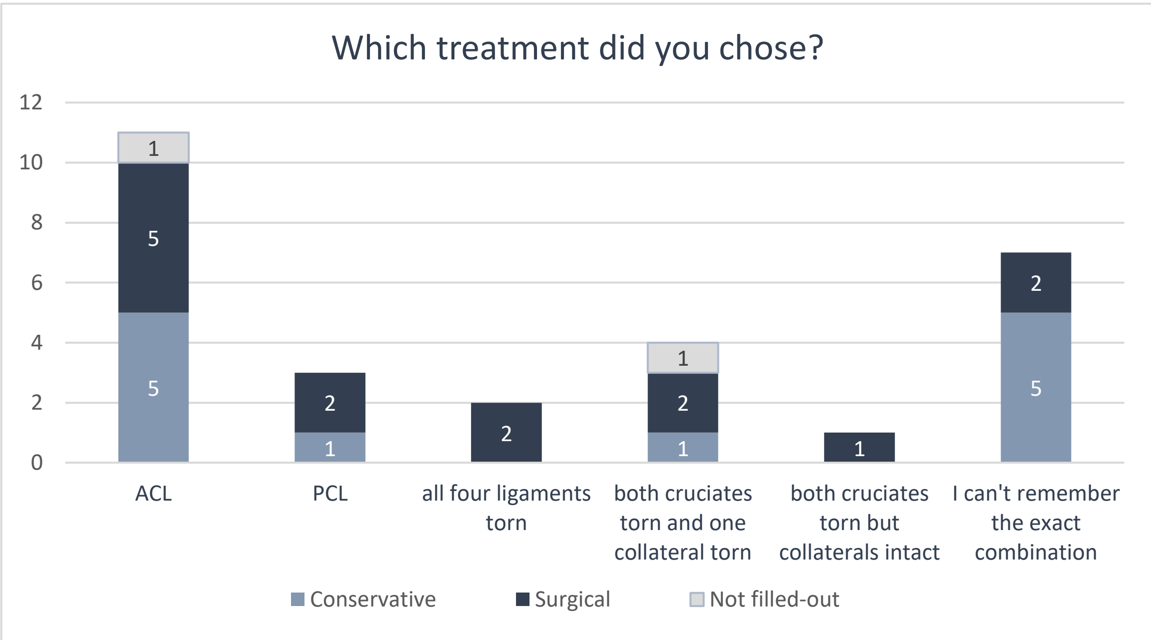
	Stretching	**Yoga or Pilates**
Chi Square Pearson	0,06	0,47
p	0,806	0,493

Of all the participants with knee injuries, most commonly the injuries affected their ligaments (19 skiers) or a combination of ligaments and menisci (16 skiers). Only a few of them, 6, had a meniscal injury without any associated ligamentous damage. One participant left this question unanswered. Of the total 27 participants with ligamentous injuries of the knee, 11 presented with injury to the ACL, 3 to the PCL, 2 injured all four ligaments (two cruciates + two collaterals), 3 injured both cruciates and one collateral ligament, and 1 skier tore both cruciates with the collaterals intact. 7 more participants indicated that they could not recall the exact combination of their ligamentous injury. Important here is that 3 skiers injured their PCL, which is with 7,14 % a fairly high percentage of total 42 knee injuries, because PCL injuries usually occur less common.

During the injury process, mostly participants with ACL injuries, +/- damage to other ligaments or the menisci, would hear or feel a “pop”. The others didn’t encounter the it as much.

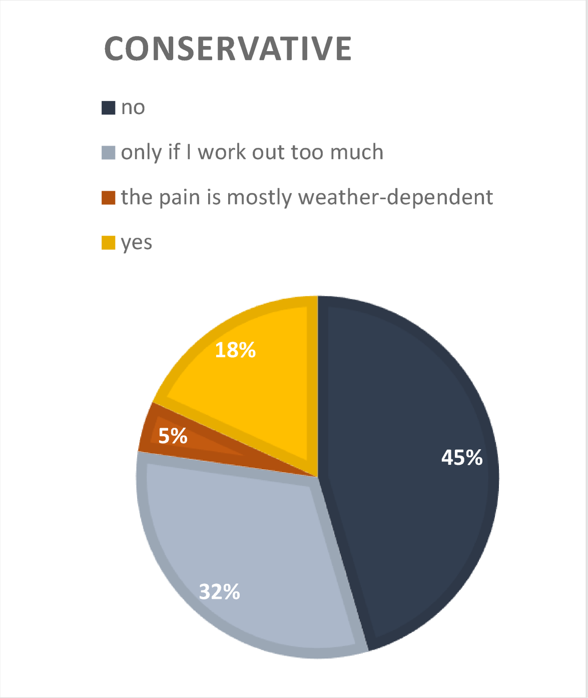
The treatment choices of the injured athletes are illustrated in Graph 5. below.

Graph 5.- Treatment choices of several types of ligamentous knee injuries

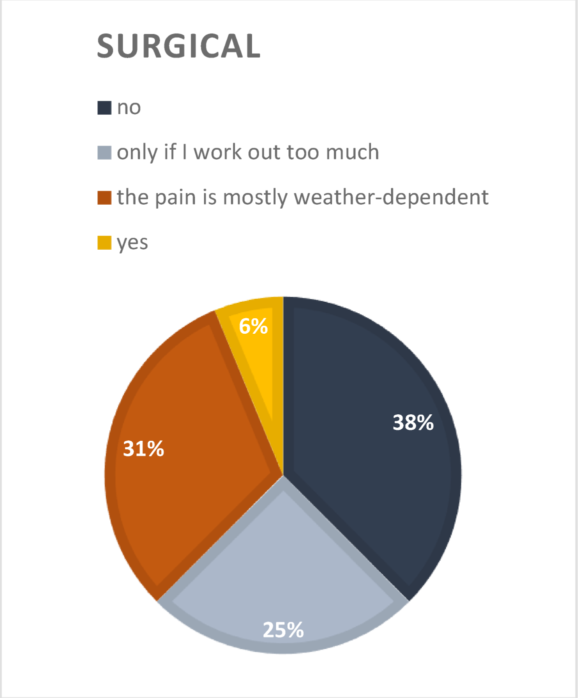


After treatment only 2 participants, who received conservative treatment, and 2 participants, who had surgery, indicated that their knee was still unstable. Pain, on the other hand, was evaluated in a more complex way. The two graphs below (Graph 6. and 7.) compare the pattern of pain after both types of treatment. After conservative management of knee injuries, 18% indicated that their knee was still painful, but only 6% who underwent surgical management would state to have pain. On the other hand, while 31% of surgically treated participants had weather-dependent pain of the knee, only 5% of skiers with conservative treatment experienced this connection.

Graph 6.- Pain after conservative treatment



Graph 7.- Pain after surgical treatment



The ROM of the knee post-treatment showed that 65% had the same mobility as before the treatment, while the other 35% had some limitations of the ROM. 6 skiers (14%) had limitations of flexion, 2 (5%) with extension, 3 (7%) with rotation, and 4 (9%) had a combination of those limitations.

After rehabilitating the knee joint, most skiers stopped using their knee brace, while some kept using it (19 participants). 12 of the brace-users only needed it while they were water-skiing. Most times the continued use of a knee brace is due to psychological reasons. It gives the skier a feeling of safety and reduces his or her subconscious anxiety from a further injury. The brace is also worn for protective reasons and to give the joint support, if still needed. Wearing a brace could soften the effect or impact of an upcoming crash. Meanwhile skiers often resent wearing it, because it restricts their range of motion while being on the water.

After knee injuries most participants (93%) are still active professional water-skiers, while some (7%) stopped being active in this sport.

12. Discussion

To discuss any of the results mentioned above, first the mechanisms and movements of this water sport must be explained properly.

Professional Water-skiing presents itself as a 3-event sport, including:

- Slalom
- Jump
- Trick

These three are variable in their association with injury, which will be discussed later, but all of them are included in level 1 risky activities to injure the knee. Over the past 20 years, the development of new bindings, which fixate the foot on the ski, and the usage of new materials for building lighter skies and safer helmets has diminished the severity of injuries due to water-skiing. Nowadays, deaths or severe disabilities by this sport are very rare, but strains keep happening on a regular level. There are many reasons to underline this fact. Every discipline exposes the skier to different kind of positioning and speed. Additionally, the angle of the external forces acting on the athlete change constantly. As in other high-risk sports, like alpine skiing, most injuries to the knee, specifically ACL ruptures, are noncontact.[162] Water-skiing knee injuries are more complicated than only being non-contact, since the fall onto the water can induce a contact injury, if the speed of the skier is high enough. To clarify what is meant by this, we will explain each discipline shortly.

Slalom

Here the skier must ski around buoys while holding on to a rope that is fixed in the boat pulling the water-skier. The speed of the boat reaches a maximum of 58 km/h for men, and 55 km/h for women. At the buoy the skier lets one hand go of the rope, to be able to counterrotate the body and achieve more speed when he or she wants to cross the wakes after that. This counterrotation is of high importance, because it keeps the rope tight giving the skier more control over his equipment and allows him or her to reach a better angle, in comparison to the boat, which will help the skier to be faster at the next buoy. (see Picture 1 and 2) Injuries to the knee, especially the ACL or PCL, are not as common in Slalom, as in the other two disciplines.

Picture 1 and 2

Trick

This discipline is most similar to wakeboarding, which is very popular nowadays. Here the athlete is supposed to do as many tricks as possible within 20 seconds. The speed of the boat is not very high, mostly between 25 and 35 km/h, which makes the impact with the water due to a fall not as painful as in the other two disciplines, but due to the variability of the movements needed to complete the tricks, the association with knee injury is present. This discipline distinguishes itself from the other two by several out-of-the-norm movement patterns. Many tricks involve, for example, hyperflexion of one or both knees. The positioning angles of the knee joints during those movement patterns influence the association with injuring them, if the skier falls. (see Picture 3 and 4)

Picture 3 and 4

The photo (Picture 3) shows a trick, called Toe-Back (reverse), which positions the knee in an opened hyperflexion while holding the tension of the rope that is fixated in the boat that pulls the skier. This should illustrate the risky angulations that a water-skier undergoes during this discipline.

Jump

This discipline is all about the distance that the athlete manages to “fly”. Jump is by far the most dangerous discipline, which will be shown in the results of the study. The speed of the boat is very high, as much as 58 km/h, and the professional skier may reach a speed of over 110 km/h when hitting the ramp. This high speed is achieved by the skiers cutting series, meaning increasing the speed by going zigzag behind the boat, before he or she reaches the ramp. The two skies of for jumping are longer than the skies of the other disciplines and when the skier goes over the ramp, the position he or she has is very important, as well as the position during the flight and the landing mechanism.

Picture 5 and 6

The photos above (Picture 5 and 6) illustrates the correct positioning after hitting the ramp and flying in the air. This can also go very wrong, seen in the photos below (Picture 7 and 8). In this case the skier didn’t bear his weight on both legs when approaching and hitting the ramp, he was not in balance, which resulted him to lose control in the “flight phase”. Since the skies are very long, it is difficult to regain control over them if the athletes body is not in the correct position. In the case of a fall, the impact with the water differs from skier to skier, always depending on the position of the skies and the rest of the body right before the impact. Due to the speed the water is very hard, so any crash will execute immense forces on the skies, moving them and possible rotating the knee, or hyper flexing it in any way. Other body parts may be affected as well, of course.

Picture 7 and 8

The correct landing technique is very important in this discipline since it can predispose the skier to possible overuse damage as well as chronic knee injuries. The photos below illustrate the position most skiers achieve during the landing phase. (Picture 9 and 10)

Picture 9 and 10

As shown, the knees are in hyperflexion and one should always additionally consider that the knees may be slightly rotated internally, which is not shown by this profile view. Risky landing techniques, associated with ACL injuries, are more commonly seen in female athletes. This can be explained by the fact that females land in a more erect position than their male colleagues encountering less knee and hip flexion. Additionally, they present with increased hip adduction and internal rotation, leading to extra valgus stress on the knee. These factors add up and associate females with a higher risk of ACL injury.[64, 163-166]

In the case of losing balance in the air, several scenarios can happen. As seen on the crash photo (Picture 7), the skier presents with hyperflexion of both legs, internal rotation of the right leg, and slight external rotation of the left leg. This will be even more pronounced when the skies cross unintentionally. If the skier, who is still in the air on the photo, would impact the water in this position, the possibility of an ACL injury would be increased, which was evaluated in a 6-year survey study about downhill skiers. This studies explanations about the skiers positioning and their injury patterns are comparable to water-skiing.[167-170]

As explained above, every discipline presents with their own risk association of knee injury. This was meant to illustrate why Graph 3. shows such a high association of injury for Jump and Trick Skiing.

The results, which presented the association of season length and knee injury, showed that prolonged water-skiing seasons were connected to more injuries than normal or short water-skiing seasons. An athlete in over-training, or prolonged training, is at risk of muscle tendon injury due to permanent overuse. The so-called “chronic overload syndrome”, studied by Herring & Nilson 1987 and Curwin 1996, presents with repetitive loading leading to partial disruption of a muscle tendons structure. Those overuse damages might be induced by forces within the physiological range for a tendon, but the frequency is so high that it doesn’t leave any space for recovery or repair to occur.[171, 172] This leads to major weakness of the muscles surrounding the knee. The constant training also increases the muscles content of lactic acid due to anaerobic metabolism, which additionally decreases its strength. Since muscles and their tendons are aiding the ligaments to stabilize the knee, any weakness or damage to them, can increase the forces acting on the ligaments, increasing their chance of injury. This means that the vulnerability of the ligaments is higher, due to their increased workload and decreased support by the muscles. Recoil, defined in Chapter 4 (see p.11), will stop occurring if the cyclical episodes of stress, in this case water-skiing, don’t give the ligament enough time to return to its original state. The stress-strain curve, also explained in Chapter 4, gives further information about the capability of the viscoelastic ligament to withstand stress. If the forces acting on it are too big, it will finally fail and rupture. (see p.12)

When we started this study, we thought that stretching or exercises like Yoga or Pilates would be influential for knee injury prevention of water-skiers, but our hypothesis was wrong. Although we must point out that that the participants didn’t receive any specific stretching protocol to execute by us. This means that every individual had their own stretching techniques, with individual choices of exercises and duration of their stretching session. As seen in the results the null hypothesis was true for both, the stretching and Yoga or Pilates. (see Table 7.)

It is widely known to use stretching for conquering hypomobility and to support post-surgical rehabilitation programmes, to avoid limitations of ROM.[34(p.232)] Many studies have been done about the impact of stretching on injury prevention, some of them proposed a positive impact and some did not. Stretching is supposed to make a joint more “flexible”, meaning increasing the ROM of a joint influenced by muscles, tendons or ligaments, and bones, in a positive way.[34(p.233)] Two studies proposed that there were more musculotendinous unit tears in athletes who had limited ROM, compared to their flexible colleagues. Hamstring flexibility was lower in the group of injured sportsmen, while the non-injured group of the same sport didn't present with it.[173, 174] On the other hand, a study by Pope et. Al in 2000 presented results where there was no positive association between flexibility and risk of injury. For his study he used a stretching protocol on military recruits that may not have been satisfactory in increasing their ROM. They showed that pre-exercise stretching was not connected to a reduction of lower limb injury risk.[175] This lays open that this topics results are conflicting, but stretching is still generally advocated nowadays.

The strength of the knee is a very important protective factor against knee injuries in this water sport. Post-surgically, 20 participants mentioned to reach their pre-injury strength of the knee joint, but 7 didn't. Starting water-skiing session before the rehabilitation phase is completed can have horrific consequences. In the worst case it could case reoccurrence of injury to the knee, since it didn't reach full strength yet. As explained in Chapter 3. And 4. the stability is and strength of the knee depends on the ligaments and the muscles. If the autograft is replacing the ruptured ligament, it is not possible to reach the pre-injury state of the ligaments strength. Deacon et al. (1991) analysed the difference between the human patellar tendon autograft and the original patellar tendon and adult ACL. They found that there are more type III collagen fibers in the remodelled graft, instead of the normal type I collagen fibers.[176] Butler et al (1985) said that the patellar tendon is a lot stronger than the 4 main ligamentous knee stabilisers, making a good candidate for an ACL graft (see Chapter 3, Table 1). It can withstand more maximum stress. If used as a graft though, changes occurred after the placement, showing more small-diameter fibrils with fewer larger-diameter patellar fibrils dispersed in between. The fibers were less oriented and loosely packed compared to the normal tendon. This explains the decreased tensile strength of the reconstructed ligament causing the graft to "stretch out" over time post-surgically and causing laxity. [177] The progression of this laxity may be avoided or slowed down by conditioning the musculature around the knee joint to reduce the stress on the ligament. The muscles surrounding the knee (see Chapter 1.3.) will support the graft, pointing out the importance of a proper rehabilitation program. Nowadays post-surgical immobilization is reduced to a minimum or is even avoided completely. This helps to divert any negative impact on the muscles by immobilization. Sometimes involuntary inhibition of muscle movements due to post-surgical pain, or effusion, will cause a lack of ability of activating the muscles around the knee.[178] The goal of a post-surgical, or in general a post-treatment, rehabilitation program is to regain the muscles strength by working on the presenting:

- reduced muscle volume,
- possible muscle hypotrophy,

- muscle wasting,
- strength difference between the extremities,
- and reduced muscle endurance.[34(p.259-60)]

By proper training, all these factors will be nullified and the operated knee will have the necessary support to reach its original strength, even with a reconstructed ligament.

13. Conclusion

In conclusion our study demonstrated that water-skiing is a high-risk (level 1) sport for PCL injuries, as well as for ACL injuries. This was illustrated by the above listed results. A prolonged season on the water will carry the possibility of athletes to injure their knees more often, due to possible overuse or fatigue of the joint. Our results proved the positive association between a long water-skiing season and a higher occurrence of knee injuries. Additionally, as our results have shown, we were able to negate that stretching has any positive effect on the prevention of knee injuries. This result is limited by the fact that there was no standardized stretching protocol used, and every skier used their own creation of a stretching program.

In our study, post-treatment states presented a difference in pain between conservatively and surgically managed patients. The pain was more weather-dependent post-surgically than randomly, as it was in conservative treatment. ROM in water-skiing is of high importance and our study showed that 35% of all participants with knee injuries had limitations after their injury and its treatment. Most surgically treated participants with knee injuries indicated to reach their pre-injury level of strength of their knee joint, while 7 participants did not and had continuing weakness. This, and the limited ROM, could restrict the skier in his skills at this sport. The athlete might even have to stop one of the disciplines, or stop skiing at all. But our study concluded that water-skiers rarely quit their sport post-injury and return to the water. Only 7% of injured participants indicated that they ended their water-skiing career after the injury.

14. Questionnaire

1. What is your age?
    - 10-14
    - 14-17
    - 17-21
    - 21-30
    - 30-40
    - 40-50
    - 50-60
    - 60-70
    - > 70
2. What Nation do you water-ski for?
3. For how many years do you water-ski?
    - Less than 5 years
    - 5-10 years
    - 10-15 years
    - More than 15 years
4. What is your favourite discipline?
    - Slalom, Trick or Jump
5. What is your LEAST favourite discipline?
    - Slalom, Trick or Jump
6. Which one is your front foot for water-skiing?
    - Right or Left
7. Do you regularly work out?
    - Yes or No
8. How many hours per week do you do endurance training?
    - 1-2 hours
    - 3-4 hours
    - 4-5 hours
    - More than 5 hours
9. How many hours per week do you do strength training?
    - 1-2 hours
    - 2-3 hours
    - 3-4 hours
    - 4-5 hours
    - More than 5 hours

10. Do you stretch before or after the workout?
    - Before
    - After
    - Both
    - No, I don't stretch
11. How many "rest days" do you have during your week?
    - 1, 2, 3, or 4
12. Do you stretch before/after your water-skiing sets?
    - Before
    - After
    - Both
    - No, I don't stretch
13. Do you warm-up before your water-skiing sets?
    - Yes or No
14. Do you do any other sport besides water-skiing?
    - Yes or No
15. Is this sport about endurance or strength?
    - Endurance, Strength or Both
16. Do you do Yoga or Pilates?
    - Yoga
    - Pilates
    - No, I don't like them
17. When does your water-skiing season ON the water start?
    - The season on the water never stops
    - January
    - February
    - March
    - April
    - May
    - June
18. When does your water-skiing season ON the water end?
    - I never put my skies away for winter
    - September
    - October
    - November
    - December
19. How many HOURS per day would you be on the skis?

- 15 minutes, 30 minutes, 45 minutes, 1 hour, 1-2 hours, more than 2 hours

20. Do you have a flat foot?
    - Yes or No
21. If yes, which foot is your flat foot?
    - Right or Left or Both
22. Do you have “X” or “O” legs?
    - “X” legs
    - “O” legs
    - I don’t know
    - No
23. Do you have any hip, knee, or ankle issues?
    - Yes or No
24. If yes, are these issues water-skiing-related or from something else?
    - Water-skiing-related
    - From something else
25. Did you ever fracture your hip / femur / lower leg- bones or your foot?
    - Yes or No
26. If yes, which side?
    - Right, or Left or Both
27. And which one of these bones did you fracture?
    - Hip, Femur, Tibia, Fibula, Ankle, Foot bones, or several of them
28. Did you ever injure yourself at water-skiing?
    - Yes or No
29. Did you injure your KNEE at water-skiing?
    - Yes or No
30. If yes, which side?
    - Right, Left or Both
31. Was the injured knee from your front foot or back foot?
    - Front, Back or Both
32. In which discipline did you injure your knee?
    - Slalom, Trick or Jump or Several
33. Was your knee somehow injured before that by some other cause?
    - Yes or No
34. At what age did you injure your knee? (with water-skiing)
35. Did you injure your ligaments or menisci?
    - Ligaments

- Menisci
- Ligaments + Menisci

36. Did you fracture a bone of the knee joint as well?
    - Yes or No
37. Did you injure your ACL or your Posterior Cruciate Ligament (PCL) or any of the collateral ligaments?
    - ACL
    - PCL
    - Both cruciates torn but collaterals intact
    - Both cruciates torn and one collateral torn
    - All four ligaments
    - I can't remember the combination
38. Did you hear a "pop" during injuring your knee?
    - Yes or No
39. Did you do conservative treatment or surgical treatment?
    - Conservative or Surgical
40. How long did you immobilize your knee after the injury?
    - 1 week, 1-2 weeks, 2-4 weeks, 4-6 weeks, 6-8 weeks, or more than 8 weeks
41. Did you have a cast or a brace or the surgical treatment?
    - Cast
    - Brace
    - Neither, just surgery
    - Surgery + a brace/ or cast after that
42. Did you take pain killers?
    - Yes or No
43. After how many weeks did you start rehabilitation?
    - Immediately after the injury, 1, 2, 3, 4, 5, 6, 7, 8, or later than 8 weeks post-injury
44. For how long did you do physical therapy?
    - Less than 2 weeks, 2-4 weeks, 1-2 months, 2-4 months, 4-6 months, or more than 6 months
45. How many minutes (hours) per day would you do rehabilitation exercises?
    - Less than 30 minutes, 30 min., 45min., 60min., 90min., 120min., or more than 120 minutes
46. Did you do any additional alternative treatment during your rehabilitation besides immobilization and physical therapy?

- Yes or No

47. For how long after rehabilitation did you still wear a brace?
    - I didn’t wear it anymore
    - Several weeks
    - Several months
    - I used it only during water-skiing
48. How long did you use the brace for water-skiing?
    - Never needed the brace during water-skiing
    - 1 month
    - 2 months
    - 3 months
    - More than 3 months
    - For the entire season
    - For 2 seasons
    - I stil use it
49. Is your knee now at the same strength as before the injury & conservative treatment?
    - Yes or No
50. Is your knee now at the same strength as before the injury & the surgery?
    - Yes or No
51. Is your knee still painful?
    - Yes
    - No
    - Only if I work out too much
    - The pain is mostly weather-dependent
52. Is your knee still unstable?
    - Yes
    - No
    - No because I regularly work out
53. Do you have any motion limitations on the affected knee?
    - Yes, with flexion
    - Yes, with extension
    - Yes, with rotation
    - Yes, a combination of them
    - No, it’s as mobile as before
54. Do you still water-ski after the injury?
    - Yes or No
55. SURGERY: Did the surgery go well without any complications?

- Yes or No

56. SURGERY: Did you have to have more than one surgery?
    - Yes or No
57. Did they have to puncture your knee because of fluid accumulation? If yes, how many times?
    - No
    - Yes, once
    - Yes, twice
    - Yes, more than two times
58. Were you happy with the treatment you chose?
    - Yes
    - No
    - No, I was kind of forced into it without hearing all my options
59. Do you have any trouble during exercise with the affected knee?
    - Yes or No
60. Do you have osteoarthritic changes on your knee as far as you know?
    - Yes, No, or I don't know
61. Did you have a total knee replacement?
    - Yes or No
62. If yes, are you still water-skiing now with the artificial knee?
    - Yes or No

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Biography

I was born on the 21.08.1991 in Klagenfurt, Austria. I have finished primary and high school (BG/BRG/SRG Lerchenfeld) in Klagenfurt, as well. My enrolment in first year of the Medical Studies in English, at the School of Medicine, University of Zagreb, was in 2010. During my studies, I was a students' demonstrator in the subject of Neuroscience for two consecutive years. Since August 2015 I am also ILS (immediate life support) certified. Additionally, I was a part of the students' organisation CROMSIC and travelled for one month, August 2016, to Morelia, Mexico, for an exchange program. There I encountered many practical skills at the Emergency and the Surgical Department. In February 2016 and in January 2017 I worked each time two weeks at UKH Klagenfurt to finish my surgical rotations and in September 2017 I was at the Department of Internal Medicine at the A.ö. Krankenhaus der Elisabethinen Klagenfurt GmbH. I will graduate in July 2018.