First International Quadriceps Tendon Interest Group Meeting Summary

The International Quadriceps Tendon Interest Group (IQTI) meeting represents a significant gathering of leading contemporary professionals in the field of Arthroscopic Knee Ligament Surgery with the focus on Quadriceps tendon as the graft choice for Knee ligament reconstruction.

The IQTI Initiative was founded with an idea of gathering the experts in the field of Arthroscopic Knee Surgery who recognize the importance and applicability of Quadriceps tendon autograft for Ligament reconstruction. The participants were those experts that both have been using this method it in their clinical practices, and have conducted research on the subject. The main goal of this experts group is to share clinical expertise and research experiences, establish future research goals, clinical and rehabilitation protocols, which would ultimately lead to better understanding and popularization of the Quadriceps Muscle tendon and its potential use as a safe, reproducible and versatile autograft choice for Anterior Cruciate (ACL) and Posterior Cruciate ligament (PCL) reconstruction.

This meeting was held for the first time from 6th to 8th of April, 2017 in the Wilderman hotel in Innsbruck, Austria.

The participants were twelve Orthopedic surgeons from different centers around the world, who held 14 presentations on various subjects. The participants of the meeting were: Christian Fink, Christian Hoser and Karl Peter Benedetto from Austria, Mirco Herbort and Jürgen Höher from Germany, John W. Xerogeanes and Volker Musahl from USA, Lars Engebretsen, Marc Strauss and Hege Grindem from Norway and Martin Lind and Peter Fauno from Denmark.

The meeting was divided in multiple sessions with the main focus areas regarding anatomical and biomechanical aspects of Quadriceps muscle tendon, existing and potential surgical techniques for its application, clinical outcome reports and rehabilitation protocols.

The sessions were as following: Anatomy, Biomechanics, ACL Current techniques/Clinical Outcome, The use of Quadriceps tendon for Posterior Cruciate Ligament reconstruction and Rehabilitation. Each of the sessions was regulated by a designated Chairman and followed by general discussion and conclusions on possible future research ideas.

The purpose of this Review is to summarize the presentations and discussion panels, held during the meeting, and to provide insight into the general conclusions and proposed research ideas established by the participants. Additionally, the summary of this meeting findings aims to present to the broader orthopedic population up to date findings on potentials and limits of this novel graft for the knee ligament reconstruction surgery.

Background

The question of which of the available autografts is the most appropriate choice for Anterior (ACL) and Posterior cruciate ligament (PCL) reconstruction remains challenging. Since the early years of Ligament reconstruction in 1960s, the main focus was in the use of Bone-Tendon- Patella Bone (BTPB) graft as the most adequate autograft for Ligament reconstruction (1-3). The advocates of BTPB prefer this graft choice mostly due to its high strength, measured to be twice that of a native ACL (4). Additionally, this graft is harvested with two bone-blocks at each end, whose placement in bone tunnels is believed to help both graft-fixation, as well as osteointegration. Despite of the well described and widely documented high incidence of postoperative surgical morbidities such as residual donor site morbidity, postoperative kneeling pain and strength deficit and numbness (3, 5-8), many surgeons around the world still consider the BTB autograft to be the gold standard in autograft selection (9-12). On the other hand, proponents of Hamstring tendon autograft - which is the most commonly used autograft in clinical practice today - cite low donor site morbidity and absence of extensor strength deficit, and claim that the best choice lays in Hamstring autograft as the most reproducible and applicable autograft (13). However, reported relatively high incidence of residual flexor mechanism strength deficit and unpredictability of graft length and diameter preoperatively, pose significant downsides. Injury to neurovascular structures, sensitivity loss in the donor site area and postoperative bone-tunnel enlargement have also been reported and are considered as disadvantages to its application(14-19) .Recent meta-analysis conducted by Freedman et al.(20) with the goal of comparing different parameters and clinical outcomes of the most common grafts, the Patellar tendon and Hamstrings tendon, showed that even tough graft failure rate was lower in the BTPB group on one hand, there was a significantly higher incidence of postoperative stiffness and patellofemoral pain compared to Hamstrings group, on the other.

The Quadriceps tendon autograft is the least utilized and thus the least researched autograft option, with many questions regarding its anatomical and Biomechanical aspects, as well as harvesting techniques and clinical outcomes, which still remain open(21).

The concept of using Quadriceps tendon autograft was first advocated in 1979 by Marshall et al.(22) followed by a report on potential harvesting technique by Blauth et al.(23) in 1984. In the early years of orthopedic ligament reconstruction, the focus was in recognizing the graft of the highest strength. In the early tests, QT autograft had proven to have lower ultimate load at failure values than of the 14mm-wide BTPB graft, which was an initial step to its general rejection(24). Quadriceps tendon graft had since then been revisited on several occasions, but due to its initial poor clinical outcome and biomechanical results, has been mostly abandoned, with its application reserved for revision surgeries or as an ultimate choice in absence of other two graft options(25). In the last three decades, the interest in Quadriceps autograft and its clinical application has been increasing. Insofar, several authors led by Stäubli et al. (26, 27), and Fulkerson et al.(28-30) continued further advocating the use of QT. They have cited that QT can produce a graft of good tensile properties, cross-sectional volume and sufficient strength along with significantly smaller incision required for harvest, similar anterior knee stability and less knee extension morbidity, as to why QT should be considered as an appropriate substitution for BTB autograft(31-35). Recent meta-analysis performed by Mulford et al. (36) including 1580 ACL reconstructed knees showed no significant difference in clinical outcome, when comparing all three graft options, and further concluded that in regards to donor-site morbidity QT graft present a more reproducible graft option than BTPB graft. In support of QT as the appropriate graft choice come the findings of Xerogeanes et al.(37) who found that QT not only yields a graft of significantly higher intra-articulate cross-sectional volume than the Patellar tendon, but at the same time harvesting it preserves much more native tissue at the donor-site. Due to this renewed interest and significantly more frequent application, the need for precise knowledge of its Anatomical and Biomechanical characteristics, as well as Clinical outcome reports and Rehabilitation protocols, is of an outmost importance in the future.

Anatomy

The first experts` session was on the subject of Anatomy of the Quadriceps tendon. It was chaired by **Prof. Martin Lind** from Denmark.

The first presentation on the subject of Quadriceps tendon anatomy was held by **Prof. John W. Xerogeanes** from Atlanta, Georgia. He presented his findings from the cross-sectional study: "*Anatomic and Morphological Evaluation of the Quadriceps Tendon Using 3-Dimensional Magnetic Resonance Imaging Reconstruction Applications for Anterior Cruciate Ligament Autograft Choice and Procurement*", published in *American Journal for Sport Medicine(37)*. In addition, he referred to a comprehensive systematic review: "*Quadriceps Tendon Autograft for Anterior Cruciate Ligament Reconstruction: A Comprehensive Review of Current Literature and Systematic Review of Clinical Results*", published in 2015, by his associate Harris Slone (21). In their study, Xerogeanes et al. have evaluated Axial proton density magnetic resonance imaging (MRI) scans of 60 skeletally mature patients, followed by Volumetric analysis of 3-dimensional models of the patellar and quadriceps tendons, performed before and after the removal of a 10 mm–wide graft from both tendons. Each of the quadriceps tendon was measured for length, thickness and width at a predetermined location. They calculated that the mean percentage of volume remaining after removal of a 10 mm–wide graft from the patellar tendon was 56.6%, compared with 61.3% when harvesting an 80 mm–long graft of the same width from the quadriceps tendon. The intra-articular volume of the proposed quadriceps tendon graft was 87.5% greater than that of the patellar tendon graft. The mean length of the quadriceps tendon was 73.5 6 12.3 mm in female patients and 81.1 6 10.6 mm in male patients.
The general conclusion of the study is that most anthropometric parameters are in a strict correlation to patient height, which in other words means that height poses as a significant preoperative selection criteria. There are many factors to be considered when choosing the most appropriate graft preoperatively. The size of the graft, including length and volume, are considered to be among the most significant. The height of the patients poses as a significant predictor to length of tendinous portion of the Quadriceps muscle(38). Width of the graft is in direct correlation to structural properties of the applied graft and based on its variations, different biomechanical properties and revision rates have been noticed(38, 39). When talking about BTP autograft the predictability and possibility of preoperative volume measurements pose as significant advantages to its use. The hamstring graft has much higher variability in terms of cross-sectional graft volume and challenging preoperative measurements, which presents a downside to its application, especially when considering the reports

of high graft failure rate in hamstring grafts smaller than 8mm in diameter(40). Xerogeanes et al. found that the thickness of the Quadriceps tendon correlates directly to individuals' height and weight. The measurement was made in the mid-sagittal 6-10mm section of tendon 3cm proximal from the superior pole of the patella. The intra-articular dimensions in terms of length and width of PT and QT autograft are the same. However, when considering the significantly higher thickness or depth of the QT, they measured that QT graft has up to 88% higher intra-articular graft volume.

The significance of these finding is substantial. It means that we can consistently harvest a graft of sufficient length and cross-sectional volume, while still preserving a larger amount of native tendon tissue than in other grafts. The high cross-sectional volume itself is significant advantage of this graft, since it is described in the literature that the large cross-sectional area decreases the possibility of bungee and windshield effects, as well as tunnel-graft mismatch, which is believed to be the cause of tunnel-enlargement (13,39).

Dr. Xerogeanes stated that in his experience people over five feet tall have tendinous portion of Quadriceps muscle longer than 60mm, which applied in clinical practice means that almost all patients can provide a Quadriceps autograft of more than sufficient length. There is also a possibility of harvesting additional 2cm of Rectus Femoris muscle tendon in order to extend the graft, and patellar bone-block that can be positioned in both femoral and tibial tunnel. In order to provide the adequate length of the graft, it is also possible to harvest the most superficial fibers of periosteal tissue from the sight of tendons insertion onto the patella, providing an additional 2cm of tissue that can be incorporated into the graft.

This practice is routinely conducted by Prof. Christian Fink and Dr. Christian Hoser as part of their newly developed minimally invasive technique for QT graft harvest published in "Minimally Invasive Harvest of a Quadriceps Tendon Graft With or Without a Bone Block" in 2014 (41). Theoretically, this additional periostal tissue could aid the tendon-bone healing rate, however, there is no evidence that shows the benefit of use, other than the possibility of graft elongation and easier graft passage.

Interestingly, a consistency of quadriceps tendon length of more than 5,5cm and thickness of 3,2mm also exist in the pediatric population, which brings an additional aspect to previously stated conclusion, that QT can be an adequate graft choice for almost all patients.

The study from Xeroeganes et al. showed that the both Quadriceps and Patellar tendon can yield grafts of adequate length, but Quadriceps provides a graft of significantly higher intraarticular volume in addition to leaving more native tendon tissue at the graft donor site and avoiding high comorbidity incidence of the BTPB graft.

Discussion

The discussion that followed yielded several questions. The question regarding the vascularization of the Quadriceps tendon was addressed. In their evaluation of the vascular anatomy of Quadriceps muscle tendon from 2007., Yepes et al.(42) reported existence of an avascular zone 1 to 2cm proximal to the superior pole of the patella. They concluded that this area correlates with the most frequent localization of spontaneous tendon rupture, but insufficient research was conducted on the matter of what effect this hypo-vascularity may have on postoperative donor-site site healing rate or graft maturation. The participants concluded that better understanding of vascular anatomy of the tendon and its variations, would help determine adequate harvesting guidelines and facilitate better clinical outcomes. Therefore, it was concluded it should be one of the main research interest areas in the future. Dilemma of whether there is an upper age limit to QT autograft application was considered. There is a documented change in the weakest point of the extensor mechanism strength in older age groups on one hand, and almost no deterioration in flexor mechanism strength, on the other. Thus, leading to the possible conclusion that Quadriceps tendon autograft is not the adequate graft choice for ligament reconstruction in older age-group patient population.

The important question regarding the potential use of bone block had also been posed, with an idea to determine whether the application of bone-block and its fixation in one of the tunnels leads to faster tendon to bone-tunnel healing rate and graft vascularization, or not. Several studies addressed the use of bone-block and concluded it helps graft distal fixation strength and also hypothesized that it may promote better and faster osteointegration of the graft. Rodeo et al. showed that the increased contact between the tendon and bone-canal achieved through the use of bone peg, leads to faster healing rate by promoting the creation of Shapey's fibers(43).

The general conclusion is that there is not enough evidence to substantiate the possible solution, what indicates a need for further research on the subject. The proposed conclusion among the participants, based on their clinical experience, was that, since it has been found that the weaker trabecular bone tissue is located in the tibia, bone-block placement is justified in the tibia as well(44). The composition of trabecular bone in tibia was first analyzed by Ding et al. in 1964. Further analysis was conducted by Ding et al.(45-47) in 1997 and Simonian et al.(48) in 1998. They found that the cancellous bone ranges in volumetric density between 0.09 and 1.26 g/cm^3. Cortical bone density on the other hand is reported to range between 2.0 and 2.2g/cm$^{3.}$(47).

When talking about comorbidities, more specifically the appearance of postoperative quadriceps tendon rupture, the general opinion was that it predominantly appears in very muscular, heavy men, leading to the conclusion that the possibility of tendon rupture is predetermined by existence of very strong extensor musculature. Another comorbidity, that proves to have a high incidence in the clinical practice is the intraoperative penetration of the joint capsule. The violation of the suprapatellar pouch leads to formation of hematoma at the tendon donor-site. This raised the question whether we should routinely close the postharvest tendon defect or not.
The general conclusion of the participants is that in case of partial-thickness tendon harvest there is no need for suturing the defect. However, in cases when the preoperatively determined thickness of the tendon is less than 6mm, which calls for full-thickness graft harvest, it is recommended to suture the tendon defect in order to prevent the appearance of postoperative suprapatellar hematoma. These recommendations were initially set by Fulkerson et al. (28) and further substantiated by evidence found by Xerogeanes, Slone et al.(49) in their description of their newly developed technique for all-inside ACL reconstruction using QT. In addition to previously stated comorbidities, another postoperative complication, has been described by Slone et al. in their comprehensive literature review on the subject (21). It is the appearance of Rectus femoris muscle belly retraction caused by violation of myotendinous junction during harvest. It is found that it causes no functional deficit, but mostly presents a cosmetic issue.

Biomechanics

The presentation on the subject of Quadriceps Tendon Biomechanical properties was held by **prof. Mirco Herbort** from University of Munster, Germany. He presented the findings from a study: “Single-Bundle Anterior Cruciate Ligament Reconstruction: A Biomechanical Cadaveric Study of a Rectangular Quadriceps and Bone-Patellar Tendon-Bone Graft Configuration Versus a Round Hamstring Graft” published in 2013(50).
Prof. Herbort and his associates have conducted kinematic measurements in 9 human cadaveric knees with robotic-universal force-moment sensor testing. The same specimens were evaluated in simulated pivot-shift test and KT-1000 (MEDmetric, San Diego, CA) under various angles: 0,15,30,60 and 90 degrees of flexion under different conditions: Intact knee, ACL-deficient knee and Single bundle ACL reconstructed knee. Three different techniques were used for ACL reconstruction: A rectangular tunnel strategy with QT, rectangular tunnel

strategy with BTB and round tunnel technique with Hamstring graft. The result under simulated Pivot-shift and Lachmann test showed a significantly lower degree of anterior translation in 0 to 15-degrees of knee flexion in specimens reconstructed with rectangular tunnel technique in comparison to round tunnel reconstruction technique with Hamstring graft. The clinical significance of these findings is substantial, since it is known that the Anterior Cruciate ligament injuries happen in most cases in the 0 to 15-degree range of knee flexion with a stabilized foot. This finding yields a conclusion in favor of Quadriceps tendon autograft application, especially in younger athletes engaged in high-pivot demand sport activities.

Discussion

Discussion that followed addressed several issues and questions that are considered undetermined or under-researched in regards to Quadriceps tendon Biomechanical properties. Initially, the main focus among the participants was in sharing, which of the available fixation techniques and tools they find in their experience to yield the best clinical outcome.

In continuation, the participants discussed graft preparation, more specifically which suturing technique and how many sutures they use in everyday practice. The consensus was that they prefer to use the Krackow stich instead if the Whip-stich (both with Fiberwire) and that there has to be a tendency to avoid filling out the entire canal with sutures. The Krackow stich, both in their experience and literature proves to be a better choice since it leads to less cut-through tendon and graft elongation(51). Krackow stich was first introduced by Krackow et al. (52) in 1986, followed by a comparative study on available suturing tools and techniques in 1988 (53). Krackow described this stitching technique as a superior alternative to, at the time most utilized, Whipstitch. Han et al. in their comparative biomechanical study reported that in terms of ultimate strength and modes of failure both stitches yield similar results, but Krackow stitch produced less gap formation, elongated the graft and preserved tendon's end-width(54). Proposed conclusion among the participants was that due to QT autografts' high cross-sectional volume, less sutures is needed for graft preparation, preferably two at each end (soft- tissue graft). For example, Fulkerson et al.(28) in their summary of Quadriceps tendon for ACLR from 1998. made a recommendation that only 2 nonresorabable sutures are needed for the

distal portions of the graft and since then this practice has been followed by surgeons around the world.
The selection of the most adequate knee model for biomechanical testing was further contemplated. The issue of selection of the most applicable specimen for testing, often presented a significant limitation or downside to many publications, challenging the credibility of their findings. Cadaver knees pose as the natural best choice, but unfortunately mean age of specimens almost never matches the mean age of population at risk of attaining ligament injuries. Additionally, previous studies have shown that the biomechanical properties of the tendon are in the direct correlation to biological factors like age and skeletal maturity. For example, Woo et al. (55) found that ultimate load to failure of native ACL in population group age from 22 to 35 to be 2.160N at 157N and the mean stiffness to be 242N/mm. These values are in an obvious decline in older population groups ranging from 1.503 at 83N and 658 at 129N for age groups of 40 to 50 and 60 to 97 years, respectively. Another factor that must be taken in consideration is the unavailability of cadaver knees and their high cost. Porcine knee is considered as an adequate substitution specimen and in regards to length and shape comparable to human knees. Nagakarti et al. (56) showed that Bone mineral density (BMD) of porcine bone is very similar to BMD of young adults. Considering that BMD decreases in humans over time (55), conclusion can be made that porcine specimens present a solid model for ligament investigation. With this said, Aerssens et al.(57) reported that even though there are similarities in cortical-bone dry weight in humans and porcine, there is a significant difference regarding the bone composition and concertation of osteo-proteins. Further supporting this finding is the result of biomechanical interference screw fixation tests conducted by Megan et al.(58) that demonstrated different graft-slippage properties within the human and porcine specimens, most-likely due to difference in bone composition.

Ultimately, the question of mechanical and histological properties of the Quadriceps tendon in a longer follow-up period was raised. Considering that most studies are limited to a shorter follow up period ranging from six months to up to two years, the state of the graft after a longer postoperative period remains unclear. It has been reported that QT after 6 months' postoperative period shows a high degree of synoviliazation in Magnetic resonance imaging (MRI). Lee et al. conducted electron microscopic evaluation of QT graft and reported that 76% of observed grafts had maintained their original fiber orientation and concluded that this might be an additional proof for biomechanical superiority of this graft. In regards to clinical outcome the publications so far have also had an insufficient follow-up period to definitely determine the benefits of QT use. One of the rare publications we identified

through our literature search is the study published by Chen et al. in 2006. Chen et al.(59) presented outcome data after a 4-7 years' follow-up period and reported high or excellent Lysholm scores in 94% and return to strenuous activity in 76% of the 32 patients examined.
It is important to mention the possibility of Double Bundle (DB) reconstruction with Quadriceps tendon auto and allograft options(60-64). Since the introduction of anatomical ligament reconstruction using semitendinosus tendon graft 1984. by Mott et al. (65) the Biomechanical aspects of Double Bundle ACL reconstruction technique have been evaluated in several studies. The advocates of the DB ACLR claim that this technique presents a true anatomical reconstruction of native Anterior Cruciate ligament and that it can restore knee kinematics of the intact-ACL knee to a higher degree, than the Single Bundle (SB) reconstruction technique(61, 63, 66-68). They hypothesize that DB ACLR technique also improves pivot-shift resistance and rotational stability of the knee(69, 70). Since Quadriceps tendon can yield a robust graft that can be split in two distinct bundles, it is considered as an appropriate choice for this technique(60, 63, 71, 72). For example, Hussein et al. showed anatomic DB reconstruction has a clinically better result than anatomic SB reconstruction and other biomechanical studies showed similar results (68). Kim et al. (73) conducted biomechanical comparison of four different techniques with different number of femoral and tibial canals, using the QT tendon and reported that DB restored Anterior tibial translation (ATT) of the ACL intact knee, regardless of number of tunnels used. They have also reported that in situ forces in DB technique under anterior tibial load and torque load, were similar to the values of native ACL, while the same measurement in case of SB were significantly less at 0,15 and 30 degrees of knee flexion. Similar findings have been reported in publications by Musahl et al.(66) and Aglietti et al.(74). These findings, even though generally accepted and recognized, are considered insufficiently relevant to suffice for major disadvantages that this technique carries. DB technique proves to be more technically challenging, thus having a large learning curve and most of all presents a significantly more time-consuming process than the SB technique. When considering limited tourniquet and anesthesia time, this can be a major downside to its application and main reasons to its general less frequent utilization. The participants agreed that even though they have and still use this technique in their clinical practice and recognize its benefits, due to the factors stated in the text above, their choice primarily remains in SB technique.

Conclusion of first session

At the end of the first session the participants established the course of future research regarding the Anatomy and Biomechanics of the Quadriceps tendon. It is agreed upon that the main focus area will be: 1. Vascularization of the tendon at the point of donor site, 2. Introspecting the effect which vascularization has on harvest site healing rate and graft vascular ingrowth 3. Determining to which degree the directional organization of the muscle fibers variate 4. Conducting further research in hysto-anatomy of the tendon, and 5. Determining which animal model is the most appropriate for in-vitro tests.

QUAD ACL Current techniques/Clinical outcome

The experts' session regarding the Clinical outcomes and Existing ACL reconstruction techniques followed. It was chaired by Prof. Volker Musahl from Pittsburgh University.

The first presentation on the subject was held by **Prof. John W. Xerogeanes** from University of Atlanta. Xerogeanes presented a newly developed technique for Quadriceps tendon harvest described in the paper: "*Minimally Invasive Quadriceps Tendon Harvest and Graft Preparation for All-Inside Anterior Cruciate Ligament Reconstruction*"(49) published with his associate Harris Slone in 2016. Xerogeanes and associates have developed a special minimally invasive technique for graft harvest for all-inside ACL reconstruction. Morgan et al.(75) introduced the all-inside ACLR technique using an allograft for the first time in 1997. Since then it has been further developed to match the needs of soft-tissue autograft reconstruction and addressed in several publications. Lubowitz et al.(76) published their technique in 2011 and a randomized control trial comparing all-inside technique with the ACLR with full tibial tunnel in 2013(77). Generally, all-inside technique is considered to cause less surgical trauma and bone removal, leading to less postoperative pain and improved cosmetics. It requires shorter grafts and since shortening the BTB graft proves to be difficult, QT graft appears to be an ideal choice for this technique. The possibility of determining the length and volume of quadriceps tendon in magnetic resonance imaging, prior to the surgery also present a significant advantage to its application, when talking about all-inside reconstruction. Xerogeanes routinely

conducts preoperative MRI measurement of the Quadriceps tendon at mid-sagittal plane, 3cm proximal to the superior pole of the patella. This area has been recognized as the point of representable tendon thickness in the previous study published by Xerogeanes et al. explained in the text above(37). Once the length and diameter of the tendon are established they proceed to determine and mark specific landmarks that helps intraoperative orientation. The proximal pole, medial and later edges of the patella are marked, with important note to distinguish later border of the patella from the lateral trochlear ridge. The horizontal mark is made just superior of the superior border of the patella and just lateral from the mid-point. The recommendation for slightly lateral harvesting direction on the tendon itself has been described by Lippe and Fulkerson(78). They found that the initial point for tendon harvest on the superior pole of the patella should be slightly more towards the lateral margin because this orientation yields the graft of highest thickness and avoids injuring the vascular arcades in the tendon portion proximal to the apex. Interesting note made by Xerogeanes is that if the arthroscopic is conducted prior to the harvest, it is important to suction all the remaining arthroscopic fluid in order to minimalize capsular distension and in that way, also minimize the possibility for penetration of the articular capsule. They apply local anesthetic or saline fluid to distend the subcutaneous tissue from the tendon. The proceeding technique to mark the proximal harvesting point of the tendon is also very interesting. It includes positioning the arthroscope without the fluid flow in longitudinal incision and while looking down on the tendon, the *Vastus medialis* and the apex of *Rectus femoris* tendon are identified. Then a mark is placed on the point of highest transillumination on the skin and measurement is made to the proximal pole of the patella to confirm graft length. To harvest the tendon, they use the Arthrex quadriceps knife, which allows for both “push” and “pull” cutting direction. In their practice, they prefer to do the “push” cutting technique. Another important mark made is that in this technique it is necessary to trim down the distal 2cm of the graft to desired circumference in order to avoid having mismatched diameters of the distal and mid-portion of the graft. For the all-inside technique, they prefer to use graft of 6,5-7cm of length and in case of a longer harvested graft it is necessary to be shortened. Routinely, the smaller end of the graft is positioned in the femoral canal. The detailed graft preparation and incorporation will not be addressed in this review.

Xerogeanes stated that in his experience, this technique yield the least harvesting time when compared to other two graft options, approximately 10 minutes. The graft failure rate he reported is 4,2% for up to 210 days’ follow-up, 8,3% for 15 to 20 years and 2,8% for 20-25 years’ follow-up. KT-1000 scores, they found, had no statistically significant difference between 6 weeks to 3 months and 3 to 6 months, postoperatively. Out of morbidities only hematoma at the

donor site stands out and almost no reports of residual extensor weakness, patello-femoral pain and patellar fracture are reported. As mentioned before they had rare reports of *Rectus Femoris* muscle belly retraction with a cosmetic defect appearance on the thigh, mostly associated with harvest of graft greater than 8cm in length.
The clinical significance of this technique is considerable. Mostly, because in the past the QT harvest was associated with a large incision and longer harvesting and preparation time. This technique with newly developed instruments presents a less time consuming, significantly less technically challenging and most of all, less structurally disruptive procedure that can be widely utilized.

The second presentation was held by **Prof. Christian Fink** from Innsbruck, Austria. Fink presented newly developed technique for minimally-invasive Quadriceps tendon harvest published in the paper: “Minimally Invasive Harvest of a Quadriceps Tendon Graft With or Without a Bone Block” by Fink et al in 2014 (41). Fink and his associate Christian Hoser from Innsbruck, Austria, recognized QT autograft as a highly versatile autograft option with good biomechanical properties and for years have been strong advocates of its use for Ligament reconstruction. They have conducted research and published several publications on the subject. Since, as we mentioned In the Introduction, QT autograft has been reserved for revision surgeries in the past, mostly due to a technically challenging open harvesting procedure with a high learning curve and less cosmetically attractive scaring, Fink et al. had a goal to develop a minimally invasive, less anatomically disruptive and at the same time easily reproducible technique for QT harvest.
Preoperatively they also conduct MRI measurements of the QT to determine its length and cross-sectional area. Important note made by prof. Fink, is that during harvesting procedure, the leg should be positioned in the 90 degrees of flexion in order to achieve full tensioning of the tendon, which proved to facilitate the harvest. Preferably, the leg is positioned in an electrical leg-holder to allow intraoperative leg positioning. Harvesting technique described by Fink et al. includes making a 2,5 to 3 cm transverse incision on the superior border of patella, or alternatively a longitudinal incision of similar length. In his experience, Fink stated, transverse scar heals better and is cosmetically more acceptable for the patient. After tendon has been properly exposed from subcutaneous fat tissue, an 8 to 12 mm Karl Storz double knife is introduced medially or slightly laterally from the mid-point of the superior edge and pushed a long the surface of the tendon to the desired length of minimum up to 6cm. The desired thickness of the graft of minimum 5mm is than excised by a specially designed Karl Storz tendon separator, also up to the length of 6cm. Ultimately the tendon is cut at

the proximal point with a special tendon cutter and protruded through the skin incision. There is a possibility of harvesting a soft tissue graft without a bone-block, or taking additional 15 to 20mm bone-block from the patellar bone. As we mentioned before, whether incorporation of 2cm bone-block has its benefits in terms of graft integration and tendon to bone healing rate, is yet to be determined in the future. In case of soft tissue graft harvest, Fink et al routinely harvest additional 2cm of periostal tissue from the superior pole of the patella. This periostal flap is then folded during graft preparation and web-stich with strong No 2. sutures. It helps create a smooth, round end of the graft which makes its protrusion through the bone canal easier and can provide additional 1cm of overall graft length. This proves to be a major benefit when using QT autograft for PCL reconstruction. Theoretically, the additional periostal tissue incorporated at the end of the graft, should help graft osteintegration, however this still remains to be determined.

Regarding the bone-block tendon construct harvest option Fink et al. made several important guidelines. They state that the bone block should be harvested at the end of the harvesting procedure. This helps avoid attaining non-matching diameters of bone-block and tendon portion of the graft. The bone-block is cut with an oscillating saw and then easily chiseled free. They found in their experience that the use of chisel should be from posterior to anterior direction. This proves to significantly decrease comorbidities associated with bone-block harvest, mostly postoperative patella fracture. They also prefer using square instead of round shaped bone-block. Fink reported 20-30% incidence of intraoperative joint opening in case of full thickness graft harvest. The appearance of postoperative hematoma is prevented by routinely closing the tendon defect at donor-site. The defect is sutured, proximally to distally by approximating only the resected edges of the fascia, not the tendon itself.

In the antero-medial portal technique they use, the femoral tunnel length is measured initially to determine the exact length of graft needed. The femoral tunnel is then rectangulated with a rasp, to a desired depth depending on the length of bone-block. Once this is done, shaver is used to smooth the anterior and antero-inferior edge of the femoral tunnel. This has proved to prevent graft cut-through at the tendinous portion, by sharp edges of the femoral tunnel. In most cases, they form a round tunnel at the tibial footprint. This proves to be functionally more plausible cause the tibial eminence is a hard bone, consequently often leading to drilling blow out and injury to the condylar cartilage or other structures(44, 47, 57).

The clinical significance and applicability of this procedure is immense. It is clear that when compared to open- harvest, this technique, when following the proposed steps and with the right instruments, proves to be a significantly less

challenging procedure that leaves a smaller and aesthetically more appealing scar.
The development of this, and other minimally invasive harvesting techniques, in addition to well-described and reported favorable biomechanical properties and clinical outcomes, is another step in world-wide popularization and more frequent use of Quadriceps tendon for ligament reconstruction.

The third presentation was held by **Prof. Martin Lind** from Denmark. Prof. Lind presented the finding from a prospective randomized study: "Is Quadriceps Tendon a Better Graft Choice Than Patellar Tendon? A Prospective Randomized Study" published in 2014, in *Arthroscopy Journal*(35). In their randomized control study, Lund et al. compared various clinical parameters and patient outcome evaluation scores in patients who underwent primary ACL reconstruction using either the Quadriceps tendon-bone (QTB) or Bone-Patellar tendon-bone (BPTB) autografts. They compared knee stability, kneeling pain, sensitivity loss at the donor site, harvest site pain and evaluated patient perception through two widely utilized patient-evaluation outcome scores the Knee Injury and Osteoarthritis Outcome score (IKDC) and subjective International Documentation Committee (KOOS). For evaluating the knee stability, they used the KT-1000 arthrometer (MEDmetric, San Diego, California) and for evaluation of knee pain, clinical assessment and knee walking test. They have included 51 patients in total through a 5-year period, and randomized 25 patients into BPTB group and 26 into QT group.
The significance of this study is great, since up to 2014, only two retrospective and no prospective randomized studies comparing BPTB and QT clinical outcome were published, in other words this study present one of a kind comparison between these two graft choices.
The main end-point of their evaluation was the anterior knee stability measurements performed by KT-1000 arthrometer. Secondary end-points were knee pain evaluated by palpation of the donor site and knee walking test. Knee walking test was performed by having patients walk on their knees for two meters and then give subjective grade that varied from problem-free, uncomfortable, difficult to impossible. Each measurement was performed at 1 and 2 years' follow-up.
The results in regards to anterior knee stability in the two groups, the QT and BPTB group, measured with KT-1000 arthrometer, were reported similar. These findings mean that both the QT and BTPB grafts can restore knee kinematics In regards to anterior and rotational stability, to a similar level. However, at 1 year

follow-up they found significantly more positive pivot shift test in BPTB group than in the QT group- 38% and 14%, respectively. This finding is somewhat surprising but can be accounted for as coincidental, because there have been reports of positive pivot shift tests in BPTB ACL reconstruction ranging from 0% to 30% in the literature. There is a hypothesis, that due to higher cross-sectional volume of the intraarticular portion of the QT graft, it should yield better biomechanical properties and be potentially stronger over time. In order for this hypothesis to be proven, a longer follow-up period is needed. The participants concluded that this should be potential research point in the future.
Concerning the sensitivity loss, the measurements as expected, showed significantly less sensory loss in the QT group. This higher sensitivity loss in the BPTB group is believed to be the consequence of the harvesting technique and the iatrogenic injury to the infrapatellar branch of the saphenus nerve. The harvesting technique for QT graft, applied in this study, included open approach with longitudinal incision 5cm in length and full-thickness tendon harvest, but only a minor horizontal incision medial to the tibial tuberosity for canal drilling. The BPTB graft was harvested from the central third of the patellar tendon with a parapatellar horizontal incision. The postoperative sensory loss has been described in the past by Kartus et al.(7) who found that the medial incision necessary for BTPB graft harvest is responsible for nerve injury. The knee walking test and pain at donor site were also reported much higher in the BTPB group. It is believed that the tendon and bone defects caused by the harvesting technique, lead to scar tissue formation and suprapatellar fat-pad hypersensitivity, thus, when pressure is applied on the anterio-superior aspect of knee, causing more pain for the patient during knee walking test. The subjective patient evaluation scores the IKDC and KOOS both showed similar results, meaning that patients subjective perception of the two grafts does not differ. The IKDC score showed a slight tendency to be better in the QT group at the 2-year follow-up period, but cannot be considered significant.
Lind et al. concluded that in regards to anterior knee stability and patient's satisfaction both graft options have similar results. In terms of anterior knee pain, knee walking pain and donor site sensitivity loss, QT grafts proves to have better results/ to be a better graft choice. Overall conclusion of the study, as made in many prior publications, is that the QT autograft option present not only a good alternative, but also a versatile primary reconstruction graft choice.

Prof. Lind continued to present several significant findings from an on-going study in Denmark, regarding the subjective and functional report comparison of ligament reconstruction using Quadriceps Tendon (QT) autograft and Hamstring tendon (HG) autograft. In their data, the patient outcome evaluation scores the KOOS and IKDC showed better patient subjective satisfaction perception in case

of HG use, than in QT, but none of the results carried a statistically significant difference. Regarding the Tegner pain score no differences were reported, as well as in regards to knee stability measurement performed by KT-1000 arthmometer, which in both groups varied around 200. Cybex Isokinetic strength testing showed strength deficit in both extensor and flexor apparatus in HG group and only extensor deficit in QT group. The most surprising finding the prof. Lind presented from the Danish registry is the Kaplan-Mayer revision rate that proved in their study to be the highest in the QT group.

Discussion

In continuation, participants took part in a mini-discussion to address the findings presented by prof. Lind. The question of why there is relatively frequent appearance of extension deficit in case of Hamstring tendon graft use in clinical practice, also presented in reported Cybex Isokinetic strength test results, was raised. This proposed conclusion is that the extension deficit is a consequence of the injury itself, since the same has been noticed in use of allografts all the way up to one year postoperatively. The credibility and applicability of most frequently used patient evaluation scores the IKDC(79) and KOOS(80) in assessing patient perception of QT in ACLR in particular, was addressed. The question is whether we need another more precisely directed and relevant score for evaluation of data regarding QT, since IKDC has initially been intended to evaluate patient perception in total knee patients. Potentially applicable score would be the Lysholm Score(81-83), but unfortunately it is known to have a very strong ceiling effect. In other words, maximum values are achieved swiftly, but with passage of time lose their relevance. When talking about Tegner activity score(83, 84), also frequently utilized tool, the participants agree that it is essential to distinguish the preoperative from preinjury state, because the score relates only to preinjury conditions.

The general conclusion of this discussion was that the main downside of these comparative studies, lays in selection of patients for the QT ACLR group. The initial inclusion criteria for the QT ACLR is the presence of valgus instability, which in other words means that in order to preserve the medial stabilization apparatus, Hamstring muscle should be preserved, making it an inadequate graft choice for these patients(85, 86). This can be seen a selection bias, and presents a general limitation for many studies published so far. An additional selection bias presents itself in the fact that patients that undergo ACLR with QT as primary choice are mostly active athletes. The participants believe that

this problem will be overcome in the future by popularization of Quadriceps tendon autograft option in the general population.

Prof. Jürgen Höher from Germany went on to present the technique for QT autograft ACLR developed with his associate Dr. Ralph Akoto, described in the paper: "*Anterior cruciate ligament (ACL) reconstruction with quadriceps tendon autograft and press-fit fixation using an anteromedial portal technique*" published in 2012(87). The technique developed by Höher and Akoto presents an arthroscopic ACL reconstruction technique using QT autologous graft option and most importantly using the anteromedial portal for tibial tunnel drilling.
As we mentioned in the text above, several authors have described the press-fit fixation technique for ACLR with QT(88-91). The main advantage of this technique is that it avoids using screw fixation and incorporation of implants, making it a more biological approach for ligament reconstruction. However, most of the described techniques for press-fit fixation include the transtibial approach with a single incision. Even tough proven effective, this technique is associated with femoral tunnel misplacement. Both Bird et al.(92) and Arnold et al.(93) have described in their publications, occurrence of non-anatomical placement of femoral-tunnel in transtibial technique, resulting in early graft failures and altered biomechanical properties of the graft. That's is why the technique using an anteromedial portal, presented by Hoher et al, is considered to better restore anatomical placement of the ACL femoral foot print.
Their harvesting technique present a somewhat different procedure than the ones described in the text above. It includes approaching the tendon through a 4-5cm long longitudinal incision at the apex of patella. They harvest a 10mm wide, 50mm long graft with an addition 20mm of patellar bone. To attain the bone-block they use a hollow burr, attached to an oscillating compression air drill. This hollow burr has a specific design, with a blunt 1/3 and serrated remaining two thirds of its circumference and a 9,4mm diameter. They use the graft sizer to ensure that the 9.4mm bone-block will completely pass through the right template. The tibial tunnel is drilled through a 2-3cm longitudinal incision on the medial aspect of the tibia, with a 10,5mm hollow burr. Using this burr, allows to simultaneously attain a cylindrical bone-block from the tibial bone. This bone fragment is then separately processed into three fragments, each having its application in the further steps of graft incorporation. The proximal part is longitudinally split to attain two smaller fragments that can be used for compressing the graft in the bone tunnel, medial part can be used to fill out the patellar donor-site and the distal fragment to ultimately fill out the distal portion of the tibial tunnel. Press-fit fixation is used to secure the bone-block in the

femoral tunnel using an impactor applied through the antero-medial portal. It is important to note that the bone-block must be over 20mm in length in order to be pushed into the femoral canal. This technique is believed to increase bone ossification and promote tendon to bone healing rate, at the same time providing sufficient strength(27, 43, 88, 94-97). The pull-out strength of the bone-block was measured on Colone, Germany to be around 400N. Tibial fixation is performed using a suture over a bone-bridge and tunnel diameter is reduced by using the cylinder bone fragment, which proves to decrease postoperative tunnel enlargement. This presents a benefit when considering a potential revision surgery in the future and overall decreased bone loss.
Höher et al. have conducted ACLR using this technique in 87 patients in a two-year period. They report no intraoperative or major postoperative complications. They have evaluated all patients in a 12-month follow-up with an International Knee Documentation Committee (IKDC) and Tegner pain score. They have also conducted evaluation of knee laxity with Lachman test and pivot-shift test, Instrumental laxity with Rolimeter and knee function with ROM and one-leg hop test.
All the results reported indicate the benefits of use of this technique with QT autograft, with very few unsatisfactory patient outcome scores and positive Lachman and pivot-shift tests reported. Additional benefit of this technique is the possibility to preserve Hamstring muscle function, assuring better medial stabilization, especially in athletes involved in high demand valgus sports like judo or wrestling etc.

Prof. Volker Musahl from Pittsburgh University presented his opinion and findings regarding the Double Bundle (DB) technique for Arthroscopic Knee ligament reconstruction from the publication: "*Anatomic single- versus double-bundle ACL reconstruction: a meta-analysis*"(66) published in 2013. in *Arthroscopy Journal*. Musahl et al.(66) performed meta-analysis of 15 eligible publications, out of the 7,154 studies identified in total. The studies were collected through a search of several different electronic data bases (PubMed, EMBASE, Cochrane Library). Their goal was to establish whether anatomic DB ACLR has an advantage over Single Bundle (SB) ACLR in terms of restoring Antero-posterior (A-P) laxity, rotatory laxity and reduced frequency of graft failures.
Their initial hypothesis was that the anatomic DB reconstruction technique yields improved rotational knee laxity and fewer graft failures due to its double-bundle tension properties. They have analyzed only publications with Level I-II evidence and extracted data regarding knee functions including Lachman, pivot-

shift and Anterior drawer tests, KT-1000 measurements, A-P laxity measurements using navigation and total internal-external (IRER) laxity, as well as graft failure incidence. Their analysis showed improved results in DB technique in regards to A-P and anterior laxity measured with KT-1000 arthromere. However, no significant improvement was seen in Lachman, pivot shift, anterior drawer tests, as well as no significant change in graft failure incidence.

When considering that Anterior cruciate ligament is a non-uniform structure, but is consisted of two distinct bundles that carry different tensile properties and are responsible for anterior knee stabilization in different degrees of knee motion, this hypothesis seemed very plausible. Amis et al. (98) in their evaluation of functional anatomy of ACL published in 1991. showed that Anterior Cruciate ligament is not an isometric and uniform structure, but instead includes two different bundles of fibers with different directional orientation and distinguished tibial and femoral foot prints. The two bundles are the Antero-medial (AM) and Postero-lateral (PL) bundle, both having insertional points in femoral and tibial bone, but express different tensile properties in different ranges and directions of motion. AM bundle is the primary anterior stabilizer in knee flexion, with highest taut at 45-60 degrees of flexion, while PL bundle is predominantly responsible for stabilization in extension, with highest taut expressed in full outstretched leg. Theoretically, bundles of a split graft applied with DB reconstruction technique, with separate tibial and femoral footprints that mimic the AM and PL bundle footprints of the native ACL, should be tensioned separately during knee motion(62-64, 66, 67, 71, 74, 90, 99-101). This would mean that, in addition to restored anterior stability, higher rotational stability and pivot-shift resistance would be achieved with this technique(70).

Quadriceps graft present a versatile graft choice for DB ACLR because of its high cross-sectional volume and enough thickness to provide two separate bundles of different diameters(49, 60, 72, 99). Prof. Musahl stated that even in case of partial-thickness harvest QT can provide a graft of sufficient volume and can longitudinally be split in two bundles, 8 and 5mm in diameter respectively. The statistical data from his clinical experience (Graft failure 4% in DB, 3% in SB) shows no significant difference between SB and DB anatomical reconstruction techniques. Prof. Musahl concluded that Quadriceps tendon graft presents a validated anatomical concept and an excellent graft choice.

Prof. Musahl went on to summarize the positive and negative sides of use of QT for ACLR, based on his clinical experience and multiple studies he has published on the subject(66, 72, 96, 97, 102, 103).

The main advantages of QT he finds, are that it presents a robust graft with high cross-sectional volume which can be determined preoperatively, can be utilized in pediatric population, is associated with less infection at the donor site and a

relatively easy harvesting technique. In his every-day practice QT soft tissue graft (without bone-block) is used as a first-choice graft for primary reconstruction surgery in athletes involved in sports like sprinting, judo and wrestling, while graft with an additional patellar bone-block is predominantly used for ACL and PCL revision surgeries. The negative sides he finds are possible appearance of suprapatellar hematoma and increasing stress riser in case of inappropriate cutting end-point during harvesting procedure.

Discussion

In the following discussion, several important aspects of both previously presented techniques and clinical practice experiences of the participants were shared and contemplated.

True indications and contraindications were discussed. The participants agreed that a strong contraindication for QT autograft use is the presence of *Patella bipartite* condition(21, 49). When talking about definite indications, as mentioned in the text above, Quadriceps tendon presents a viable graft option for patients of almost all age groups and activity levels, but in practice today is mostly reserved for young active athletes involved in high pivot and rotational stress sports. Several publications denoted in which patient groups the QT should be the primary choice(14, 15, 36, 104-112). When keeping in mind the high incidence of kneeling pain reported in BTPB use and long-term flexor deficiency in HG option, the QT autograft presents an ideal graft for patients who due to the nature of their profession or religious and cultural traditions have to kneel for a prolonged time.

The question of adequate graft choice for ACLR in professional ski jumpers was clarified by Prof. Lars Engebretsen from Norway. Prof. Engebretsen has a vast experience in treating athletes involved in various winter sport disciplines, among others a significant number of ski jumpers. He stated that due to the kinematics of their sport, more specifically the high impact landing, ski jumpers need a preserved anterior knee stabilization, while at the same time, due to necessary fully extended knees for flight control, focus must be in preserving their extensor mechanism. This shifted the choice of appropriate graft towards the Hamstring tendons. However, in the recent year QT autograft has proven to have growing popularity among these athletes.

The participants agreed that in case of ACRL in tall, heavy basketball and American football players, QT autograft presents an adequate graft choice. Prof. Musahl explained that the low incidence of QT application in National Football League (NFL) players in the USA, is mostly due to the recommendation of the league for the use of BTPB grafts.

It was agreed upon, that in order to set a definite recommendation for graft choice in high-risk athletes involved in high collision, impact and pivot-shift demand sports, further research on a specific population group must be conducted in the future. The proposed study is a Randomized Control trial (RTC) on a high-risk patient group, best young female active athletes. A study on a specific population group of these characteristics would call for a less extensive patient population pool. Short onset was made regarding the use of BTPB graft and the general conclusion among participants was that, due to the reported high incidence of multiple comorbidities and equivocal biomechanical properties compared to other two graft options, the significantly decreased utilization of this graft is more than justified.

The participants addressed the problem of a high learning curve of the techniques that were presented in the meeting, as one of the main obstacles of broader popularization of this autograft option. The proposed solution to overcome this problem and at same time one of the major benefits of this initiative in general, is the possibility of finding common ground and through sharing experiences and knowledge, learn from each other. The ultimate goal of this initiative would be to develop a technically and technologically superior procedure, easily reproducible in centers around the world. This would help the popularization of the Quadriceps tendon autograft immensely, which is also one of the primary goals set before this experts' initiative.

Posterior Cruciate Ligament (PCL) reconstruction

The presentation on the subject of Quadriceps tendon graft use in Posterior Cruciate ligament reconstruction was held by **Prof. Karl Peter Benedetto** from Innsbruck, Austria. Prof. Benedetto presented the technique for PCL reconstruction with the QT published in the paper: "Hintere Kreuzbandrekonstruktion in offener und arthroskopischer tibialer inlay-Technik" (113). Benedetto found, that the main negative side of the QT utilization in general, is the cosmetically less-attractive scar. This being true, in case of the traditionally used technique with an open approach through a long longitudinal incision. His preference for PCLR is the Inlay technique, instead of the widely utilized transtibial technique. In his experience, the transtibial technique is associated with a higher risk of graft failure, because it includes the so-called

killer turn which requires for the graft to bend around the tibial curve. One of the main advantages of the inlay technique is that it avoids the killer turn and at the same time allows for more precise anatomical positioning of the graft.(114) In inlay technique Benedetto stated, you are almost in straight direction, which leads to bone-block almost self-locking in the canal. The bone-block prof. Benedetto uses is a thick block, about 10 x 11 x 11mm in diameter. Another interesting point made is that the insertion point of the PCL seems to at the area of former bone physis.

Discussion

In the discussion that followed, the participants shared their experiences and practices in regards to PCL and Multiligamentary reconstruction procedures. Prof. Musahl denoted his technique that includes the use of BTPB graft through the anteromedial portal. He positions the bone-block in the femur and preforms soft-tissue fixation in tibia. The extra-cortical graft fixation he performs with EndoButton fixation tool. Prof. Engebretsen and Dr. Strauss from Norway shared their procedure that includes the Double bundle (DB) technique with Achilles tendon allograft, with two tunnels in femur and one tunnel in tibia. In their experience, such tunnel positioning and use of Achilles tendon which, if necessary, provides additional tissue, leads to higher collagen concentration. In case of a knee dislocation with injuries of multiple structures, in particular when there is an injury to the peroneal nerve, prof. Engebretsen stated it is essential to maintain passive range of motion.

The discussion focused on determining the appropriate sequence of ligament reconstruction procedures in case of Multiligamentary knee injury. Xerogeanes and Musahl as representatives of US practice, stated that they initially perform the PCL, followed by Postero-lateral corner (PLC) reconstruction. The practice of Fink and Hoser is to first reconstruct the PCL lesion, followed by PLC and then ultimately ACL reconstruction. This sequence they find, is based on the fact that in case of primary reconstruction of the ACL, rotation of the tibia may occur. Mirco Herbort performs reconstruction in two steps, first being the PCL and PLC reconstruction and second the ACL reconstruction. Prof. Engebretsen is currently conducting the study on the matter of appropriate reconstructing sequencing.

The use of DB reconstruction technique for PCL has been further contemplated. The main issue in testing this technique in vitro, is acquiring sufficient number of porcine or cadaver knee specimens. As Mirco Herbort explained, the problem in testing techniques with different number of drilled tunnels in the same specimen, is that once a rectangular tunnel is filled out, it has the tendency to easily collapse, regardless of fill-out material. Additional specimens add to the overall cost of the study. When talking about DB PCLR the same hypothesis

applies as for the ACL reconstruction and states that by spreading the insertion area of the graft and incorporating two distinct bundles, some fibers will be tens and others loose in different angles of knee motion(98). This would then contribute to knee anterior and rotational stability in different angles of joint flexion and extension. The proposed research idea is to test the DB reconstruction technique with two femoral insertion sites with rectangular holes and a single insertion in tibial bone.

Rehabilitation

The experts section on the subject of Rehabilitation was the last session held in the meeting. It was chaired by **Dr. Hege Grindem**, from Norway who has published several publications on the subject of Rehabilitation after ACL injuries. The first presentation in this session was held by **Prof. Christian Fink**. Fink presented the findings from a recently published study: "Higher hamstring-to-quadriceps isokinetic strength ratio during the first post-operative months in patients with quadriceps tendon compared to hamstring tendon graft following ACL reconstruction"(115).

Fink et al. compared isokinetic quadriceps and hamstring muscles strength in patients who underwent primary ACL reconstruction surgery using either quadriceps (QT) or hamstring autografts at two time intervals within the first year postoperatively. Isokinetic strength testing was performed in one hundred and twenty-four patients in total. Two isokinetic strength tests were conducted under an angular velocity of 60% including both the injured and contralateral side. The testing protocols included concentric quadriceps and hamstring contractions, initially on the non-injured leg by performing four repetitions at an angular velocity of $60^{o}/_{s,}$ followed by the same procedure on the injured leg.

Fink stated that the most important finding of their study is the reported significantly higher H/Q ratio within one year after surgery in the patients who had ACLR with Quadriceps tendon autograft. As expected, the extensor strength was found to be significantly lower in the QT group. The side-to side differences were higher in the HG, however the flexion deficit was much lower in the QT group respectively. The results of this study show that the postoperative extensor deficit is in direct correlation to the graft choice, however the same doesn't not apply for the difference in flexion strength. The clinical significance of their findings is also considerable. Myer et al. reported that the relative strength deficit in hamstring muscles combined with a relative high strength of

quadriceps muscle presents a risk for ACL injury in female active patients(116-119).
When considering these findings, it is possible to conclude that the choice of QT autograft might have a protective effect in this population group. An additional conclusion made is that, since the strength deficit of extensor musculature is more related to the choice of graft than the postoperative rehabilitation protocol, perhaps rehabilitation should be adjusted to the choice of graft(85). Ultimately Fink et al. showed that with an appropriate rehabilitation protocol, adjusted to the choice of graft used, can lead to achieving normal thigh strength over time.

Discussion

In the discussion regarding the rehabilitation after an ACL reconstruction, the participant addressed several dilemmas and issues. The data in terms of higher H/Q ration in the QT reconstructed knees, presented by Fink was further contemplated. The question of whether this difference in H/Q ratio compared to HG use, can potentially have a functional protective effect and what would be the appropriate means to measure it, was raised. The participants agreed, that the main focus of the early postoperative rehabilitation in ACLR using QT autograft must be in regaining extensor strength(120). There is an apparent extension deficit in clinical practice in about 6-7% of the patients, in most cases in correlation with cyclops formation(103, 121).
The question of whether we can predict the formation of cyclops lesion and what the ideal surgical timing to address it would be, was further discussed. The general conclusion is that the early indication for the possible formation in the form of different degrees of extension deficit, can already be seen five day postoperatively. If the deficit is not corrected with physical therapy in the following months, clinical diagnose can be made(122-124). Prof. Engebretsen believes in terms of appropriate surgical timing, it is better to address the issue sooner, because longer time allows not only for the full cyclops to form, but also increases the possibility of process spreading on other structures of the knee, as well. The practice that Christian Hoser uses, is to handle the lesion already at 3 months postoperatively, with an additional posterior capsular release.
In regards to comparing the clinical outcomes of ACL reconstructions with Hamstring and Quadriceps tendon grafts, several issues and dilemmas regarding the use of Hamstring autograft were addressed. The participants agreed that in case of HG use, with appropriate rehabilitation protocols the flexor mechanism strength should be regained already nine months postoperatively(125).
If postoperative morbidities exist, such as muscle belly retraction and hematoma at the harvest site, they should generally disappear in 4 to 6 weeks. Interestingly,

it is well documented in the literature that HG too are associated with a relatively high incidence of postoperative morbidities. This is believed to be the consequence of the harvesting technique and consequent unintentional muscle fiber deficit(86). However, Semitendinosus can potentially grow back and have a normal appearance in imaging with an apparent tendinous portion. This has been reported in several previous studies(126).

The participants concluded that in order to prove the flexor muscle tendon deficit in HG, a randomized control study including a specific population group that has a high flexion activity, is needed. The proposed ideal patient groups would be professional climbers or bailey dancers, both groups with repetitive frequent flexions of the knee in their every-day activities.

The participants agreed on a certain rehabilitation protocol in terms of beneficial postoperative exercises in different periods of postoperative phase. Cycling after 6 to 8 weeks, light jogging after 3 months, dynamic squats at the point when intraarticular effusion has decreased and static squats at any time in the postoperative period, are considered among participants to be beneficial(86, 115, 120, 125).

Additional interesting remark was made by Xerogeanes, who shared with the collegium the recommendations of physio therapist from Pittsburgh who he has been working with in the past. They believe that additional stress on the Quadriceps muscle achieved through specific exercises in different ranges of knee flexion, promotes the healing of the harvesting site. The general conclusion of this expert sessions was that in order to popularize the QT graft use and improve clinical and patient satisfaction outcomes, exact rehabilitation protocols must be determined in the future.

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