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Midterm Outcomes of Arthroscopic Reduction and Internal Fixation of Anterior Cruciate Ligament Tibial Eminence Avulsion Fractures with K-Wire Fixation

Abstract

Purpose:

To determine the clinical and radiological outcomes of patients who underwent arthroscopic reduction and internal fixation of a tibial eminence avulsion fracture with Kirshner-wires (K-wires) at mean of 8 years following surgery.

Methods: This was a retrospective study with prospectively collected data. Participants underwent arthroscopic reduction and internal fixation of tibial eminence fracture with K-wires between 1989 and 2015 and at a minimum of 18 months follow-up assessment included the International Knee Documentation Committee Ligament Evaluation, Lysholm Knee Score and clinical outcomes. MRI was performed to evaluate the ACL and evidence of osteoarthritis.

Results: A total of 48 participants met the inclusion criteria, and 32 were reviewed at a mean of 8 years (range 18-260 months) after surgery. The mean age at the time of surgery was 24.5 years (10-55 years). Subsequent ACL injury occurred in 5 participants (10.4%) on the index knee and in 1 participants also on the contralateral knee. 86% had a normal examination, and no patients had >5mm side-to-side difference on instrumented testing. The mean IKDC subjective score at 8 years was 86 (40-100). On MRI scan assessment, 82% of participants had no evidence of chondral wear on the medial compartment and 73% had no changes in the lateral compartment according to Magnetic Resonance Image Osteoarthritis Knee Score (MOAKS) Classification. On MRI scan qualitative assessment of ACL and tibial eminence, 7 participants (32%) were found to have high signal at the fracture site. Significant kneeling pain was reported by 8 participants (25%).

Conclusion: This study indicates that internal fixation with K-wires is an acceptable approach to reduce tibial eminence avulsion fractures, providing excellent clinical and radiological outcomes at a minimum of 18 month follow up.

Level of Evidence: Level of Evidence IV – Therapeutic case series.

Background

Anterior cruciate ligament (ACL) distal avulsion fractures are a major intra-articular injury that represent 2-5% of paediatric injuries[1] and up to 3% of all ACL injuries in adult population[2] . Although this injury is traditionally more prevalent amongst skeletally immature patients [3], the injury does occur in an adult population [4, 5]. Theoretically, the most common mechanism reported is a hyper-extension trauma with valgus load and external rotation of the tibia and relatively internal rotation of the femur [6], which leads to an avulsion of the ACL from the tibial eminence, rather than a mid-substance rupture.

Classification of tibial eminence fractures is based on the modified Meyers-McKeever model. In this classification grade I fractures are non-displaced, grade II present a superior displacement of the anterior part of the fragment, with the posterior portion still attached to the rest of the proximal tibia, in grade III the fragment is completely displaced and grade IV is displaced and comminuted [7]. It is accepted that grade I and minimally displaced avulsed fragments can be managed non-operatively, however a displaced fragment requires surgical fixation. The method by which fixation is best achieve remains debatable. Current methods include open reduction and internal fixation or arthroscopic reduction and internal fixation [8-11]. Fixation may be achieved with screw, transosseous sutures, Adjustable Suspensory Fixation (ASF) or Kirschner wires (K-wires) [12-19].

The goal of surgery is to achieve anatomical reduction to restore normal length and tension of the ACL. Although the gold standard is considered to be arthroscopic reduction and internal fixation (ARIF), there is concern that screw and suture fixation are associated with residual laxity of the knee in 51% to 87% of patients [8, 20, 21] This is a significant concern as residual knee

laxity is known to correlate with secondary osteoarthritis at long-term follow up [8, 20, 22, 23]. Furthermore, stiffness and lack of full extension has also been reported as has subsequent surgery secondary to arthrofibrosis following ARIF with screws[10] . There are reports of the use of percutaneous K-wires as a temporary means to reduce the avulsed fragment in paediatric population[21, 22, 24] as well as arthroscopic reduction and definitive fixation with K-wires[13, 14] however with only twelve months follow up and mixed interpretation of laxity. Even used as a definitive implant, a potential concern needs to be addressed with this method, such as risk of breakage and necessity of additional procedure to removal the k-wires

The purpose of this study is to determine the clinical and radiological outcomes of patients who underwent arthroscopic reduction and internal fixation of tibial eminence avulsion fracture with Kirshner wires (K-wires) at mean of 8 years following surgery. It is hypothesized that the technique of ARIF of tibial eminence avulsion fracture with K-wires will provide anatomical reduction, restore knee stability, range of motion, return patients to functional ability and prevent secondary degenerative arthritis.

Material and methods

PATIENTS

From August 1989 to August 2015 patients from a single centre who had surgery for anterior tibial eminence avulsion fracture were identified. . All tibial avulsion fractures were classified at least as Grade II on Meyers-McKeever grading.[6] Criteria for inclusion was fixation of tibial eminence fracture with Kirshner wires, minimum of 18 months from index surgery, and informed research consent. Participants were excluded if they had concomitant multi-ligament reconstructions, a contralateral ACL rupture, an abnormal contralateral knee joint, or were seeking compensation for their injury. Ethics approval for the study was obtained from St Vincent's Australia Human Ethics Committee (Reference 17/233). The primary end point of this study was restoration of clinical ACL stability, without further ACL injury. Secondary outcomes include patient reported outcomes and objective evaluation with clinical examination and KT1000. Radiological examination of ACL position and integrity on MRI and evidence of osteoarthritis was also considered.

SURGICAL TECHNIQUE

Main procedure

All operations were performed by two senior authors (LP, JR) by ARIF with retrograde K-wires. A standardised surgical technique, and postoperative rehabilitation protocol was followed for all patients. The surgical technique is demonstrated in the accompanying video file (Video 1). The patient is placed supine on the surgical table. Following induction of general anaesthesia, a thigh tourniquet is placed on the proximal aspect of the operative limb. Anterolateral and anteromedial arthroscopic portals are created and the lipohaemarthrosis is drained. The

fracture haematoma is evacuated and bone fragments are assessed as regarding the size and possibility of fixation as well as the continuity of ACL bundles (Figure 1) and the feasibility of anatomical reduction of the fragment is checked (Figure 2). The C-shaped Drill Guide is set up in 55^{o} in mature subjects and In children with open growth plates the drill guide was aligned as vertically as possible to minimise the area violating the growth plates. 3-4 retrograde 1.4mm Kirshner wires drilled and projected 5 mm through the bed of the fracture in an equal distance from each other to ensure a more stable fixation (Figure 3). The K-wires are then withdrawn 5mm and using a curette, the fragment is anatomic reduced and the K-wires are then drilled through the tibial eminence fragment to allow temporary fixation. Once the position and reduction of the fragments are secured, the K-wire ends are folded 180 degrees into a hook and then pulled back under arthroscopic visualization (Figure 4). The final position and tension of the ACL fibres are checked (Figure 5). Full range of motion is checked at this point and under arthroscopic visualization the fragments must show a rigid fixation and correct ACL bundles tension during the excursion. At the proximal tibia, the ends of the K-wires are folded close to the cortex and then cut at 10mm length. The skin is closed in a routine fashion.

Routine radiographs are obtained postoperatively (Figure 6). Patients are not braced, allowed to weight bear as tolerate and commence an early accelerated rehabilitation program [25]. Return to sport was permitted after 6 months from surgery, assuming rehabilitation goals had been achieved.

Kirshner wire removal

Patients were reviewed 6 weeks after surgery. Once ligament stability and radiographs confirmed signs of union, the procedure was scheduled for the following week and the K-

wires were then removed in a day surgery procedure. Patients underwent general anaesthesia and a skin incision was performed at the previous anteromedial wound. Soft tissue was dissected and the K-wires unfolded and pulled back with a needle holder. Once the distal part of the K-wires is pulled back, the intra articular portion is naturally unfolded and the k-wires are removed with no breakage. No arthroscopic visualization was required.

CLINICAL ASSESSMENT

Subjects were routinely evaluated preoperatively and at 6 weeks and 6 months from surgery. At 6 to 12 months, an objective assessment of rehabilitation goals was performed to assess readiness to return to sport, especially those that involved pivoting or side-stepping activity. Further assessment was performed at a minimum of 18 months after surgery and included the IKDC Knee Ligament Evaluation Form. Ligament laxity was assessed with Lachman test, pivot-shift test, and the KT-1000 arthrometer (Medmetric Corp) using the side-to-side difference of manual maximum anterior displacement between knees. The single-legged hop test was used for functional assessment. Radiographs and MRI scans were also performed. An experienced physiotherapist and orthopaedic fellow [redacted] performed the clinical evaluation.

RADIOLOGIC ASSESSMENT

Weightbearing anteroposterior, 30 ^{o} flexed posteroanterior, patellofemoral, and lateral knee radiographs were performed. MRI scans were also performed to assess ACL position, medial tibial eminence height and cartilage lesions. A 3D water selective (WATS) image reconstruction was performed to increase analysis reliability. All images were assessed by an

independent musculoskeletal radiologist. MRI were performed at the same day at the clinical examination at longest follow-up.

Assessment of the ligament fibres continuity and bone healing status: on a sagittal T1-weigthed image, a best-fit line along the ACL is drawn (Line C) as reference and fibres and bone high signal is assessed [26](Figure 7)

ACL distal attachment on sagittal plane: on the slice where the distal ACL insertion point is better visualized (Figure 8), the anterior (point 1) and posterior (point 3) margin of the ACL are determined and the midpoint is selected (point 2). Total anterior-posterior diameter of the tibial plateau is then measured (Line A). The distance from the centre of the ACL (point 2) to the anterior tibial plateau (Line B) is divided for the AP diameter (Line A) and multiplied by 100.[27]

Tibial eminence height on coronal plane: in the coronal plane, a line is drawn from lateral anterior edge of tibial plateau to medial anterior edge (Line B). The distance from the top of the anteromedial tibial eminence to the line B is informed (Figure 9)[28]

Articular cartilage lesions were classified according to the criteria defined in the Magnetic Resonance Image Osteoarthritis of the Knee Score (MOAKS)[29] which defines Grade 0=no chondral defect; Grade 1 <10% of subregional volume loss; Grade 2 =10-75% of subregional volume loss and Grade 3 >75% of subregional volume loss (figure 10).

STATISTICAL ANALYSIS

Descriptive statistics were utilised for the purposes of this study. Mean and standard deviation was calculated for the IKDC Subjective Scores and the Lysholm Knee Score. Ratios were calculated for categorical variables (effusion, Lachman grade, Pivot shift grade, manual max ligament grade, IKDC ligament grade, range of motion grade, hop grade and overall IKDC grade). Statistical analysis was performed using IBM SPSS version 24 (New York, IBM Corp). Differences between the groups were assessed with chi square test for categorical values and one-way ANOVA for comparing means. Level of significance was considered <0.05.

Results

Between August 1989 and August 2015, 48 patients (48 knees) (21 females and 27 males) met the inclusion criteria. The mean age at time of surgery was 24.5 years with a range from 10-55 years The age distribution of subjects is detailed on Figure 11. 52% of injuries were to the left knee and 48% of injuries were to the right knee. Skiing represented the main activity responsible for injury in 18 (56%) patients, followed by soccer in 7 (22%) and rugby in 5 (16%). The remaining patients were injured in miscellaneous activities.

At time of surgery 92% of patients had an isolated injury with no meniscal damage. One patient had a partial medial meniscus tear which was repaired, another patient had an injury with prior medial meniscectomy. A partial lateral meniscectomy was performed in 2 patients. The articular cartilage was graded normal in 45 patients, minimal in 2 patients and with moderate changes in 1 patient.

Final assessment was performed at mean 98 months from surgery (range 18-260 months). Five patients had subsequent ACL rupture, including one patient who had both an ACL rupture and contralateral ACL injury, for a total of 6 further ACL injuries. The ACL ruptures occurred from a range of 7 to 144 months following surgery, and all during team ball sports. Of the remaining 43 patients, 32 (74%) completed patient reported outcomes and 29 (67%) also attended for clinical review and 22 patients (51%) had radiological review. 11 (26%) patients were lost to follow-up.

The mean Lysholm Knee Score was 92 (SD 11), the mean IKDC subjective score was 86 (SD 14. 23 patients (72%) reported that they regularly participating very strenuous or strenuous

activities. Difficulty with kneeling was reported as minimal in 9 (28%), moderate in 6 (19%) and extreme in 2 (6%).

The IKDC evaluation includes subcategories of effusion, range of motion, ligament evaluation, and overall IKDC grade. The clinical IKDC grade for each subcategory is shown in Figure 12.

Clinical ACL laxity with Lachman's test was grade 1 in 4 patients (14%), and grade 0 in 25 patients (86%). Pivot shift testing was graded as 1 in one patient (3%) and 0 in 28 patients (97%). On instrumented KT-1000 testing the mean side to side difference of manual maximum was 1.7mm (range 0-4mm), and 25 patients (86%) had <3mm. All patients achieved full flexion range and 93% full extension. Two patients had an extension deficit of 3 degrees. On functional assessment using the hop test 25 (86%) achieved 90-100% the distance of the contralateral leg, 2 patients achieved 76-89% and a further 2 patients achieved 50-75%.

On MRI scan qualitative assessment of ACL and tibial eminence, all 22 patients were found to have intact ACL with normal trajectory and fully healed bone. Seven patients (32%) were found to have high signal at the fracture site. Three patients (14%) were found to have high signal on T2 in the intra-substance of the ACL. Two with high signal at the proximal end, also were found to have grade 1 MOAKS in the femoral compartment. One patient had a high signal at the distal insertion of the ACL without arthritic changes. The height of the medial and lateral tibial eminence was also assessed. The average medial tibial eminence height was 9.2mm (range 6.3mm-1.31cm) and the lateral tibial eminence height was an average of 6.7mm (range 0.38mm-0.97mm). On sagittal MRI view, the centre of the distal attachment of the ACL in proportion to the width of the tibial plateau was 46%.

MRI Osteoarthritis Knee Score (MOAKS) classification is shown in Table 1. 18 patients (82%) had no evidence of chondral loss in the medial compartment, and 16 patients (73%) had no evidence of osteoarthritis in the lateral compartment.

There were 8 patients in total who scored MOAKS 1 or 2 for one or more compartment of the knee with partial thickness loss. Of these patients, one patient was found to have cartilage loss to both femoral condyles and the lateral tibial plateau. It is noted that she was 52 years-old at time of injury and 57 years-old at follow up. Another patient with bi-compartmental disease was 64 years-old at follow up. Two patients with evidence of degeneration were teenagers at time of injury (15 and 17 years-old) both had evidence of grade 1 on the lateral femoral condyle at follow up at age 19 and 21. One had documented lateral meniscal tear at time of injury, this was not deemed repairable intra-operatively. Detailed functional and radiological scores according to age group are shown on table 2.

Discussion

The results of this study suggest that an excellent midterm outcome can be achieved with ARIF of ACL avulsion fractures with K-wire fixation. In our study five patients (10.4%), had a repeat injury to the ACL. The reported re-rupture rate for ACL reconstruction in adults ranges from 7 % at 5 years[30, 31] to 12% at 15 years[32]. This suggests that the re-injury rate following K-wire fixation of the tibial eminence is in keeping with re-injury rates after ACL reconstruction in adult population.

Demographic distribution and activity related to the mechanism of injury in our population was found to be different from a population with mid-substance ACL tear. In our study, skiing represented the main activity responsible for injury in 56% of patients, followed by soccer in 22% and rugby in 16%, the remaining patients were injured in miscellaneous activities. A typical mechanism of injury in a young population with ACL mid-substance rupture is rugby (32%) followed by soccer (16%) with skiing only the fifth most common activity (7%)[33]. In children, ligamentous structures are stronger than their associated physeal insertion sites, making them prone to avulsion fracture injuries. However, our sample had average age of 24.5 years at time of surgery with maximum of 55 years. Thus, it may be that a different mechanism of injury could predispose to tibial eminence avulsion fractures rather than mid-substance ACL ruptures in adults. ACL ruptures in adults are most commonly due to a non-contact pivot mechanism with the knee partially flexed and the foot planted on the ground or by hyperextension of the knee with a valgus or rotational force[34]. It has been suggested that, tibial eminence avulsion fractures are more likely to occur when the knee loading rates are slower which may be the case in recreational skiers[35, 36].

It is generally accepted that tibial eminence avulsion injuries are more common in children[8]. In our study the mean age of injury was 24.5 years with several patients in their late 40s and early 50s. Our practice is an adult referral centre and thus this population is reflected in our data. The majority of research on this topic is performed on the paediatric population and reports good outcomes for children [8, 9, 26]. There is evidence that outcomes traditionally are not as reliable in adults. One study reported poor outcomes after performing arthroscopic fixation of tibial eminence avulsion fractures with suture in adults. Although the repair was successful in regards to the bony union and restoring ACL stability, there was significantly reduce range of motion at follow up, with one patient having a 20-degree fixed flexion contracture at seven months [37]. Similarly, Edmonds et. al reported that in 57 patients treated with ARIF with suture fixation or ORIF with cannulated screws, 23% did not achieve full range of motion [38]. Meyers and McKeever also documented poor results in adults with tibial avulsion injuries, with 45% reporting ongoing symptoms [7]. In our study of primarily adults, there were only two patients who did not achieve full extension, and the block was minimal at 3 degrees. These findings could be explained by the absence of anterior impingement confirmed on our MRI analysis, with an average medial tibial eminence height of 9.2mm, which is similar to normal average of 9.4mm reported by the literature[28]. It is possible that arthroscopic reduction and fixation with K-wires not only achieves anatomical reduction but is also less invasive to the knee and results in improved range of movement post-operatively. Furthermore, it allows for accelerated rehabilitation without restriction on weight bearing or range of movement. It also must be considered that avoiding further arthrotomy to remove hardware can also decrease the risk of secondary arthrofibrosis and loss of range of motion. May *et al* reported average loss of extension between 7-10 ^{o} in 22 patients treated with ARIF and screw fixation and 57% of patients underwent symptomatic hardware removal[10].

Patients without further ACL injury reported a mean IKDC score of 86 at a mean 98 months after surgery. There was one patient in particular, a triathlete, who scored particularly poorly on pain severity and swelling with activity. This patient was stable on knee examination and he did not report symptoms of instability but experienced considerable anterior knee pain with activity. It was noted, intra-operatively, that there was significant damage to the lateral tibial surface. Other patients that scored lower IKDC score (63, 64, 71) were all over the age of 49 and had associated meniscal injuries at time of surgery. Thus, the symptoms reported on patient reported outcomes may be more related to the irreparable meniscal injury or chondral loss at time of injury or degenerative changes related to age, rather than to ACL fixation.

The mean IKDC score was 86 , and on ligament laxity testing normal ligament laxity was found in 82% at mean follow-up of 98 months, confirming the clinical acceptability of laxity with this technique. Four patients (14%) had Grade 1 laxity on Lachman's test and one patient (3%) had Grade 1 laxity to the pivot shift test. The literature however has reported up-to 44% of patients having clinical instability on physical examination after ARIF with screw or suture[11], and 21% showing increased laxity with KT-1000 > 3mm [39, 40] whereas in our study, four patients (14%) had laxity grade > 3-6mm demonstrated on KT-1000. The low incidence of clinical anterior instability in our study may be the result of the anatomic reduction of the fragment and rigid fixation, allowing the bone and fibres to heal in the native ACL position. On sagittal MRI views we found the centre of the ACL at 46.01% (range 43.29-50%, SD 2.09%) mark of tibial plateau's antero-posterior diameter, while the literature has reported the mark at 46.0% for the native ACL [27]. An anterior ligament position may lead to anterior

impingement and extension deficit, while a posterior position would result in insufficient control of knee antero-posterior and rotatory instability [41]. Janarv et. al.[42] examined 61 children who had tibial avulsion fractures, either managed with cast immobilization, or open reduction with wires or sutures and found persistent laxity in 38% at 16-year follow up. Despite this all patient reported excellent functional status [42]. Literature has suggested that with an avulsion injury there is also a potential lengthening of the ACL and/or intrasubstance tear prior to fracture at the tibial eminence[8]. In our study, only 3 patients (14%) presented mid-substance ACL high signal on T2-weighted MRI scan after 8 years follow-up average, suggesting that anatomic reduction and secure fixation of the fracture site prevents lengthening or further injury.

A particular strength of this study is the midterm follow up of adult patients and the ability to assess for the development of secondary chondral wear. It is well recognized that ACL injury is a risk factor for the development of osteoarthritis [43] and early repair may prevent meniscal injury and cartilage degeneration [44]. It has been suggested that at the 10-20 year follow up post-ACL injury, 50% of patients will have evidence of osteoarthritis [45]. In our study, eight patient had evidence of chondral wear on MRI imaging, with the most common location being the lateral femoral condyle. Bruising to the lateral femoral condyle is known to be associated with ACL rupture, and may indicate the force and severity of the injury. Four of the eight patients with evidence of chondral wear were over the age of 50 at time of review, three of these patients had chondral defects noted at time of surgery. This indicates that the development of arthritis in those patients may be unlikely to be related to persistent ACL laxity or the reconstruction and that the fixation with K-wire provides acceptable stability to prevent secondary osteoarthritis. Only 3 patients (13.6%) did not have pre-operative risk

factors that could explain the development of minor partial thickness cartilage loss at final follow-up. However, as osteoarthritis is a prolonged degenerative process, further long-term follow up would be of benefit to assess for ongoing development of osteoarthritis.

The surgical technique of using K wire fixation was associated with excellent clinical outcomes in this series. However, some limitations of the surgical technique should be considered. Firstly, the need for removal of the k wire at 6 weeks after the primary procedure, however this is a non-articular day surgery procedure, associated with low morbidity. Secondly the high incidence of kneeling pain (56%), which is comparable to reported incidence after ACL reconstruction with bone patellar tendon bone[46]

Limitations of study

One limitation of this study is that the severity of the fracture based on the modified Meyers-McKeever model was not documented. Reduction of a displaced, type III fragment, is technically more difficulty and along with comminuted, type IV, fractures may be associated with worse outcomes and likelihood of developing degenerative changes. Reynders et. al found more unfavourable outcomes in regards to range of movement and need to return to theatre in patients with type III injuries compared to type II . Another limitation of the study is that 32 (74%) completed patient reported outcomes and 22 (52%) attended for clinical review which introduces the potential for transfer bias. Eleven patients were lost to follow up as they were not able to be contacted. Unfortunately, this leads to questions in their outcomes and the repeat injury rate following their management. Similarly, not all patients were available for objective follow up, several patients had moved and one patient was pregnant at the time review. Although these patients participated in subjective

measurements, the clinical data would have been improved by their involvement. As no control group was available in this study, comparison to other treatment techniques was not possible.

CONCLUSIONS

This study indicates that internal fixation with K-wires is an acceptable approach to reduce tibial eminence avulsion fractures, providing excellent clinical and radiological outcomes at a minimum of 18 month follow up.

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TABLES:

Table 1. MRI Osteoarthritis Knee Score Classification

Chondral wear MOAKS classification	Medial Compartment		Lateral Compartment	
	Femur	Tibia	Femur	Tibia
Grade 0: none	18 (82%)	22 (100%)	16 (73%)	20 (91%)
Grade 1: <10% of region of cartilage surface area	4 (18%)		4 (18%)	2 (9%)
Grade 2: 10–75% of region of cartilage surface area			2 (9%)	
Grade 3: >75% of region of cartilage surface area				

499 Table 2: Clinical and radiological outcomes according to age group.

Functional and Clinical Outcomes by Age				
	Age < 18 years	Age 18 – 40 years	Age ≥ 41 years	Slg
Mean follow-up (months)	90 (84)	113(59)	100(74)	.75
Overall IKDC Subjective, N	31	10	8	.27
Mean (SD)	90.5 (10.2)	85.0 (17.4)	80.6 (12.8)	
IKDC evaluation, N (%)	7	8	7	
No Effusion	7 (100%)	8 (100%)	7(100%)	.99
Grade A ligament Laxity	6 (86%)	6 (75%)	6 (86%)	.82
Grade A Range of Motion	7(100%)	7 (100%)	7 (100%)	.40
Grade A Overall IKDC	6 (86%)	5 (63%)	6 (86%)	.46
Mean Side-to-side difference on KT-1000 instrumented laxity (SD)	1.4 (1.5)	2.0 (1.0)	1.7 (1.4)	.70
Overall MOAKS score [7], N (%)	7	6	8	
Grade 0	5 (72%)	4 (67%)	4 (50%)	.76
Grade 1	1 (14%)	2 (33%)	3 (38%)	
Grade 2	1 (14%)		1 (12%)	
Grade 3				

500

501 FIGURE LEGENDS

502

503 Figure 1. Underneath the bone fragment ACL avulsion (left), the haematoma is cleared and

504 the bed of the fracture is exposed (right)

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Figure 2. the edges of the fracture are checked (left) and the anatomical reduction is achieved (right)

Figure 3. with a Drill Guide (left) the 1.4mm K-wires are drilled into the bed of the fracture (white arrows).

Figure 4. Once the anatomical reduction is confirmed, the k-wires are drilled through the fragment and bent with a needle holder (black arrow) into a hook (blue arrow) to be pulled back for rigid fixation

Figure 5. Once the K-wires are pulled back, the position and tension of the ACL is checked arthroscopically

Figure 6. Post-operative X-rays are performed to confirm reduction and K-wires position. The distal ends of the K-wires are folded close to outer tibial cortex (right).

Figure 7. *Method of assessment of the ligament fibres continuity and bone healing status:* a sagittal T1-weighted. A best-fit line along the ACL is drawn (Line C) as reference and fibres and bone high signal is assessed. Figure 8. *Method of assessment of the centre of the ACL in proportion to tibial plateau's width:* the anterior (point 1) and posterior (point 3) margin of the ACL are determined and the midpoint is selected (point 2). Total anterior-posterior diameter of the tibial plateau is then measured (Line A). The distance from the centre of the

ACL (point 2) to the anterior tibial plateau (Line B) is divided for the AP diameter (Line A) and multiplied by 100. Figure 9. *Medial and lateral tibial eminence height measurement:* In the coronal plane, a line is drawn from lateral anterior edge of tibial plateau to medial anterior edge (Line B). The distance from the top of the anteromedial tibial eminence to the line B is measured. Figure 10. *Method of assessment of chondral wear according to Magnetic Resonance Image Osteoartritis of the Knee Score* (MOAKS).

Figure 11: Distribution of subjects age at time of surgery

Figure 12. Clinical IKDC Grading at final review