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Article

Management of Juvenile Osteochondral Fractures Utilising Absorbable PLGA Implants

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Abstract: The incidence of articular injury, particularly osteochondral fractures (OCF), has seen a notable increase in recent years. Regardless of their location, fragments might be overlooked by plain radiographs which might lead to osteoarthritis in the long run. Diagnostic imaging has a pivotal role in the assessment and classification of the fracture severity, as well as the presence of any associated dislocations. These fractures require surgical intervention for the restoration of joint function and the reduction of long-term complications. The paper aims to present the surgical correction and post-operative treatment of osteochondral fractures with absorbable implants in three children. Affected areas are discussed as follows: lateral condyle of the femur, patella, and radial head. Utilising absorbable implants for the management of OCFs provides numerous advantages, including the elimination of the need for reanaesthesia and reoperation, reducing complications, and enabling early rehabilitation. This approach also minimises the period of hospitalisation and proved effective in pediatric OCF treatment.

Keywords: osteochondral fracture; absorbable; PLGA; osteosynthesis; articular fracture; OCF; articular congruency

1. Introduction

Juvenile osteochondral fractures (OCF) represent around 1-10% of fractures and their incidence is on the rise [1,2]. This condition is portrayed by the separation of subchondral bone and the articular cartilage from the articular surface, it may only involve the articular cartilage in which case it is known as a chondral fracture. OCFs have a higher incidence in boys, with a prevalence of 2-4 times greater, and it is most frequently observed between the ages of 10-20 with a prevalence ranging from 8-30 per 100,000 cases [1–3]. The condition usually affects young athletes or children who lead an active lifestyle. Typically, OCFs arise due to traumatic events or rotational torsion of the joint and present acutely. Most commonly these are the result of low-energy traumas or sports injuries [2–6]. The existing literature primarily emphasises on chronic conditions, specifically osteochondritis dissecans (OCD) or osteochondral lesions that develop over time. OCD was initially documented by Konig in 1887, addressing the presence of loose fragments within the knee joint [7–10]. At first, thought to occur due to significant trauma, repetitive microtrauma or spontaneous necrosis. However, nowadays the term refers to an area of necrosis of the subchondral bone, which may or may not be separated from the articular surface[7–10]. In this report, we will concentrate on OCFs in an acute setting.

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Osteochondral lesions are associated with joint instability, resulting in abnormal motion yielding rotational, impaction, or shearing forces [1,3,4,11]. They are also often associated with sprains and dislocations, frequently in the elbow, ankle, knee - femoral condyles and patella - and hip joints [11]. At the knee joint, anterior cruciate ligament (ACL) injuries account for less than 1% of cases, however, it was found that the incidence of OCFs might be as high as 80% in the case of ACL injuries [1,11–13]. This is attributed to the valgus stress which results in shearing forces yielding damage to the cartilage of the femoral condyles[1,11]. The incidence of OCFs was found to be 70% in cases of patellar dislocation. As the patella shifts laterally, shearing forces act on the medial patellar facet and the lateral femoral condyle. MRI studies have estimated the incidence of OCFs in case of lateral dislocations to be between 40-78% [11,14–19]. Diagnosis remains challenging, even with a comprehensive physical exam and X-ray imaging, as symptoms are often concealed by damage to local tissue and lack specificity. Pain is portrayed to be the predominant symptom, which intensifies during or after weight bearing or activities. Mechanical symptoms, such as locking or catching, are typically induced by loose fragments within the joint space. Swelling and a reduced range of motion (ROM) are typical signs. In skeletally immature patients, the presence of hemarthrosis is highly indicative of OCF. However, given the potential for acute disability due to concomitant ligamentous injury, minor pathologies or more severe injuries, a thorough diagnostic evaluation is imperative [1,11,13,14,18].

Imaging serves several critical purposes, including confirming clinical suspicion, assessing the extent of articular surface damage, detecting instability or dislocations, and monitoring disease progression [1,11,18]. Following acute joint trauma, the standard examination includes plain radiographs. However, identifying OCFs might be difficult to identify as small bony fragments cannot be visualised, as opposed to a large piece of detached articular cartilage. Features indicative of OCFs on plain radiographs include irregular bony contours, fragmentation, or a thin piece of radiodense subchondral bone. According to the literature, the sensitivity of X-rays for diagnosis of OCFs is between 32-69%, depending on the location. For instance, OCFs affecting the talus can be diagnosed with X-ray with 69% accuracy, while OCFs of the knee and hip reach only 32%, as demonstrated and proven by McCarthy et al [1,20,21]. Therefore, in acute settings, radiographs should be extensively and thoroughly searched for OCFs. Awareness should be given to prevalent locations of the lesions such as the talar dome or the lateral recess in case of patellofemoral injuries [3,14,21].

In cases where fractures affect the articular surfaces alternative imaging modalities are recommended, as well as for surgical planning. Computed tomography (CT) and magnetic resonance imaging (MRI) which are superior to plain radiographs for the detection of OCFs. CT is particularly effective in identifying small osteochondral fragments and thin bony plates with high-resolution images. However, it lacks the capability to depict bone marrow oedema. As an addition, CT angiography can reveal small chondral pieces as well. MRI is also able to detect chondral injuries with high sensitivity and specificity, depending on the region, of about 75-93% [22–25]. A study observed and noted that the sensitivity of MRI is slightly higher than that of CT, but this difference is not statistically significant. A potential advantage of MR imaging is that it can detect other soft tissue abnormalities and injuries which are often associated with OCFs. This can be particularly beneficial in cases concerning sprains and ligament or tendon abnormalities which may contribute to continued instability and pain [1,22–25]. MRI findings indicative of lesion instability include the presence of fluid signals between the fragment and its origin. Other indications of fragment instability encompass the collapse of the articular surface, extensive bone marrow oedema and cystic changes [1,21–24,26]. Contrast material, when positioned between the fragment and the subchondral bone, can also serve as an indicator of instability, detachment or dislocation. Consequently, both CT and MR arthrography are sufficient to assess the instability of the fracture and to achieve accurate staging [11,22–25,27,28].

The staging system, for osteochondral lesions, can be based on various imaging modalities, including X-ray (Berndt and Harty), CT (Ferkel) MRI (Happle) or arthroscopic (Cheng-Ferkel) in cases affecting the talus [23,29–33]. Nevertheless, depending on the size and location of the fragment

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and the amount of bone involvement, radiographs might not be able to show loose bodies. CT and MRI attempt to grade the stability and severity of the injury and are utilised further for surgical planning. A summary of these assessments can be seen below:

A. **Stage I**:
   a. Injury limited to articular cartilage
   b. Subchondral Edema on MRI
   c. X-ray: Negative
B. **Stage II**:
   a. Cartilage damage with subchondral fracture without detachment
   b. Thin Sclerotic Margin
   c. X-ray: Negative or slight sclerosis
   d. Subtypes:
      1. Type A: Cystic on CT and Edema on MRI
      2. Type B: Non-displaced and incompletely undercut by fluid (MRI) and lucency (CT) with an open connection to the articular cartilage.
C. **Stage III**:
   a. Detached, Non-Displaced
   b. MRI: Rim-sign - high signal around fragment
   c. X-ray: Lucency between fragment and normal bone.
D. **Stage IV**:
   a. Osteochondral fragment is displaced
   b. Joint effusion
   c. X-ray: Loose body, lucency
E. **Stage V**:
   a. Subchondral Cyst formation
   b. Secondary degenerative changes
   c. X-ray: Secondary Osteoarthritis

As the inherent capacity of the articular cartilage for self-repair is limited, it is imperative to ensure appropriate and timely management to prevent the development of secondary osteoarthritis. Embedded within the extracellular matrix, chondrocytes make up about 1% of the cartilage volume [34–36]. Primary components of the matrix include collagen, water and proteoglycans. Type II collagen forms a dense network of fibres which anchor proteoglycans in place. Proteoglycans constitute 5-10% of the matrix and are formed by a protein core with attached glycosaminoglycan chains [11,34–37]. Three principal forms are dermatin sulfate, chondroitin sulfate, and keratin sulfate. Tthese molecules serve to provide structural rigidity to the cartilage through the following mechanism:

1)Hydrophilic nature, which pulls in water

2)Strong negative charge, yielding the Donnan Osmotic Effect

3)Swelling pressure provided by dense structure within the matrix which results in strong repulsive forces [11,34,36].

Hyaluronate, another glycosaminoglycan, acts as an anchor, binding proteoglycans concurrently as hyaluronic acid. Chondrocytes, responsible for extracellular matrix production, are stimulated by mechanical load. However, their ability to divide diminishes past skeletal maturity and their numbers are downsized with age [36,38].

The report aims to describe the diagnosis, management and rehabilitation of osteochondral fractures utilising bioabsorbable PLGA implants, without the need for a second surgery. The paper aspires to add to the literature as there is little written about the diagnosis and treatment of OCFs in acute settings. Affected areas are discussed as follows: lateral condyle of the femur, patella, and radial head.

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2. Materials and Methods

2.1. PLGA Implants:

Biodegradable polymers were developed in the past decades for medical purposes, such as poly-glycolic acid (PGA) and poly-lactic acid (PLA) [38–40]. These degradable polyesters derive from monomers known as lactide and glycolide [41–43]. The newer generation of absorbable implants are made from PLGA: Poly L-lactide-co-glycolic acid. This biocompatible polymer can be sterilised by gamma radiation, which provides sterility and reduces the molecular weight of the implant. PLGA offers a distinct advantage for controlled bioabsorption of the implants over a span of two years. The oriented PLGA's structure prevents premature breakage and the formation of sizable, jagged or sharp-edged fragments. In vivo, degradation gives rise to minute angular or spherical particles, which slowly disappear along with a mild inflammatory reaction. The speed of degradation depends on the size of the implant and its molecular properties - primarily depending on the ratio of copolymers within the implant [40–44]. The copolymerisation addresses the issue of PGA degrading too rapidly and PLA too slowly.

Degradation primarily occurs through hydrolysis. Secondarily, non-specific enzyme pathways also contribute to the bioabsorption process, albeit to a lesser degree. Absorption takes place via hydrolysis, giving rise to intermediary products such as glycolic acid and lactic acid. Subsequently, these intermediary products are then metabolised by the body to produce carbon dioxide and water, which are exhaled and excreted [40–44]. Prior to application, the implant exhibits visual transparency and slight malleability. From the point of implantation up to the sixth month, hydrolysis initiates, which can be seen as a decline in molecular weight and strength over time. In vitro, the appearance transitions from transparent to whitish during hydrolysis, signifying proper degradation. Following the initial six months, the implant retains its solidity; however, fragments can be broken off with substantial force. In vivo, a fortnight after being implanted into rabbit cranium, histological analysis reveals modest microvascularisation, along with fibroblast and osteoblast activity at the perimeters. By the 24th week, implants are predominantly fragmented, accompanied by notable osteoblast activity in the vicinity and macrophages in the surrounding area [38–40,45]. The implants maintain their mechanical strength and properties for a duration of at least eight weeks and eventually undergo complete absorption in about two years [38,41,42,44].An attribute of these implants, that makes them exceptionally suitable for clinical scenarios, is their ability to expand in diameter and contract in length by approximately 1-2% during the initial postoperative weeks. These effects stem from water absorption and structural relaxation of the molecular arrangement. Thanks to these dimensional alterations, the implant will be locked in place effectively. These characteristics provide intimate contact and firm compression of the fracture line [38,40,41,43,44]. A disadvantage of PLGA implants without tricalcium-phosphate tips (TCP), is that they are nearly invisible on X-ray. However, they are compatible with MR imaging.

2.2. Surgical Methods:

The clinical application of the technique was accepted and permitted in 2019 by our medical review board, the Hungarian Pediatric Trauma Committee, and the Hungarian Pediatric Surgery Committee. The work was performed in Pécs and Budapest at the Surgical Division, Department of Paediatrics, Medical School, University of Pécs, 7 József Attila Street, Pécs, H7623, Hungary and at the Department of Paediatric Traumatology, Péterfy Hospital, Manninger Jenő National Trauma Center, 1081, 17 Fiumei Street, Budapest, Hungary.

Prior to undergoing general anaesthesia, all patients received antibiotic prophylaxis (Cefazolin). All operations took place in exsanguinated conditions with the patient in a supine position and all patients received postoperative anticoagulant therapy (Clexane), as is used routinely. In all cases, implants used were produced by Bioretec, namely ActivaNail™. The application of these implants requires drilling and guide-wire positioning marking the appropriate position for the implants. The implant is then removed from its container and inserted into the hole with the applicator, which is

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designed to sink the nail 1-2 mm below the cortical surface [46]. Sinking the nail is of utmost importance to avoid irritation of the surrounding tissue and to preserve functionality.

First patient: A nine-year-old girl injured her knee during a careless step, resulting in a sprain. The left knee was slightly swollen, and the patient complained about pain, but other pathologies could not be identified with the physical examination. Therefore, an X-ray was requested. Results revealed an approximately 8 mm large broken piece of the femur's lateral condyle, positioned at the border of the lateral recess (Figure 1).

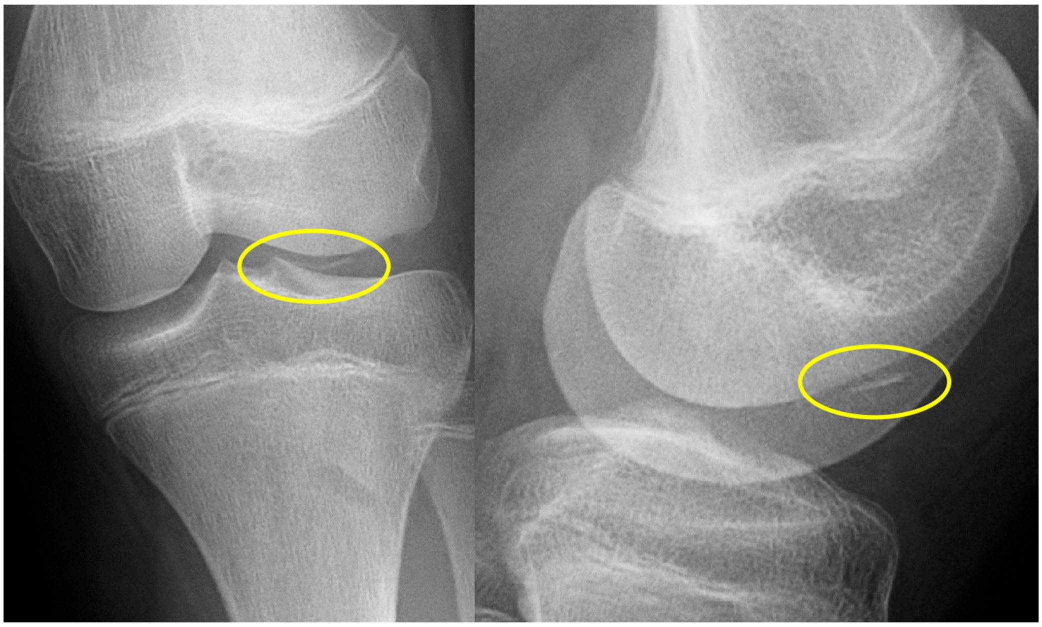

Figure 1. Preoperative X-ray shows the osteochondral fragment of the lateral condyle of the femur.

After arthroscopy, a lateral arthrotomy was performed, and the fragment was repositioned with the aid of K-wires. The piece was stabilised to its proper position using three 1.5x15 mm resorbable nails. After applying a drain, the joint cap and subcutaneous layers were reconstructed (Figure 2).

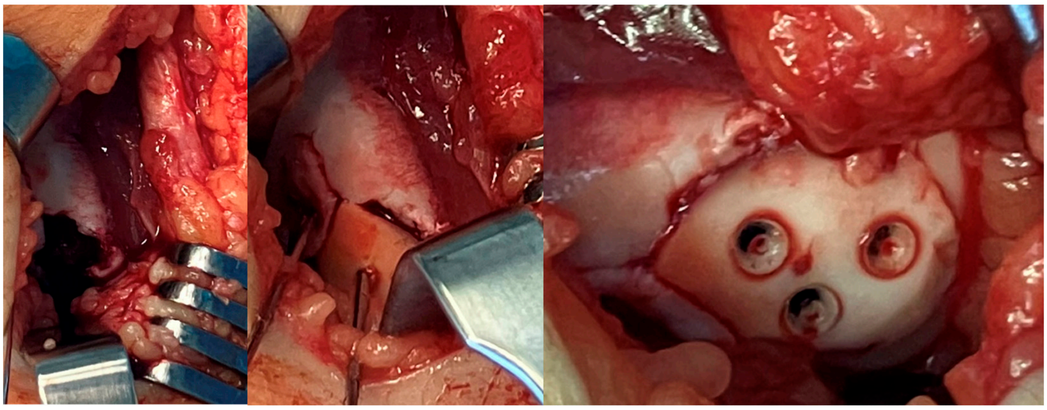

Figure 2. Intraoperative pictures showing the defect (a), fixation of the fragment with K-wires (b), and the stabilised fragment with absorbable nails.

The following day, the drain was removed, and physiotherapy was started immediately after the operation by CPM. A brace was worn for six weeks with no body-weight bearing initially, which increased throughout the recovery period gradually. Control examinations revealed good functional results, and the X-ray showed the ideal position of the fragment. Control MRI was performed one year after surgery (Figure 3).

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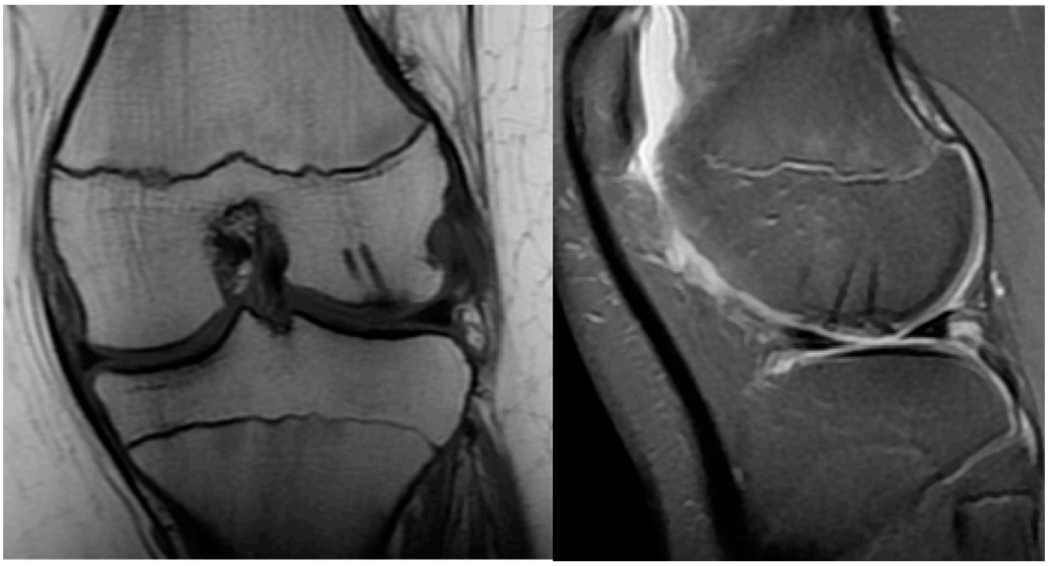

Figure 3. Control MRI one year after surgery. The remainder of the absorbable nails can be seen inside the femoral condyle.

Second patient: A fifteen-year-old boy was admitted after he suffered a fall. The patient complained of pain and difficulty with weight-bearing. Knee extension was painful during the physical examination and a hematoma could be felt in the suprapatellar bursa. Primary X-rays showed the osteochondral fracture of the patella, which was confirmed by CT imaging, with the broken piece in the lateral recess (Figure 4).

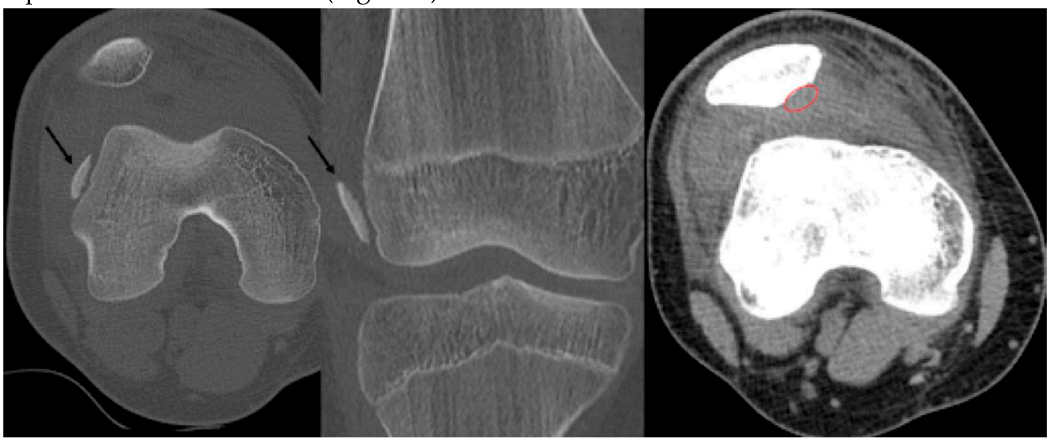

Figure 4. CT images of the knee, showing the fragment (black arrow) and the location of the missing piece (red circle).

An arthroscopy of the right knee was performed to identify the missing piece and exclude any associated injuries. After medial arthrotomy, the patella was repositioned, and the broken piece became visible on the lateral aspect of the knee joint, in close relationship to the tibial condyle. The fragment and patellar defect were covered by fibrin, so the coagulation was removed to yield a fresh spongious surface.

The approximately 2x2 cm piece was repositioned with three 1.5 mm K-wires - a proximal, a distal, and a central slightly medially - drilled until the opposing cortical surface. After measurements, three 1.5 mm in thickness and 15 mm in length absorbable nails were applied successfully for desired stability (Figure 5). The capsule and the medial patellofemoral ligament were reconstructed before complete closure. Swathing and elastic bandaging took place before the application of a brace, in a 15-degree position.

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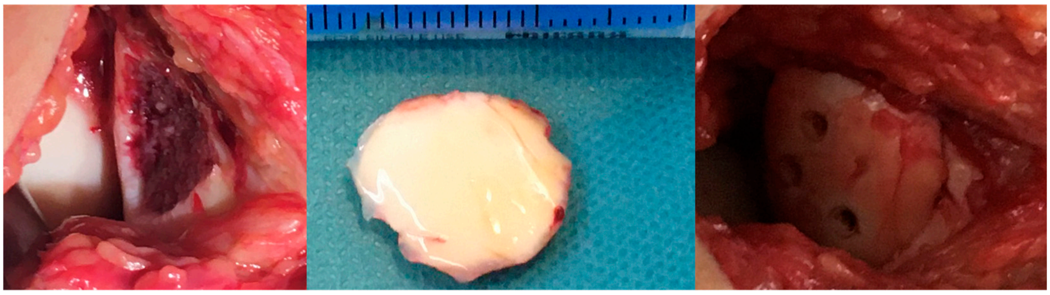

Figure 5. Intraoperative pictures showing the defect of the patella before reduction and fixation of the osteochondral fragment (a). The fragment can be seen after removal and cleaning (b) and after stabilisation with absorbable implants (c).

The patient was hospitalised for two days and received physiotherapy. Four weeks after the operation, the weight-bearing capacity was near 100%. The patient could walk without a limp with full extension and flexion. A control X-ray was performed (Figure 6).

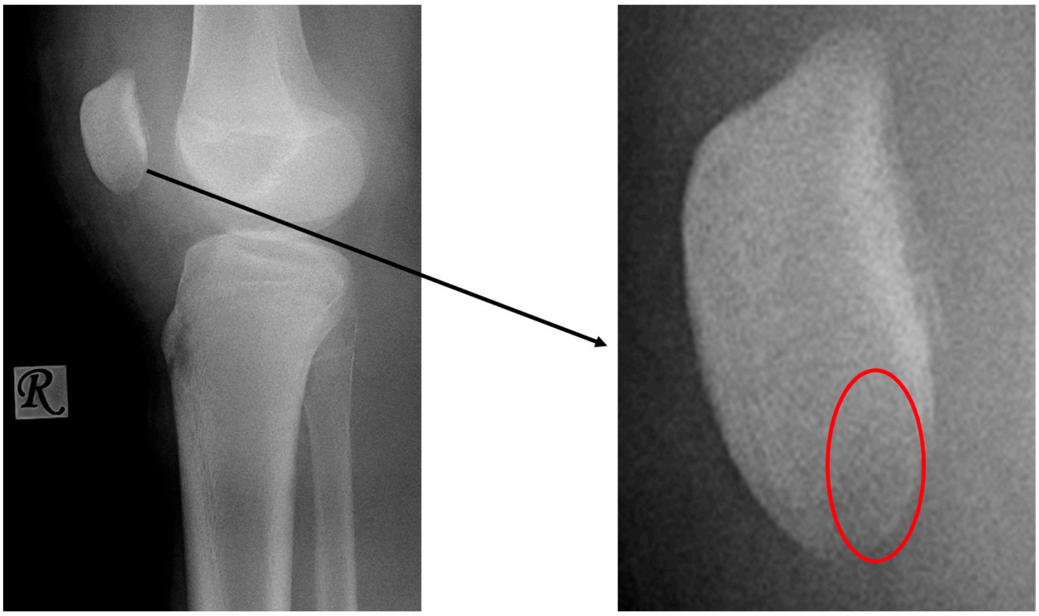

Figure 6. Postoperative X-ray presents the proper position of the osteochondral fragment of the patella.

Third patient: A 17-year-old patient was admitted following a snowboarding injury, affecting her elbow. Although the patient reported pain and the swelling of the proximal forearm was visible upon inspection, the Moberg test was negative. The fracture of the radial head was confirmed by the initial X-ray, after which a CT was performed, which established the Mason type II fracture and dislocation of the radial head (Figure 7).

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Figure 7. The CT images confirm the Mason type II fracture and dislocation of the radial head.

After disinfection and draping, a 4 cm incision was made radially just above the radial head. The fracture line could be seen clearly by passing the fascia and the joint cap, while the radial head fragment could be seen in a lateralised position. The fragment was temporarily placed into a wet dressing and repositioned using three 1.5 mm K-wires and then stabilised with four absorbable nails (Figure 8).

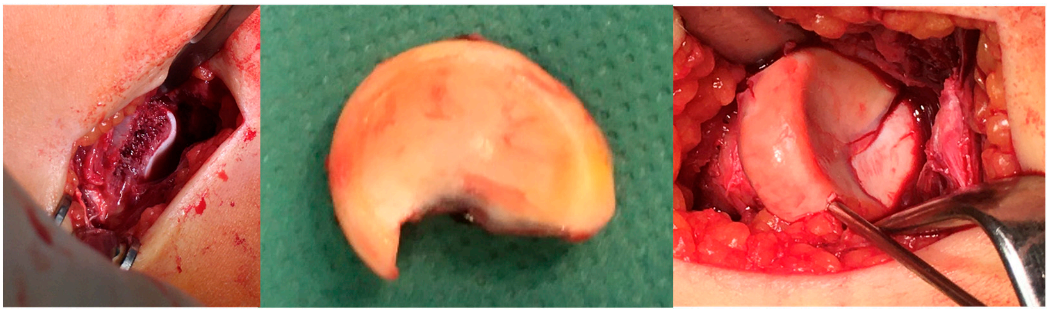

Figure 8. Intraoperative images of the defect (a), the fragment (b) and the results of the correction (c).

The stability was confirmed by pronation and supination without dislocation after which the joint cap was reconstructed. A 90° dorsal cast was applied and the patient was discharged after one day. Received physiotherapy in the hospital and continued exercise training at home. A month after surgery, follow-up X-rays demonstrated the correct positioning of the radial head without any articular surface incongruence (Figure 9).

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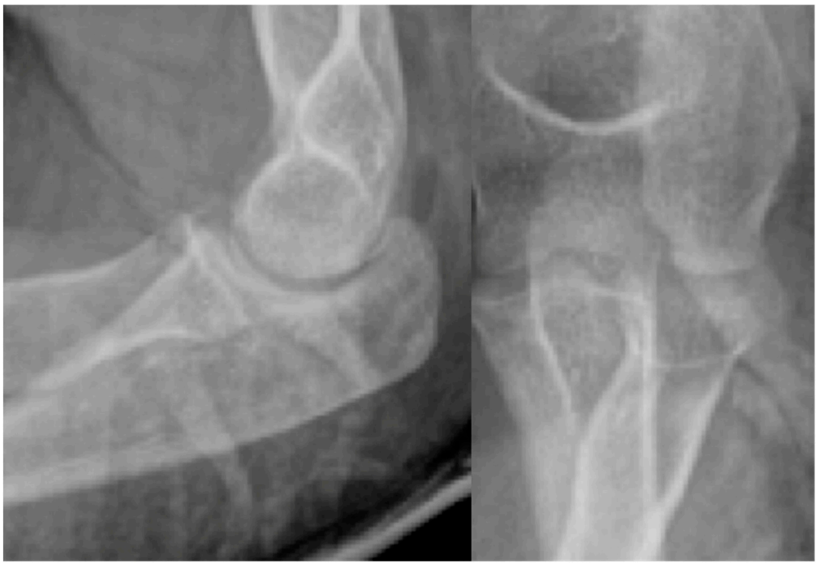

Figure 9. Postoperative X-ray showing the perfect position of the radial head (c). .

Six weeks later, the control X-ray revealed no signs of complications; however, the affected side was missing 15 degrees of extension at this point (Figure 10). With further physiotherapy over time, the extension was bettered and the joint movements were not limited in any way and were closely identical to the opposing side by week 12.

Figure 10. Post-op image six weeks after surgery describing the 15-degree shortcoming of the affected side during extension.

4. Discussion

Presently, the existing literature indicates that OCFs have a higher incidence in children, who live active lifestyles, such as sports, dancing, or gymnastics. Research has shown that the pediatric age group is more susceptible for OCFs due to their lower resistance to sheer forces [1,13,47,48]. As previously discussed, diagnosis can be challenging given the difficulty of visualising small pieces on plain radiographs, presence of non-specific symptoms, and limited access to diagnostic tools. It is worth noting once more, that symptoms such as pain, swelling, locking and catching, and hemarthrosis are common and are suggested to be positively suspicious of articular surface injury [1]. A straightforward diagnostic algorithm was proposed in a 2015 paper authored by Pedersen et al [11]. We recommend that this algorithm is adequate and can serve as a useful template when deciding on diagnostic evaluation of the injury. The importance of high risk signs should not be neglected and they should warrant further evaluation for fitting diagnosis and treatment.

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Traditionally, the management of fractures affecting the articular surface neccesitates osteosynthesis of the fragment with various approaches. Typically, OCFs are to be treated operatively [1,48]. The literature discusses the utilisation of several fixation methods, such as the use of Herbert screws, compression or headless compression screws, magnesium screws, meniscus arrows, bone tunnel sutures, or bioabsorbable screws and pins [1,15]. In specific cases, when the fragment is too small for fixation (usually less than 5-10 mm) or if the fixation is otherwise contraindicated by degenerative conditions, it might be necessary to remove the fragment and address the defect with cartilage restorative methods. Restorative options encompass debridement, autologous chondrocyte implantation, mosaicplasty, allografts, or the use of biomaterials [1,11,15].

The authors would like to emphasize that in children, the appropriate management strategy for OCFs is contingent on various factors, including the placement of the lesion within the joint, the age of the child, their growth stage, size, and the specific anatomical site of the defect will all dictate the proper management strategy. This implies that a 5 mm defect might neccessitate different management strategies based on wether it is located in the knee (as it is a weight-bearing surface) in contrast to the elbow. Additionally, a 5 mm defect in a small child holds greater significance compared to an almost skeletally mature patient. In these cases, fragments should be reattached to achieve optimal outcomes.

Delayed or inappropriate treatment may significantly impact the quality of life. The primary objectives are to achieve a stable fixation, restore articular congruity and joint stability, and allow for early passive motion. Complications arising from implant protrusion or migration can result in injury of the surrounding meniscus, bone or cartilage. Malunion, nonunion, inflammation, infection, pain and functional deterioration can all occur in case of malposition and are more frequent with metal implants [1,11,47,48]. Metal implants might provoke more irritation or hardware reactions such as inflammation or foreign body reactions. Biodegradable instruments were groundbreaking in this aspect as they are associated with fewer complications [46,49,50]. Consistently with other research findings, the size of the bony fragment should define the fixation tool (screw, pin, nail, adhesives) and the size of the chondral part is critical to determine the treatment method. Considering the enhanced healing capacity of the adolescent population, we suggest the operative treatment of OCFs if weight-bearing surfaces are affected, mechanical symptoms are present, diagnostic evidence can be found and the fragment is sufficient in size [29,30]. We suggest that operative treatment takes place promptly for OCFs, with particular focus on restoring articular surface congruency. It is advisable to clean the fragments of fibrin-coagulum using a curette and that smooth edges are created to ensure proper attachement with the underlying fresh spongious surface, if feasible, without gaps or incongruency [1,11,29,30].

Timely and appropriate treatment is vital to prevent long-term joint dysfunction, deformities and a restricted range of motion. While chondral part of the fragment may potentially receive nutrients via diffusion from the synovium, however the same cannot be said about the bony element, which exhibits a reduced ability to heal over time [1,30]. Nevertheless, it will retain its role as a scaffold. Bioabsorbable implants have been recommended as a suitable treatment for OCFs by Schleter et al. and Hsu et al. among many others [1,9,51,52]. Our suggestions for the indication of absorbable implants are as follows:

1. Osteochondral or chondral fragment
2. Single, isolated body
3. Sufficient size
4. Instability, detachment or movement

The authors propose the arthroscopic removal of the fragments if:

1. Fragment is less than 5 mm
2. Bodies are multifragmented and small

In cases of pediatric intra-articular fractures, metal implants can be substituted for biodegradable implants. These implants are thought to be less detrimental to the surrounding tissues and cartilage, however, they might provide less stability [49,50]. Beneficial mechanical properties,

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which are not provided by metal implants, include the diametric expansion of the implant and longitudinal contraction. An additional advantageous attribute resides in the bending modulus, which is closer to that of bone in the case of absorbable implants, in contrast to metal implants. This characteristic safeguards the fixation from adverse effects due to stress shielding [44]. Absorbable implants are less prone to interfere with growth, promote bone remodelling and lead to fewer biochemical reactions that might harm the patients' recovery [1,11,49,51].

Rehabilitation following surgical treatment involves physiotherapy and brace use for 2-6 weeks depending on severity. Children should start rehabilitation right after surgery with the help of physiotherapeutic training [47,53–56]. We advise early mobilisation during the immediate postoperative period as well as continuous passive movement (CPM) and ROM exercises, beginning on post-op day 1 and lasting until day 21. Physiotherapy and active motion exercises began after the first week, on day 8. In the case of weight-bearing joints, we suggest that weight-bearing is limited in the beginning with a gradual increase until weeks 6-8. We suggest the return to sports activities after the 4-6th months. The utilisation of these techniques allows for proper healing and helps decrease the occurrence of postop complications [1,11].

These implants do not need to be removed and thus, require no additional operation. A second anaesthesia would increase cost and prolong the length of hospital stay. Complications arising from a second surgery are eliminated. Because of this it greatly reduces the burden on the child and healthcare provider. The overall length of hospital stay is decreased. The expenses of the healthcare provider can be reduced as there is no need for staff, operating room or materials to be used at a second surgery. The child may recover from the comfort of their home and may begin physiotherapy sooner. Nonetheless, the real incidence, prevalence and outcome of the condition cannot be found in the literature. Neither can generalised guidelines be found regarding diagnostic and treatment algorithms for OCFs. More extensive studies are needed in both, pediatric and adult populations.

5. Conclusions

With the application of absorbable implants, the need to re-anaesthetise and reoperate was eliminated; thus, the strain on the patient was significantly reduced. Furthermore, possible risks relating to the surgery are also decreased - such as infections or other complications. Patients may begin physiotherapy sooner due to the reasons mentioned above. The countersink option provides frictionless environment for healing, decreasing the chance of complications due to shear forces which are the result of protrusion or malposition.

Supplementary Materials: Information regarding the implants, their production, application, and other supporting information such as whitepapers, studies, operation videos and animations can be downloaded at: https://bioretec.com/educational-materials

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