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HIP

Avascular femoral head necrosis in young gymnasts: a pursuit of aetiology and management

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Aims

Avascular femoral head necrosis in the context of gymnastics is a rare but serious complication, appearing similar to Perthes' disease but occurring later during adolescence. Based on 3D CT animations, we propose repetitive impact between the main supplying vessels on the posterolateral femoral neck and the posterior acetabular wall in hyperextension and external rotation as a possible cause of direct vascular damage, and subsequent femoral head necrosis in three adolescent female gymnasts we are reporting on.

Methods

Outcome of hip-preserving head reduction osteotomy combined with periacetabular osteotomy was good in one and moderate in the other up to three years after surgery; based on the pronounced hip destruction, the third received initially a total hip arthroplasty.

Results

The described pathology is quite devastating, and extensive joint preserving surgery (which has been shown successful in Perthes' cases) was less successful in this patient cohort.

Conclusion

Supraselective angiography may be helpful to improve pathomechanical understanding and surgical decision making.

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Introduction

To date, cases with avascular femoral head necrosis have been reported in 13 out of 16 young gymnasts or dancers aged between ten and 15 years; however, a dark figure may be assigned to classic Perthes' disease without complete understanding of the underlying etiology. All were aged around growth plate closure and hence were older than the typical Perthes' age range.[1,2] In the absence of obvious trauma, it was speculated that repetitive mechanical impact could be the reason for vascular occlusion,[1] while less mature joints would be better protected.[2] However, a more precise pathomechanical cause was not offered.

Previous work using in vivo laser-Doppler flowmetry to study femoral head perfusion in adult hips showed decreased intracapital perfusion when contact occurred between the posterolateral femoral neck and the rim of the posterior acetabular wall, which typically occurs in full extension/external rotation.[3] These reversible changes were explained by compression of the retinacular branches of the medial femoral circumflex artery localized at the posterolateral femoral neck circumference.[4] The hypothesis for the necrosis in our three gymnasts was therefore that the vascular insult was provoked by repetitive impact to the retinacular vessels, potentially undergoing occlusion by the trauma itself or by reparative processes of the vessel wall. 3D simulation performing the potentially impinging joint positions was undertaken to study the hypothesis by using CT of the affected and unaffected hips.[5,6]

Based on the experience with classic Perthes' hips with severe head deformation,[4,7,8] a combination of head reduction

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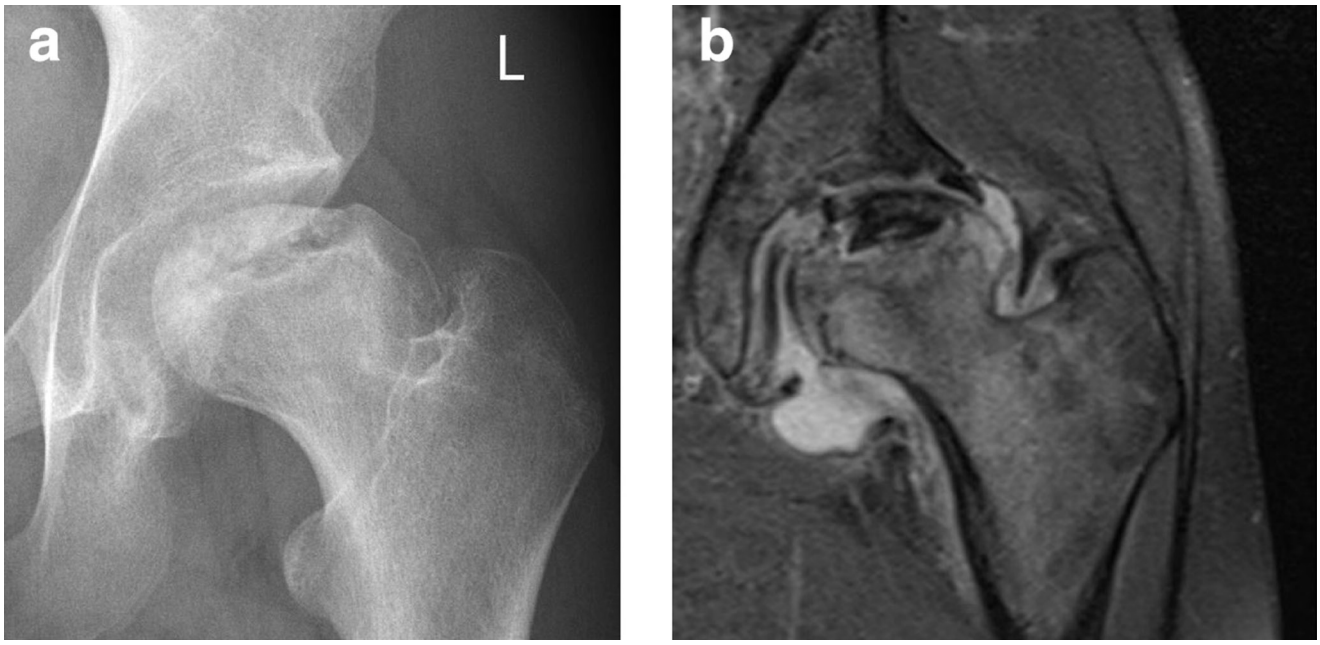

Fig. 1

Case one: a) Preoperative anteroposterior adiograph and coronal MRI of the left hip with femoral head subluxation; and b) flattening due to partial necrosis.

and periacetabular osteotomy (PAO) was used when there was a healthy lateral pillar large enough to prevent the head from further collapse after reduction.

Methods

Statement of informed consent. Consent was obtained from all patients and their parents. No ethical approval was necessary due to the use of information already obtained during previous regular follow-up controls from completely anonymized patient data without any risk of harming the patients through the use of the data.

Case one. Case one is a high level gymnast, who commenced sports at the age of six years. At age of 11 years, training amounted to 20 hours per week with additional periodical workout camps. At the age of 13 years, training had to be reduced after left hip pain, diagnosed as trochanteric bursitis. However, by the age of 14 years, training had to be completely discontinued for exacerbation of pain. MRI showed partial necrosis of the femoral head, which initiated conservative treatment with partial weightbearing on crutches, and oral intake of calcium and of Miacalcic (Novartis, Switzerland) via nasal spray. While pain and limitation of range of motion (ROM) slightly improved, the radiological appearance deteriorated over the following year with subluxation and flattening of the femoral head. Radiologically, load transmission was concentrated to the necrotic area, while the vital lateral pillar was extruded. MRI depicted the necrosis as even more pronounced, with the and the vital pillar becoming smaller in size towards the anterior border of the head (Figure 1). The parents, both medical doctors, were informed about the borderline indication, but agreed with joint preserving surgery in view of the young age of their daughter.

Computer simulation aided in planning the optimal osteotomy orientation for resection of the necrotic part of the head, sphericity and size of the "new" head, as well as preservation of the blood supply of the remaining parts of the head. Indication and amount of correction for additional PAO could also be estimated.[9]

The combined procedure was performed at age of 15 years. Capsulotomy revealed clear effusion with generalized synovitis masking eventual signs of trauma. There was no intracapsular blood and the round ligament was not disrupted. The retinacular area revealed synovial irritation. After preparation of the periosteal flap containing the lateral retinaculum, the resection of the central necrotic part of the epiphysis was guided by prefabricated templates based on the preoperative simulation.[9] Substantial parts of the necrosis had to be left on the mobile fragment to keep a sufficiently large head size. The necrotic bone at the osteotomy site was reason for a sparsely visible bleeding of the mobile fragment. The contour fit between mobile and stable part of the head was without a step when the mobile fragment was tilted into varus of about 15°. The resulting gap between the bony parts was filled with bone from the resected part. Three 3.5 mm screws allowed stable fixation. Best coverage and joint stability required additional PAO; the ischial cut was performed through the lateral approach

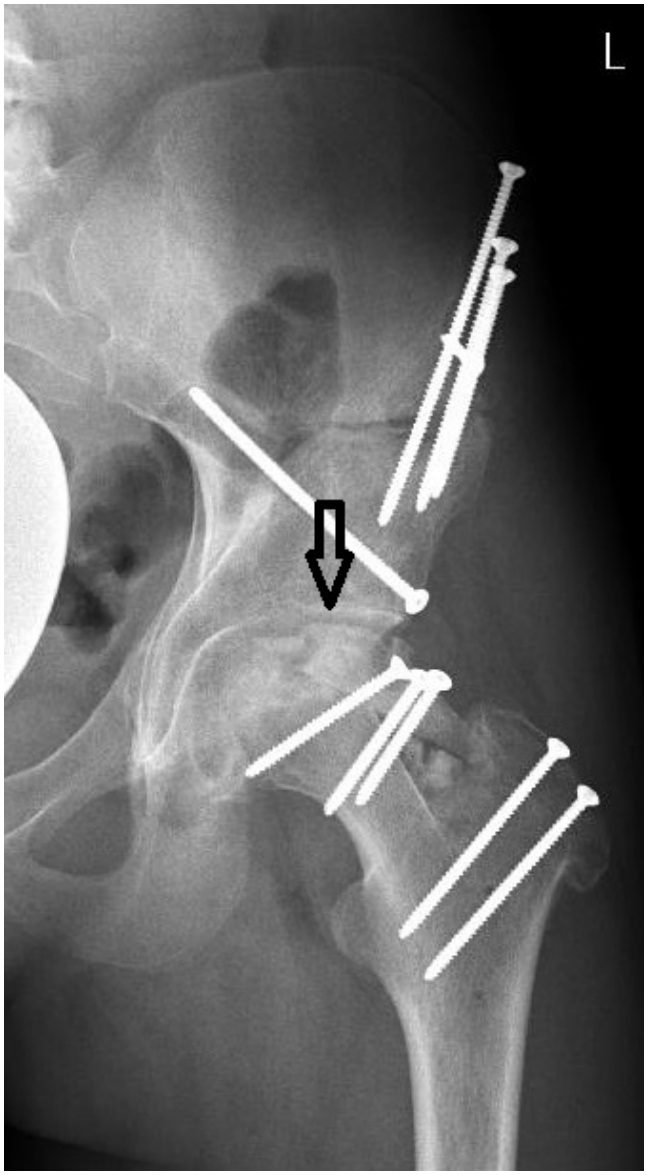

Fig. 2

Case one: Anteroposterior radiograph control of the left hip three months after periacetabular osteotomy and femoral head reduction osteotomy showing good joint congruency and containment but still visible osteotomies. Arrow points to the very small healthy part of the lateral pillar.

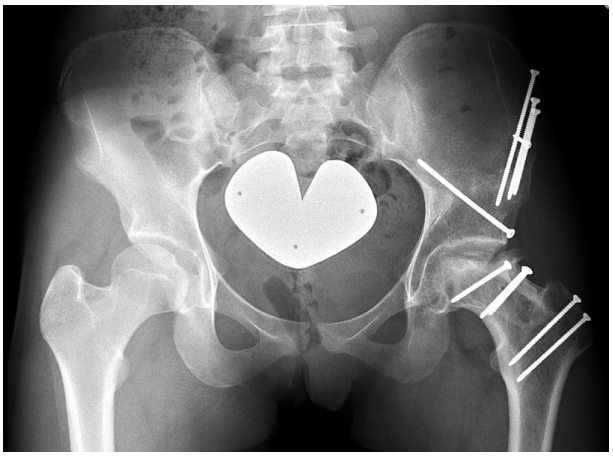

Fig. 3

Case one: Latest follow-up anteroposterior pelvic radiograph at three years after surgery showing a well centred femoral head with good coverage but partial resorption of the necrotic part of the lateral pillar and sclerotic changes of its metaphyseal part.

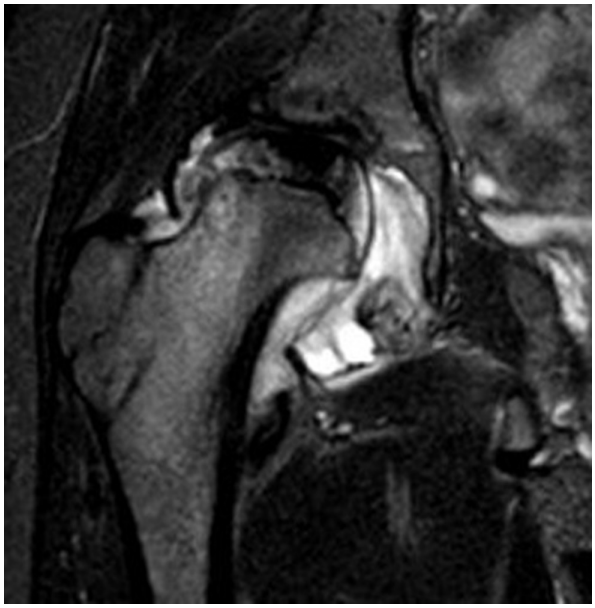

Fig. 4

Case two: Preoperative coronal pelvic MRI shows flattening of the right femoral head with central necrosis. The head is subluxed and the capsule is expanded due to joint effusion with a flattened acetabular roof.

during head reduction surgery. For the remaining osteotomies, the patient was turned into supine position. The postoperative radiography showed sufficient recentering of the head with a congruent joint space. In this projection, the vital lateral pillar (arrow) is even smaller than it was planned by the simulation, which may be caused by the new projection after additional fragment rotation (Figure 2).

Postoperative partial weightbearing had to be extended up to six months to allow ingrowth of the central bone graft. Over several months, during increased weightbearing, pain intermittently returned, but finally subsided completely. Hip flexion improved but rotation but remained markedly reduced. Radiology revealed some resorption of the necrotic part of the lateral pillar and sclerotic changes of the metaphyseal extension. However, the head remained well centred with a reasonably large joint space (Figure 3).

At three years after intervention, the patient was only mildly limited in their daily life. Professional gymnastics were given up completely, but they were again able to

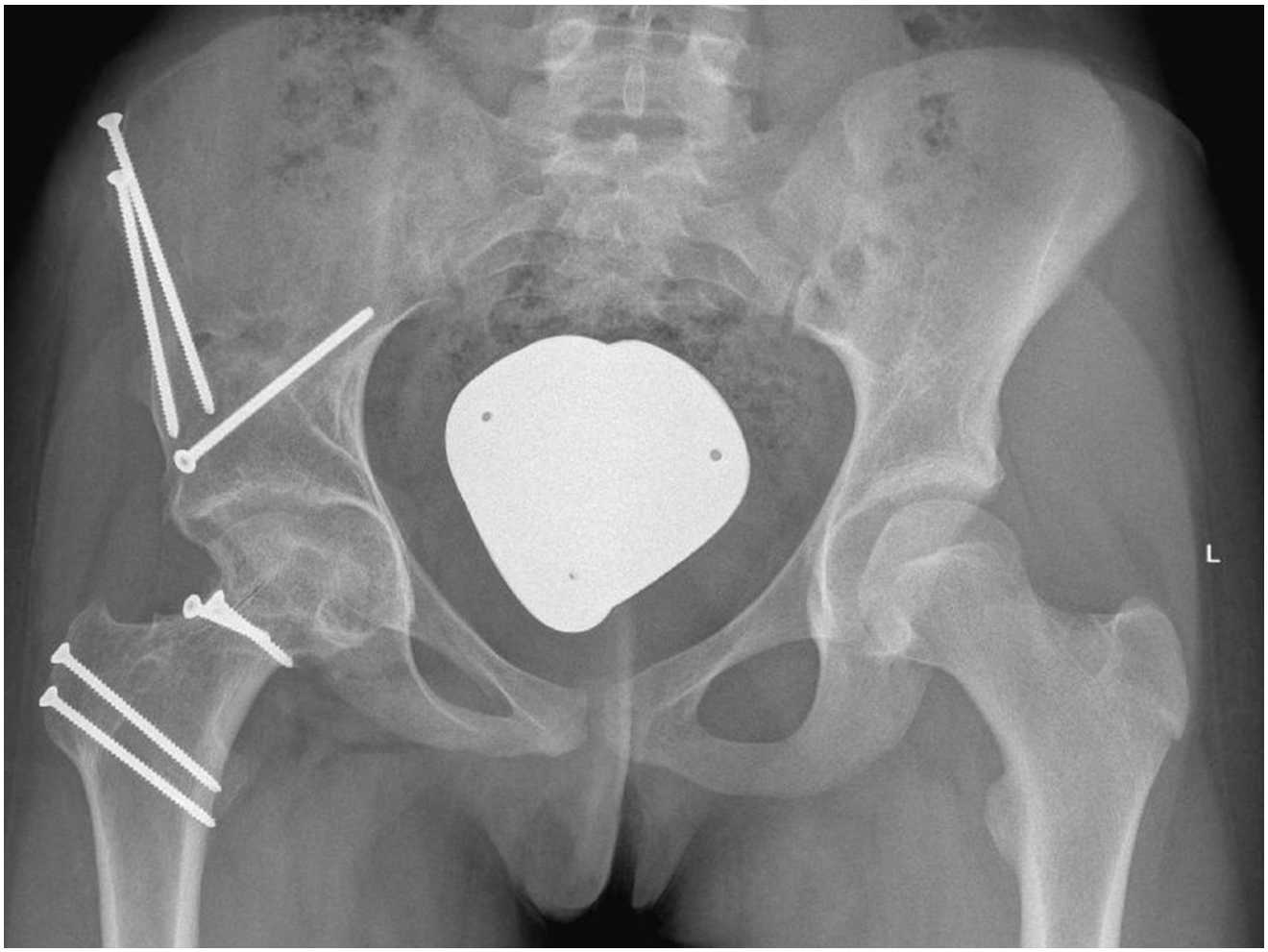

Fig. 5

Case two: Anteroposterior pelvic radiograph control 19 months after surgery showing healed osteotomies, and a well reduced, vital femoral head.

participate in recreative alpine ski activities, cardiological exercise, and weight training at the gym.

Case two. Case two covers a 12-year-old female, who performed competitive gymnastics at differing levels for several years. The patient experienced discomfort and reduced muscle force in the right hip, followed by increasing pain and limitation of ROM. Regular training was reduced stepwise from 12 hours/week to a complete stop without substantial relief. MRI three months after onset revealed flattening and subluxation of the right femoral epiphysis with central avascular necrosis; however, the vital lateral pillar had a reasonable size. An attempt to revitalize the necrotic area with stem cells was not successful. One year later, MRI revealed increased flattening of the head with adaptive flattening of the acetabular roof (Figure 4).

Clinically, the hip was held in 15° fixed adduction; any attempt to test abduction was painful. Consequently, the gait pattern was severely altered with secondary pelvic obliquity. The large lateral pillar allowed for a good indication of joint preservation using again the technique of head reduction combined with PAO after simulation of best size and optimal cutting directions for the segment resection.[4,7-9] At capsulotomy, only minor reactive synovitic changes were visible, and the retinacular area, as well as the round ligament, showed normal findings without any alterations alluding to sequelae of recent or former trauma. Using the cutting templates resulted in exact fitting cancellous bone surfaces with congruent borders. Both surfaces showed clear bleeding. Reposition of the mobile fragment resulted in a nearly spherical head. Within one year after surgery, ROM increased significantly. Flexion remained limited at about 90°, and limitation of extension was at about 5°. Internal/ external rotation was reduced by one third. Two years after surgery, the patient was pain-free. ROM was slightly improved but still not equal to the opposite side. The gait pattern was normal. Participation in non-impact sport activities, such as cycle riding, was possible from one year after surgery. Radiological follow-up showed a vital head

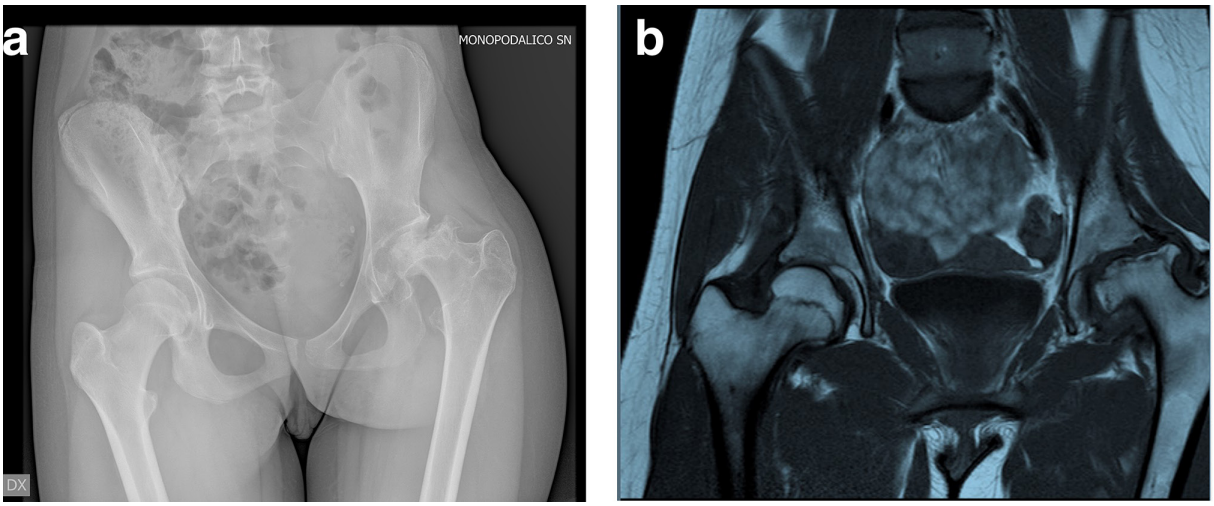

Fig. 6

Case three: a) Preoperative anteroposterior pelvic radiograph and pelvic MRI with large epiphyseal necrosis of the left femoral head, especially of the lateral pillar. Femoral head subluxation and severe hip contracture in adduction. b) MRI showing an almost total head involvement.

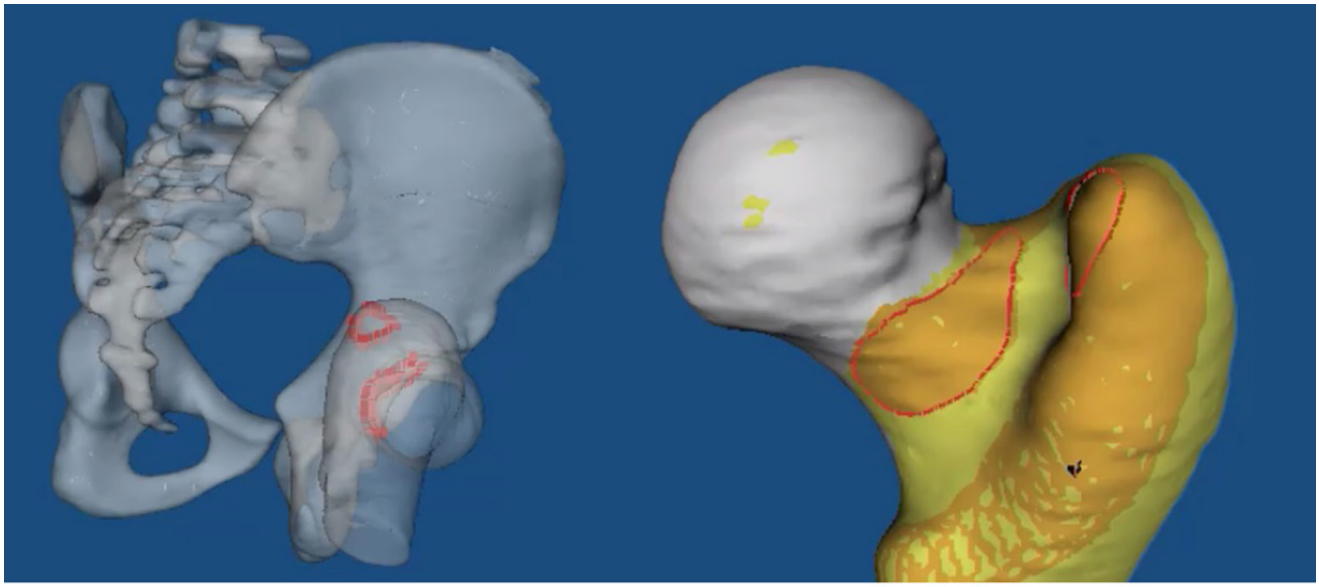

Fig. 7

Case one: 3D reconstruction and simulation of range of motion shows contact between posterosuperior neck and posterior-inferior rim when the hyperextended femur was externally rotated. The contact area on the posterior neck is coextensive with the retinaculum containing the mean blood suppliers of the femoral head.

with well healed osteotomies, a fully reduced joint with improved congruency, and a large and regular joint space (Figure 5).

Case three. Case three is a 16-year-old female gymnast, who attended dancing lessons from the age of five years. At the age of ten years, they began professional gymnastics, and performed at a national level. At the age of 15 years, the patient developed pain around the left hip. Diagnosis of a femoral head necrosis was made three months later. It was followed by a one-year period of visits to several specialists, with the patient receiving a several nonoperative recommendations, including stem cell therapy. Meanwhile, she developed severe adduction contracture and became unable to walk without crutches. Radiologically, with conventional radiograph, MRI, and CT, necrosis and collapse involved nearly the entire epiphysis and the acetabular cartilage was extensively destroyed, offering no realistic chance for improvement with joint preserving techniques (Figure 6).

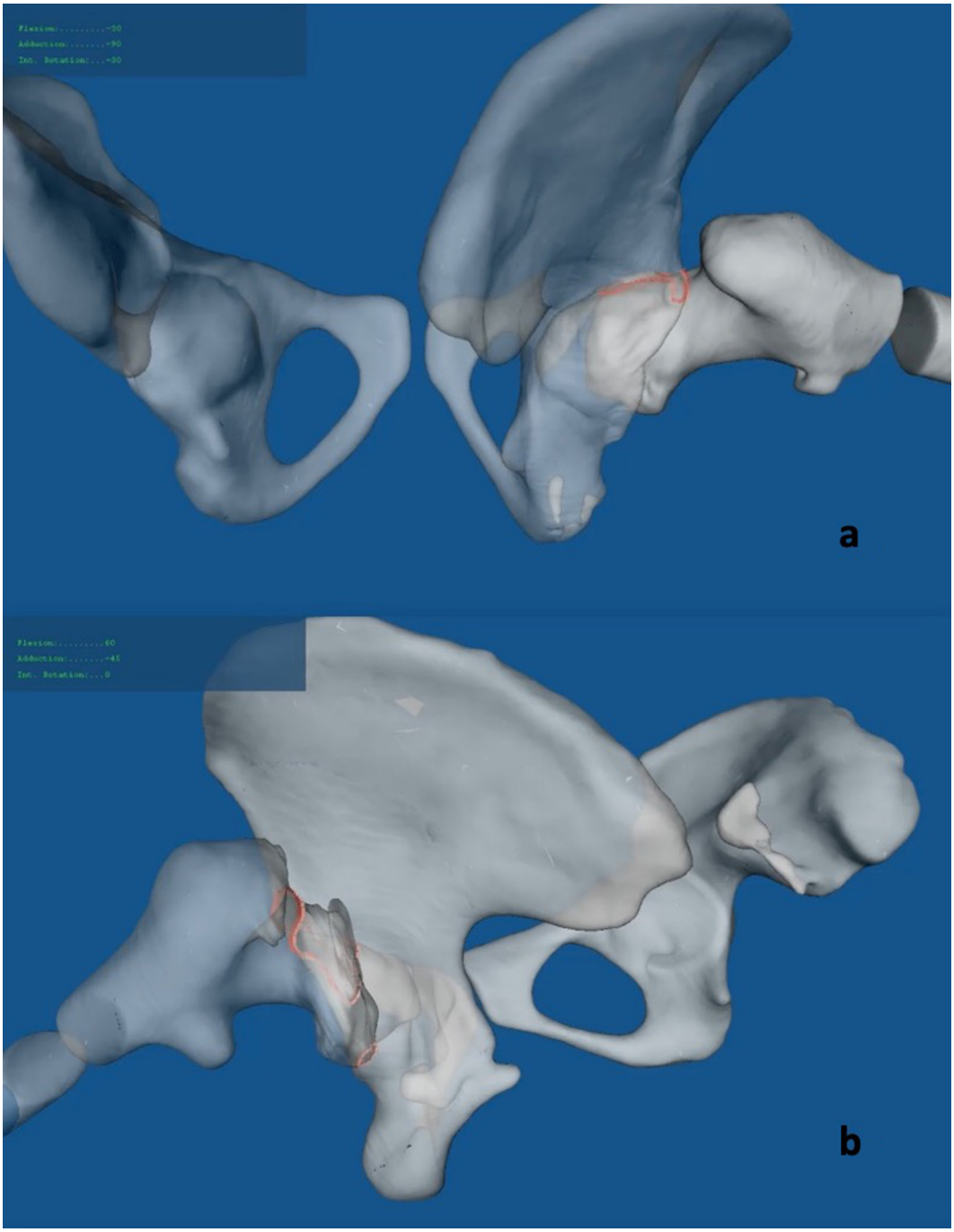

Fig. 8

Contact between the retinaculum and the acetabular rim in the affected hip during the 3D animation was seen in a) case two: 30° extension combined with 30° external rotation and approximately 90° abduction, respectively; and b) case three: 45° abduction combined with 60° flexion (men's splits).

Total hip arthroplasty was elsewhere undertaken two years after onset of symptoms. Although it allowed the patient a normal daily life within three years, there was a complete end to all gymnastic activities.

Results

None of the three gymnasts had a history of an identifiable trauma, or a family history of avascular necrosis (AVN) or Perthes' disease. The history of medication included intermittent vitamin supplements, as well as painkillers after onset of symptoms, but the use of known risk factors for

AVN, such as steroids, was denied. Laboratory control during pre-interventional evaluation showed no evidence for immunological or haematological aetiology. None of the patients were taking contraceptives or growth hormones. Hormonal status had only been tested in one of the patients during extensive preoperative check-up, and was neglected in the two others by the initially treating physician as they showed normal development and growth pattern. No suspicion of vascular disease was given, and no other known risk factors could be identified. Clinical evaluation revealed high general ROM; however, none of the patients had generalized joint hypermobility. In all patients, the radiological parameters of the unaffected hip were within normal ranges. Growth plates around the hip were still open in the two younger females. During surgery, visible pathologies could be interpreted as being related more to the necrosis than to earlier trauma.

Overall, 3D CT-based simulation of motion conducted at the healthy contralateral side showed contact between the retinaculum area of the neck and the posteroinferior acetabular rim in hyperextension and external rotation, with the pathological movement described by Nötzli et al[3] in one of the patients (Figure 7). In the other two patients, we were able to demonstrate the contact between the retinaculum and the acetabular rim in the affected hip during the 3D animation in movements also used in gymnastics, such as extension combined with external rotation and abduction respectively abduction combined with flexion. Contact increased and shear became visible when subluxation was initiated. For gymnasts, these critical positions are essential and frequently adopted poses of their regular stretching exercises (Figure 8).

Discussion

To date, trauma is the most likely etiological background of AVN in gymnasts, but pathomechanical causes remain undefined.[1,2] Femoral head necrosis in young gymnasts differs from the classic Perthes' necrosis by the age at onset. While Perthes' is seen before the age of nine years,[2] diagnosis in the published 16 cases (80% female), as well as in our three female, gymnasts, was made at an age range between 12 and 15 years. All three of our patients were small-sized, ranging in height from 142 to 153 cm, and all had a more slender posture, while most of the internationally successful gymnasts are also small-sized but rather mesomorphic, a factor which may be protective for joints against excessive load. Regular training began early in childhood by the age of five to six years, and increased over time, peaking in several hours each day at adolescence (12 to 14 years). True trauma was not recalled by all three patients. Therefore, repetitive trauma has been hypothesized, but no pathophysiological explanation could be given.[1,2] In impact sports, trauma to the physis is known to cause the development of cam deformities, but AVN has not been reported through sports, including martial arts.[10] Non-appearance at younger age was explained with the fact that a mechanical impact in these smaller patients would be not high enough.[2] Major trauma (e.g. intracapsular tamponade after (sub)luxation or undisplaced neck fracture) is rather unlikely without a history of interruption of training or some visible residuals (e.g. a broken round ligament). However, it also cannot be ruled out. On the other side, Nötzli et al[3] have shown with intraoperative laser-Doppler flowmetry in adult hips that extreme joint positions, especially external rotation in full extension, can stop the perfusion during contact of the posterior acetabular rim with the posterolateral area of the femoral neck. It is the area where the retinacular vessels of the medial femoral circumflex artery are located, the main blood supplier of the femoral head.[11] It seemed naturally to adopt the findings and see it as potential cause in our patients, all the more as they practice such extreme positions repeatedly, often with high velocity or long duration.

Collision simulation using pre-interventional CT scans hip confirmed in all three cases the potential of such an impact during different movements and exercises typically used in gymnastics.[5,6] Although direct traumatic occlusion of retinacular vessels could happen, it seems to be more likely that chronic impact triggers inflammation in and around the vessels. High general mobility is a predisposing factor for extreme joint positions; it may facilitate impact, a prerequisite of subluxation,[12] which may even increase impact and concomitant shear may even be more destructive.

Femoral head reduction osteotomy combined with PAO has shown to lead to good results in severe deformities of Perthes' disease,[4,7,8] although a reduced number of retinacular vessels in Perthes' hips has been reported.[13] One of our two cases presented at two years clinically and radiologically saw a similar good result. The evolution of the other case, however, showed a less favourable course. The vital part of the lateral pillar was smaller than anticipated. The abnormal appearance of the mobile fragment two years after surgery is not fully understood, and could be interpreted as sequelae of borderline perfusion. As consequence and to better understand the preoperative vascular status, suprasselective angiography may become part of the preoperative evaluation.

Finally, coaches of young female gymnasts should be aware of the fact that femoral head necrosis is a possible and a severe complication of this sport; it is probably provoked by aggressive extreme movements of the hip joint. A discussion should be initiated to modify accordingly or to adapt targeted training units. Furthermore, it is not a stretch to see in a well-trained hip musculature with stabilizing forces on the hip joint, a protective effect against excessive loading of an impingement area.

Take home message

- Femoral head necrosis in young gymnasts may be caused by aggressive extreme movements of the hip joint provoking compression on the main supplying vessels on the posterolateral femoral neck and the acetabulum.
- Typical extreme movements provoking contact were hyperextension with external rotation, extension with external rotation in abduction as well as abduction combined with flexion.
- Extensive joint preserving surgery shows less successful results in this cohort of patients compared to classic Perthes' cases, therefore supraselective angiography may be used to improve presurgical decision-making.

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- M. Tannast: Formal analysis, Methodology, Writing – review & editing.
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- R. Ganz: Project administration, Investigation, Resources, Writing – original draft, Writing – review & editing.

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