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KNEE ARTHROPLASTY

Periprosthetic fractures after medial unicompartmental knee arthroplasty: a narrative review

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Abstract

Introduction On rare occasions, fractures of the tibial plateau may occur after uni-compartmental knee arthroplasty (UKA) and account for 2% of total UKA failures. The purpose of this narrative review is to identify and discuss potential risk factors that might lead to prevention of this invalidating complication.

Materials and methods Electronic database of Pubmed, Scopus, Cochrane and Google Scholar were searched. A total of 457 articles related to the topic were found. Of those, 86 references were included in this narrative review.

Results UKA implantation acts as a stress riser in the medial compartment. To avoid fractures, surgeons need to balance load and bone stock. Post-operative lower limb alignment, implant positioning, level of resection and sizing of the tibial tray have a strong influence on load distribution of the tibial bone. Pain on weight-bearing signals bone-load imbalance and acts as an indicator of bone remodeling and should be a trigger for unloading. The first three months after surgery are critical because of transient post-operative osteoporosis and local biomechanical changes. Acquired osteoporosis is a growing concern in the arthroplasty population. Split fractures require internal fixation, while subsidence fractures differ in their management depending of the amount of bone impaction. Loose implants require revision knee arthroplasty.

Conclusion Peri-prosthetic fracture is a rare, but troublesome event, which can lead to implant failure and revision surgery. Better knowledge of the multifactorial risk factors in association with a thorough surgical technique is key for prevention.

Keywords Uni-compartmental knee arthroplasty · Peri-prosthetic fracture · Aseptic loosening · Fracture load · Tibial plateau

Introduction

Medial uni-compartmental knee arthroplasty (UKA) is a valid option for the management of isolated anteromedial osteoarthritis in selected patients [1, 2]. Despite better functional outcome, lower blood loss and infection rates, registry data show that UKAs are revised earlier and three times higher rate than total knee arthroplasty (TKA) [3, 4]. Reported reasons for revision are instability, aseptic loosening of the tibial component, disease progression, infection or unexplained pain [5, 6]. On rare occasions, fractures of the medial plateau may occur with a frequency of 0.2% [7], which accounts for 2% of the UKA failures [8].

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In contrast to TKA, where fractures are more frequent at the supracondylar level, peri-prosthetic fractures in UKA occur most frequently at the tibia. An undersized implant, covering the bony surface less optimal and providing less cortical support without a tibial keel or stem extension, such as in TKA, might play an important role in the fracture mechanism [9]. Literature has shown that large fragment fractures, involving the meta- and diaphyseal area of the proximal tibia, can be treated with open reduction and internal fixation. Subsidence fractures, often limited to the epiphyseal zone of the knee, can be treated conservatively, except if they lead to implant failure and need revision knee arthroplasty [5, 10]. Whether this revision can be performed with a primary TKA or not, depends of the area of tibial anatomy impacted by the implant failure. If it involves the epi- and metaphyseal regions lower than 10 mm referenced of the unaffected lateral side, a need for bone substitution (wedge/cone) and stem extensions will exist [5].

Considering the important impact of this rare complication on functional outcome and the complexity of the treatment of peri-prosthetic fractures, prevention by understanding the risk factors contributing to the pathophysiology of these fractures might be important. The purpose of this narrative review is to identify and discuss potential risk factors that might be influenced by surgical knowledge and better insights.

Materials and methods

A systematic literature search was conducted by the authors (LT and DM) in September 2020. The senior author (ET) advised about inclusion of a paper in case of doubt between the other two authors. The electronic databases searched were: Pubmed, Scopus, Cochrane and Google Scholar. Search was based on "unicompartmental knee arthroplasty" [MeSH Terms] AND "periprosthetic fracture" [All Fields]) OR "failure of implant". Other keywords utilized were "fracture", "implants", "tibial failure" and "aseptic loosening" [All Fields]. Initially, 457 articles were found. Based on the title and abstract read and after removal of duplicates, 73 articles remained. The full text of each of these articles was read and another 44 articles were considered non-relevant and removed from the database. The final number of articles included in this review was 29. Their data and content as well as relevant referenced articles were used to develop our narrative review with 86 references.

Results

This narrative review aims to highlight the different contributive factors involved in peri-prosthetic fractures. Various fields are involved, such as biomechanics, tibial metaphyseal bone distribution and implant positioning. In addition, some case series relate to surgical experience and suggest technical tips to avoid this troublesome complication.

Biomechanics

Peri-prosthetic fractures occur because of an imbalance between load, load transfer and bone resistance to this experienced load. Mechanical load in the medial knee compartment can be evaluated by the adduction moment around the knee used as a surrogate measure. The magnitude of this adductor moment is directly proportional to the lower limb alignment and body mass index (BMI) [11]. More varus leads to a higher adduction moment and more load through the medial compartment, which is already taking 60% of the overall load of the knee. While obesity has been associated with tibial implant failure in total knee arthroplasty (TKA), the influence of BMI upon UKA failure remains controversial. Some authors advocate that BMI should be considered as a risk factor for early-implant failure and defined a BMI of 32 as a threshold above which a higher failure rate is observed [12–14]. Recent consensus stated that obesity should not be a contra-indication for UKA given the excellent survivorship and clinical outcome in these patients. The only concern remains for active mesomorphic male patients where a higher failure rate has been observed [1].

Following implantation, each UKA design will generate increased loads in the medial compartment and paradoxically a load transfer to the lateral compartment during weight-bearing. This phenomenon is attributable to the important discrepancy in elasticity between both compartments after UKA implantation. The implant allows no elastic deformity in contrast to the native cartilage and therefore load is transferred to the lateral compartment during the stance phase of gait [15]. This underling mechanism could lead to a stress riser at the transition zone of the medial and lateral plateau in the region of the tibial spines.

Young's elasticity modulus dictates the load transfer pattern from the implant to the surrounding bone. Because the modulus of cortical bone is higher than that of cancellous bone, the load is practically entirely transferred onto cortical bone. For fracture prevention, this is the best mechanical condition. Under-sizing and loading of cancellous bone with the higher elasticity modulus of the implant, might lead to subsidence or fractures under the tibial tray. In a physiologic setting, bone remodeling will address a progressive or sudden stress rise. In the scenario of UKA with its recent bone cuts, potential bone oedema and post-surgical transient osteoporosis, these changes can lead to stress fractures or in a milder form residual anteromedial tibial pain, even up to one-year post-operatively. Pattin et al. were able to identify a critical damage threshold in tensile and compressive forces above which bone-remodeling alterations occur [15, 16].

After UKA, the tibial plateau must resist a cantilever-like bending moment during weight-bearing. Tensile forces apply along the sagittal cut, while the cancellous bone below the resected surface must resist compression forces. The quality of the underlying bone plays therefore a major role and bone stock preservation will counter these stress risers. Higher compression forces will be tolerated better by a more conservative tibial cut, while a more lateral sagittal cut (close to the anterior cruciate ligament (ACL)) will protect more bone against tensile forces and increase the implant contact surface for better strain distribution [6].

Chang et al. showed that tensile forces rose at the intersection of the sagittal and coronal plane of the resected tibial surface. This strain concentration is emphasized by the orthogonal geometry of the junction known to act as a stress riser. In addition, this intersection plane of both cuts is peroperatively fragilized by the implant keel preparation.

To lower the mechanical failure risk, some authors suggest to perform a radial-shaped intersection using a pin. As a result, a significant redistribution of strain was obtained in the area with load transfer towards the implants pegs [17].

Based on quantitative computed tomography, Lee et al. demonstrated the areas of the tibial cut of higher bone quality. In both male and female patients, bone density was higher in the central area and lower at the posterior aspect of the tibial cut. In female subjects, an additional decreased density area was found anteriorly. Maintaining an intact tibial cortical ring in these areas is mandatory to conserve the tibial plateau compressive strength and avoid bone failure [18]. Breaching the posterior cortex by a too posterior sagittal cut creates a notch effect responsible for a decreased mean load to fracture. The failure mechanism is a distraction force creating a vertical oblique fracture in line with the sagittal cut, extending towards the medial metaphyseal cortex and allowing a tibial medial condyle displacement. According to Clarius et al., these extended sagittal cuts can be encountered in up to 18% of the cases when performed by inexperienced surgeons [19–21].

Despite a continuous tibial cortical ring, pure subsidence fracture may occur. The tibial surface preparation fragilizes the underlying cancellous bone by preparing keel and pegs. In addition, these metaphyseal extensions of the prosthesis act as stress risers in the anterior and posterior aspect of the tibial cut where the cancellous bone is of lesser quality. Use of multiple fixation pins for the tibial cutting block might create a metaphyseal zone of cortical weakness by a "post-stamp effect" [8].

There is therefore a distinct difference between fractures of the cortical bone and the cancellous bone after UKA. Both phenomena ask for respect of the bone at the level of the proximal tibia.

Bone trabecular pattern and load distribution

Bone stiffness or mineral density of the underlying bone is a crucial factor in resisting the new load distribution after UKA. Osteoporosis measured at the femoral neck has an incidence of 20% in the US and European population [22]. Assessment of osteoporosis is based upon bone mineral density (BMD) measurements, routinely performed at the femoral neck or the lumbar spine, using dual-energy X-ray absorptiometry (DEXA). High pre-operative bone mineral density and bone mineral content (BMC) are associated with lower failure rates and better functional outcome scores in UKA procedures [23, 24]. From that perspective, osteoporosis management could be integrated in the routine pre-operative assessment of the OA patient. Dual-energy X-ray absorptiometry used as a screening tool is not cost-effective given the exponential increase of the osteoarthritic population. To overcome this limitation, surrogate measurements techniques have been developed using standard radiographs [25].

Local DEXA measurements of the knee have not been performed because they are influenced by local features of the OA joint, such as the presence of osteophytes and flexion contracture [26–28]. Bone mineral density is not the unique component for fracture risk assessment in the osteoporotic patient. Other non-skeletal factors have been identified and compelled in the FRAX score. Using this score allows to define the probability of osteoporotic fractures in ten years with respect to the age. Based on the FRAX score, thresholds have been defined for osteoporosis treatment [29]. Labuda et al. used a similar approach in determining osteoporosis prevalence in a pre-arthroplasty population based on patients' history to identify where pre-operative osteoporosis management would be indicated [30].

Biomechanical conditions change after UKA inducing BMD alterations. Intra-operatively, the procedure is responsible for mechanical damage during implant site preparation and induces thermal and chemical damage. Thermal damage occurs by heating of the oscillating saw blade and the exothermal reaction of cement polymerization in cemented implants. Bone cement adds chemical toxicity by releasing chemical free radicals. This deleterious association can be responsible for bone necrosis in a more or less extensive area of the bone, which can take 3 months to repair [31]. Bone remodeling combines resorption processes (by stress shielding) and new bone apposition, depending on the differences in stiffness between the implant and the surrounding bone. For instance, after UKA, bone areas under the rigid metal base plate show a lower BMD, compared to the tip of the keel where a relative BMD increase can be observed secondary to increased bone reaction [23]. Overall, bone mineral density in the metaphyseal area, drops steeply until 3 months after surgery. Under mechanical load, the tibial tubercle area of the implanted knee will show a BMD normalization around 6 months post-operatively. Conversely, central areas show complete recovery at only 24 months [32]. Signals allowing osteoclasts or osteoblasts activation under mechanical strain are poorly known. The assumption is that osteocytes act as mechanoreceptors and activate osteoblastic or osteoclastic cells through a RANKL-RANK system [31]. Higher strains associated with transient osteolysis raise the fracture risk during the early post-operative period.

Bone metabolic changes after knee arthroplasty enhance the ongoing focus on peri-operative bone health management in orthopedic procedures. Vitamin D and calcium are essential to bone metabolism, development and remodeling [33]. Vitamin D deficiency is defined as levels beneath 20 ng/mL for an adult and is common in the arthritic population [34]. Studies have shown that the effects of vitamin D supplementation were not limited to bone quality and were associated with benefits on gait, muscle strength and balance amongst the elderly. On the other hand, no significant outcome differences have been described [35]. Therefore, pre-operative vitamin D deficiency does not contra-indicate arthroplasty procedures, but post-operative supplementation is recommended. The ideal vitamin D level for arthroplasty has yet to be determined, but experts agree that vitamin D and calcium supplementation sufficient to prevent secondary hyperparathyroidism is a good indicator [36].

Osteoporosis treatment relies on agents promoting bone formation or inhibiting bone resorption.

Parathyroid hormone is an anabolic agent increasing bone formation, trabecular connectivity and cortical thickness. It improves significantly the bone micro-architecture and biomechanical properties. In an animal model, increased implant bone ingrowth and bone healing in areas of gap between the implant and surrounding bone were observed [37, 38]. No studies on the use of PTH in joint arthroplasty were found. Nevertheless, based on animal model findings, parathyroid hormone-derived agents could prove beneficial in reducing and treating osteolysis in joint arthroplasty.

Bisphosphonates act as inhibitors of bone resorption by osteoclast inhibition. In the setting of knee arthroplasty, bisphosphonates have been associated with higher implant survival rates and lower overall risk of fracture [39]. Bisphosphonates have a short-term favorable effect (up to 12 month) on peri-prosthetic bone preservation. This effect is notably superior around the implant at the tibial metaphysis compared to the diaphysis, probably because of increased stress shielding [39, 40].

Denosumab is a human antibody preventing the RANK and RANK ligand interaction responsible for osteoclast activation and bone resorption. The RANK-RANKL system has been incriminated in the osteolysis phenomenon secondary to mechanical load redistribution after joint arthroplasty [31]. In their recent study, Murahashi et al. showed immediate denosumab administration after TKA allowed significant bone preservation in the tibial metaphysis up to one-year follow-up [41]. This therapeutic strategy appears effective for early-implant fixation and preventing early-implant migration.

Implant position

Based on finite models, three studies investigated different features of the implant position and the impact on the strain level applied to the bone cuts surface after UKA. Regarding implant orientation, load transfer is similar between neutral alignment and 3° of varus. Malalignment exceeding 3° of varus or valgus, creates a progressive strain increase up to 6° of malalignment from which the exceeding load remains stable. A valgus position, after medial UKA, is therefore an unfavorable configuration associating higher loads to iatrogenic bone stock weakening. On the other hand, malalignment in the sagittal plane with incorrect slope reproduction seems of less effect on strain variations [15, 21].

Another factor, aside tibial component alignment, reported to influence load balance is its sizing and positioning as well as the level of resection.

The influence of the tibial resection is multifactorial. Achieving accurate sagittal and coronal cuts is mandatory, to resist tensile and compressive forces applied at the resection level and allow ideal implant positioning. Maintaining the relationship between the sagittal and the coronal cuts gives a correct fit of the implant avoiding ML and AP coverage mismatches.

Performing a more lateral sagittal cut increases the AP diameter in the sagittal axis of the tibia and the bearing surface, allowing better tensile force management by a decreased cantilever and a higher bone resistance. The larger tibial trey surface reduces compressive forces. Mean and peak Von Mises strain show a slight increase together with the depth of tibial resection. Given the metaphyseal anatomy of the tibia, a lower resection will automatically reduce the bearing surface of the tibia and will often end in poor-bone-quality tissue located beneath the sclerotic reaction to osteoarthritis [42]. Correct implant positioning is therefore crucial as it may lead to significant stress risers [15, 43, 44].

Proper sizing of the implant seeks optimal bone coverage to allow an ideal strain distribution and to avoid soft tissue impingement. Reduced clinical outcomes, resulting from soft tissue impingement due to tibial component oversizing, have been described [45]. Overhang of the tray can also be responsible for a stress rise at the tibial plateau. This effect was observed for a 3-mm overhang. Conversely, under-sizing of the tray showed a decrease of the tibial strain. If a compromise in implant sizing must be made, one must remember, strain concentrates at the medial tibial metaphyseal cortices and at the anterior and posterior corner of the resected surface after implantation [21]. In addition, the tibial cut shows higher bone density in the central part and poor bone quality at the posterior aspect [18].

It appears sizing of the implant must focus on achieving cortical support in ML and AP directions. In case of compromise, AP coverage must be privileged given the poor cancellous bone quality compared to the central area. Facing an ML mismatch, two options are available for the surgeon: ML minimal oversizing within a 3 mm overhang limit or sagittal tibial cut lateralization.

After surgery, the implant must resist a combination of both compressive and tensile forces. Direct compressive strain disperses into the implant with respect to the bone/implant elastic modulus relationship previously discussed. Bone resistance to direct compression depends on pre-operative bone tissue quality and trabecular bone management during surgery. After implantation, an underling mechanism combining bone remodeling and stress shielding may lead to failure with pure subsidence trabecular fracture or, in a milder form, residual antero-medial tibial pain [15]. Tensile forces, on the other hand, result from a cantilever-like effect, comparable to the knee adduction moment, applied locally at the tibial cut intersection. Implant positioning and orientation are key in countering this distraction constraint and must aim for maximal lateral bone stock preservation and to reduce the distance between the cut intersection and the implant femoro-tibial contact point (i.e. the lever arm) [6]. Tensile overload will lead to split fractures separating the medial tibial condyle from the metaphysis along the sagittal cut plane.

Surgical technique

Uni-compartmental knee arthroplasty is a tibia first resurfacing procedure. Accordingly performing an adequate tibial cut is paramount. Goals for ideal strain resistance have been previously exposed and can be summarized as follow: thinnest cut accepting the tibial-bearing in full extension; achieving the widest tibial tray surface by positioning the sagittal cut immediately medial to the ACL footprint and minutious implant sizing and positioning to allow cortical coverage, while avoiding overhang. Recent innovations by the industry have provided the surgeons with more efficient tools to fulfill these objectives. A mismatch between the implant and the bearing surface should alert the surgeon to recheck his cuts, especially the coronal position of the sagittal cut [46].

UKA fractures can occur intra-operatively, what calls for caution during tibial preparation and highlights the importance of the surgical learning curve [47, 48]. Risk factors are posterior cortex breaching, iatrogenic damage to the underlying bone and acute stress risers such as hammering [49, 50].

These risk factors have been illustrated throughout literature by reported case series and case reports. Brumby et al. were confronted to a series of tibial plateau subsidences at a mean post-operative period of 8 weeks without any cortical breach, they concluded the pins used to stabilize the tibial jig acted as additional stress risers in the cancellous bone leading to tibial plateau subsidence fractures [51]. Leenders et al. described a high rate of tibial fractures while using patient-specific instruments. They attributed this to a conversion from cemented to cement-less implants, requiring stronger hammering [52]. Hence, restricting tibial jig fixation to a single pin and careful tibial tray impaction are key to fracture prevention.

Perioperative radiolucencies of the components emphasize the need for an efficient cementing technique. Cleaning the resection surface is a pre-requisite for adequate cement penetration and interlocking, enhancing the biomechanical properties of the cement mantel [53]. Pulse lavage can be used for that purpose [54].

When confronted with a peri-prosthetic fracture, the surgeon needs to decide whether conservative or surgical treatment is indicated. This decision relies essentially on whether the implant remains sealed and the displacement of the bone fragment carrying the implant. Loose implants require implant revision. Fractures around sealed implants need more subtle decisions. Indeed, given the rare occurrence of this complication and the lack of literature, clear guidelines have not been issued.

Different concerns rise with respect to the fracture type. Pure subsidence fractures are intrinsically stable. Surgical indication depends on the new varus alignment and its consequences on patient outcome and implant survival. No real HKA cut-off values for surgical revision have been established. Nevertheless, medial compartment overload becomes symptomatic in the non-implanted knee when malalignment reaches 10°, while load distribution to the medial compartment rises up to 90% from 6° lower limb varus overall alignment [55, 56]. Hence, these angular thresholds could be utilized to decide depending of patient's age and expectations.

The magnitude of the bone fragment displacement in split fractures guides the choice between conservative and surgical treatments. Displacement of the implanted medial plateau impacts bone healing, knee stability and implant function [57]. Moreover, distal displacement leads to a new overall alignment raising the same concerns as pure subsidence fracture. Guidelines for intra-articular split fractures in non-implanted tibial plateau consider a 2 mm threshold before requiring surgery [58]. Angular displacement in the coronal plane must keep the implant orientation in the safety interval from neutral alignment to 3° varus regardless of the chosen treatment to ensure long term survival. The medial collateral ligament will promote movement of the fragment during flexion of the knee. Sagittal angular deformity on the other hand is more forgiving [21].

Loose implants and excessive subsidence of the tibial plateau require revision TKA often with a tibial wedge and stem. Open reduction and internal fixation by buttress plating and screws are advised for split fracture management [49].

Discussion

The most important findings of this narrative review were that different factors might influence the balance between strain and bone resistance after UKA, which may lead to compartment overload or in case of reaching the tipping point of resistance, peri-prosthetic fractures.

Bone quality plays a major role in resisting strain after UKA implantation. Both quality and quantity must be preserved to maximize bone resistance in the area. The specific micro-architecture of the proximal medial tibial plateau has been described and combines a highly connected trabecular network of plate-like trabeculae and a high bone density [59]. The mechanical resistance of this structured cancellous bone is enhanced by the peripheral cortical bone ring. Removing the worn tibial surface is mechanically deleterious and lowers the failure threshold in this area. Indeed, the cortical ring is lost in the sagittal and coronal plane, while the new bearing surface lies more distally where the bone density is lower and the cancellous bone architecture less effective [42]. Excessive bone removal also reduces the tibial-bearing surface which raises the pressure to the underlying bone for a constant applied force. Therefore, care should be taken to achieve the largest tibial-bearing surface especially in small patients. Accurate performance of the sagittal cut helps achieve a larger tibial-bearing surface and avoids ACL impingement [10, 60, 61].

Co-morbidities, such as obesity, osteoarthritis and osteoporosis, are responsible for local alterations and can lead to a loss of normal mechanical properties. Obesity has been thought to protect against osteoporosis with adipocyte-derived hormones and increased mechanical loading. Negative effects of obesity upon bone metabolism are mediated by induced endocrine impairments reaching the GH/IGF-1 and gonadal steroid axis. The GH/IGF-1 axis plays an important role in both the bone metabolism and body composition by stimulating osteoblast lineage and bone strength, as well as increasing muscle mass and decreasing abdominal adiposity. In the male patient, obesity tends to lower testosterone levels, whereas estrogen production is increased in proportion to bodyweight. In addition, vitamin D, a bone metabolism regulator, shows reduced levels in the obese patient due to its entrapment in the adipocyte tissue. Interestingly, studies show that increased BMI does not correlate directly with decreased bone properties. Instead evidence links fat accumulation in specific compartments with bone loss, particularly the abdominal depot. Despite its effect on the GH/IGF-1 and gonadal steroid axes, visceral abdominal tissue (VAT) has a deleterious effect on bone metabolism because of the release of pro-inflammatory cytokines secreted by adipocytes, such as IL-6 and TNF α, and adipokines, such as E-selectin, stimulating osteoclast activity [22, 62–64].

At the onset of osteoarthritis, the mineral density increases under the worn surface but paradoxically the bone tissue modulus decreases up to 60% changing the normal relation between stiffness and bone volume fraction and lowering bone resistance [65]. On the other hand, osteoporosis is responsible for a decrease in bone quantity up to 12% and a cancellous bone architecture shift towards a less connected rod-like subchondral support [42]. Similar alterations of the bone structure were highlighted amongst the aging population for both genders. As this regional bone structure loss, impairs the mechanical competence of the tibial condyle to bending and compression, these ascertainments warn off against elder patients and raise concern about the non-substituted post-menopausal female patient [66–68]. Moreover, peri-prosthetic osteopenia secondary to surgical damage and load redistribution is inherent to arthroplasty procedures. This transient osteoporosis reaches its paroxysm around 3 months post-operatively before normalizing after 6–24 months in TKA patients [32]. Bone resorption inhibitors, such as bisphosphonates and denosumab, have been effective to counter this implant-related osteopenia over a one-year period offering a promising solution for secure implant fixation and fracture prevention [40, 41].

Load in the medial compartment is expressed by the adduction moment applied to the knee, which is directly proportional to the mechanical axis deviation (MAD) [11, 69]. The amount of correction during UKA is conditioned by the magnitude of the deformity and position of the center of rotation and angulation (CORA). The mechanical alignment test developed by Paley allows to locate the CORA and classify the knee according to the Thienpont and Parvizi varus classification [70, 71]. Intra-articular deformities are easily correctible by the surgical procedure and represent ideal UKA indications. The real challenge originates from metaphyseal deformities, type M knees, which may be found in a significant portion of the population [72]. Indeed, in these patients, residual varus deformity must be anticipated as with the technical goal of a tibial cut, horizontal to the floor, will not lead to deformity correction. Experts suggest that a correctable deformity is present when the mechanical alignment of the lower limb is 10° varus or less (HKA-angle > 170°) [1]. Post-operative classification on full-leg-standing radiographs, according to Kennedy's epiphyseal zones, allows to estimate the residual adduction moment applied at the knee and identify patients at risk for post-operative fractures from compartment overload and potential bone-remodeling dysfunction [16, 73].

The adduction moment of the knee is calculated as the product of the MAD and the ground reaction force which, according to Newton's action-reaction law, is directly proportional to body weight [11]. From that perspective, partial weight-bearing using crutches appears beneficial to relieve the overloaded UKA. Perioperative osteoporosis, measured as a BMD reduction, is critical during 3 months [31]. In addition, bone remodeling because of excessive strain, has been associated with pain. Patients at risk should be advised to use crutches up to 3 months post-operatively, using relief of pain as an indicator for remodeling and reduced load.

At the bone/implant interface, load distribution is conditioned by the Young's modulus of the implant, its design, position and size [15, 18, 43]. All polyethylene trays have been proven to behave poorly mechanically and are associated with significantly more cancellous damage than metal backed implants [74, 75]. Differences in the fracture risk between cemented and un-cemented implants seem limited and rely essentially on the heavier impaction required for un-cemented implants [49, 52]. No studies about the impact of implant geometry were found during this review. Uncertainties remain regarding load distribution across the implant itself and potential strain concentrations around the keel and pegs, as observed around TKA stems [76]. Sizing and positioning of the implant may act as stress risers. Achieving a tibial cut within the green zone of 0°–3° varus is critical [15]. Sizing the implant must aim to cover the anterior and posterior weak areas of the tibial surface and avoid overhang. Recent innovations in the industry involve morphometric implants. In comparison with a symmetric tibial plateau, morphometric implants were associated with better positioning and lower medial and posterior overhang (> 3 mm) rates. Surgeons' exposition to compromise is therefore reduced. In addition, superior short-term clinical outcomes were found [77]. Given UKA is a mini-invasive procedure using conventional tools, these results deeply rely on the surgeon experience [78]. From that perspective, use of new technologies such as robotics could be an advancement [46]. Currently, a minimum threshold of 13 UKA surgeries per year is suggested to avoid increased revision rates [79].

Given the low occurrence of this complication, no management guidelines exist and decision-making relies on surgical experience. Opinions diverge on how to manage a peri-prosthetic tibial plateau fracture, especially with a sealed implant. In a case series of 4 pure subsidence fractures, Brumby et al. [51] revised all 4 patients to TKA with bone allografts and wedge augmentation. Loosening of the implant was not specified. At the knee level, the new position of the tibial plateau alters the biomechanical relationship between bone and implant. Two millimeters' subsidence and a coronal orientation of 0°–3° varus have been highlighted as a green zone for implant survivorship. Moreover, resultant overall lower limb malalignment under 6° varus may preserve patient outcome. Considering these thresholds, revision TKA is not mandatory for pure subsidence fractures and non-surgical treatment could be reliable in selected cases.

Similarly, some authors promote systematic revision TKA surgery when dealing with periprosthetic tibial plateau fractures [10, 80, 81]. Based on a case series describing medial plateau split fractures, Van Loon et al. [10] claimed that neither conservative treatment nor open reduction and internal fixation could prevent a medial plateau collapse. In their cases, conservative treatment consisted in non-weight-bearing for a 6-week period and ORIF was achieved using compressive screws. Modern conservative treatment of non-displaced tibial plateau fractures advocates hinged knee bracing and unloading for a 10–12-week period. Surgical strategies have also evolved towards buttress plating for more stability [58]. Failure of the non-revision treatment in this series is attributable to early weight-bearing and weak surgical stabilization.

Sloper et al. [49] confirmed, in a case report, that ORIF using buttress plating could reach good clinical outcomes. New designs of low-contact-angle stable plates enhance fracture stability, confers higher mechanical resistance to load and do not impede cortical blood flow which preserves fracture healing potential [82]. Peri-prosthetic fracture fixation therefor requires buttress plating. Moreover, fracture fixation should systematically be considered as it permits implant survivorship and, in case of poor clinical outcome, bone stock reconstruction facilitating revision TKA.

Substantial differences exist in surgical management of these two fracture types. Pure subsidence fractures are stable and decision-making, between conservative and revision TKA, must be based on the implant's final position and fixation. Technically, bone loss from the index surgery can be compensated by augments and stems. Split fractures, on the other hand, are associated with important metaphyseal bone loss. From that perspective, immediate revision TKA procedures are particularly complex. Hence, fracture fixation must be considered in any displaced split fracture for implant conservation and/or bone stock reconstruction. It must be noted that in the event of a loose implant, staged procedure associating ORIF and revision TKA might be necessary for bone stock management.

The limitations of this narrative review lie essentially in the low occurrence of this complication and therefore the fact that this was no systematic review. A narrative review allowed the authors to list the different risk factors and to describe the underlying mechanism. The ambition of this work was to help surgeons understand how to prevent this complication.

Conclusion

Peri-prosthetic fractures after medial UKA are a rare, but troublesome event. Better understanding of the risk factors, as explained in this narrative review, should help prevent post-operative fractures. Achieving specific surgical goals, such as avoiding malalignment, over-resection, tibial under-sizing and use of multiple pins allows to avoid bone fragilization and tibial overload. Fracture management depends on the fracture type and/or the presence of implant loosening.

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