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Knee post-traumatic consequences: possible surgical approach and management when everything goes wrong

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Summary

Post--traumatic osteoarthritis (PTOA) of the knee is a development of arthritis following an acute trauma, often associated with intraarticular fracture and ligament injury. The knee is affected in 12% of all cases of knee OA, the prevalence of PTOA after a fracture in the literature is between 21-44% and is the result of a combination of unfavorable factors. The number of surgical treatments for post-traumatic arthritis has increased slightly over the years, but is a demanding and common problem for the surgeon because it is associated with poorer outcomes and higher rates of complications. The reasons for this are likely multifactorial, due to technically challenging for the previous surgery and scarring, secondary deformity, bone loss, hardware retained, poor bone quality and ligament incompetence. The aim of this study is to review the possible surgical approaches in these cases, and the management of soft tissue and previous hardware.

Key words: post-traumatic, arthritis, knee, wound, hardware

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Introduction

Post-traumatic osteoarthritis (PTOA) of the knee is a development of arthritis following an acute trauma, often associated with intraarticular fracture and ligament injury [1]. It usually occurs after a variety of joint injuries, like sports trauma, motor vehicle accident or fall and is considered a particular type of osteoarthritis. The main difference is that cartilage wear occurs as a result of acute damage and not gradually, as in the case of osteoarthritis [2,3] (Fig. 1).
Knee is affected in 12% of all knee OA cases, the prevalence of PTOA after a fracture in literature is between 21-44% [4] and is the result of a combination of unfavorable factors. A prior knee joint trauma increases the risk to develop PTOA by 3-6 times and with an early appearance of 10 years compared to those without history of injury [5].

Pathogenesis

The pathogenesis of PTOA is not fully understood, but is thought to be a combination of mechanical damage associated with ligamentous laxity and meniscal tears. The acute

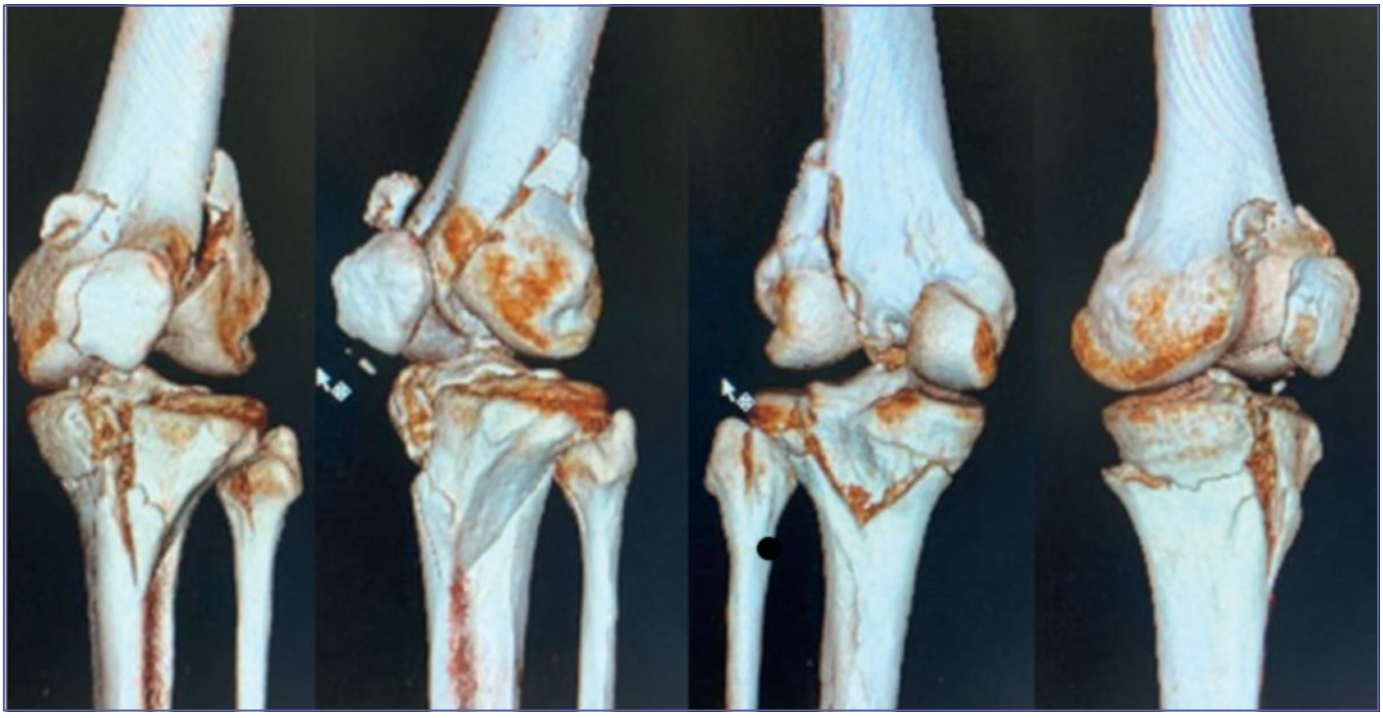

Figure 1. Articular knee fracture after acute trauma.

fracture severity and its reduction seems to be the most important factors leading to a good outcome, but the relative contribution of these factors to the subsequent progression of arthritis has not been well characterized [6,7]. The articular injury to cartilage surface induces chondrocyte death or dysfunction, resulting in degeneration of the entire articular surface. Chondrocyte death progression can progress over 48 hours after trauma [8]. Lower limb malalignment induced by insufficient reduction of the articular surface or by extraarticular deformity, ligamentous laxity due to mechanical imbalance, and meniscal tears can lead to a chronic abnormal stress on articular surfaces and cartilage degeneration [9]. Specifically, the combination of instability and articular surface incongruity induces disproportion in contact stress areas and can anatomically shift the articular surface loading pattern, although there is no consensus on the maximal acceptable articular step-off [7]. Secondly, the release of the pro-inflammatory cytokines interleukin-1 and tumor necrosis factor alpha along with intra-articular hematoma induces cartilage cell necrosis and improper cartilage healing [10]. Other factors like patient age and BMI also contribute to poorer clinical outcomes and a higher risk of osteoarthritis.

Treatment options

The number of surgical treatments for post-traumatic arthritis has increased slightly during the years and is the third most common cause of total knee replacement after primary arthritis and rheumatoid arthritis [11]. Treatment of early stages post-traumatic knee OA is a combination of activity modification, physical therapy, and anti-inflammatory medications [12]. Management of PTOA is not different from primary osteoarthritis. However, when conservative treatment failed or in more advanced stages of OA, surgical options become an alternative solution for these patients [13].

PTOA is a demanding but common problem for the surgeon: total knee arthroplasty (TKA) is an option for the treatment of the end-stage, but, in the literature, ai associated with poorer outcomes and higher complication rates in these patients than in those treated with routine primary TKA [4]. The reasons are likely multifactorial, due to technically challenging for the previous surgery and scarring, secondary deformity, bone loss, hardware retained, poor bone quality, and ligament incompetence [9,14]. (Fig. 2) In particular, a prior surgical scar and retained metalwork increase the risk of wound breakdown and infection and must be managed carefully.

However, a more recent study reported no difference between TKA after PTOA and TKA for primary osteoarthritis in outcome scores [15]. Lizaur-Utrilla et al. reported that TKA for PTOA after tibial plateau fracture has a significantly higher complication rate, but the complications observed were not severe and did not affect functional post-operative outcomes compared with primary TKA [16]. However, there are other surgical techniques such as osteochondral autograft or allograft, osteotomies, or arthrodesis, which can be performed in these patients and make the appropriate surgical treatment challenging.

Before the choice of surgical treatment, adequate surgical approach is crucial, and it must consider removal of prior hardware to reduce the risk of wound dehiscence and infection.

Figure 2. Complex knee arthroplasty after post-traumatic osteoarthritis.

Surgical approach

Previous incision performed for prior surgery represents a challenge for the surgeon and a risk factor for wound healing. Lonner et al. [4] reported that the main post-operative wound complications are infection (10%) and wound breakdown (6%) needing additional flap coverage (Fig. 3).
Other risk factors for skin necrosis are rheumatoid arthritis (RA), diabetes, steroid use, immunosuppression, malnutrition, and peripheral vascular disease [17,18]. In the presence of a single previous incision, it should be used especially when is a longitudinal scar and can be fully incorporated in the TKA approach. This is associated with a lower rate of wound complications, such as skin necrosis between the incisions [19]. Scott et al. [20,21] prospectively reviewed 888 patients between 1995 and 2008, finding that surgical scars and retained metalwork can increase the risk of wound breakdown and superficial infection after TKA. They found a lower rate of wound complications in patients with a longitudinal scar and this can be fully incorporated into the TKA approach. Especially in case of a single antero-lateral incision for lateral tibial plateau fracture, a Keblish approach can be used to perform hardware removal and TKA or osteotomy at the same time. Even in case of multiple incisions, the most lateral one should be performed to preserve the blood supply and oxygen tension to the medial flap [22].

Figure 3. Knee post-traumatic wound and damage of soft tissue.

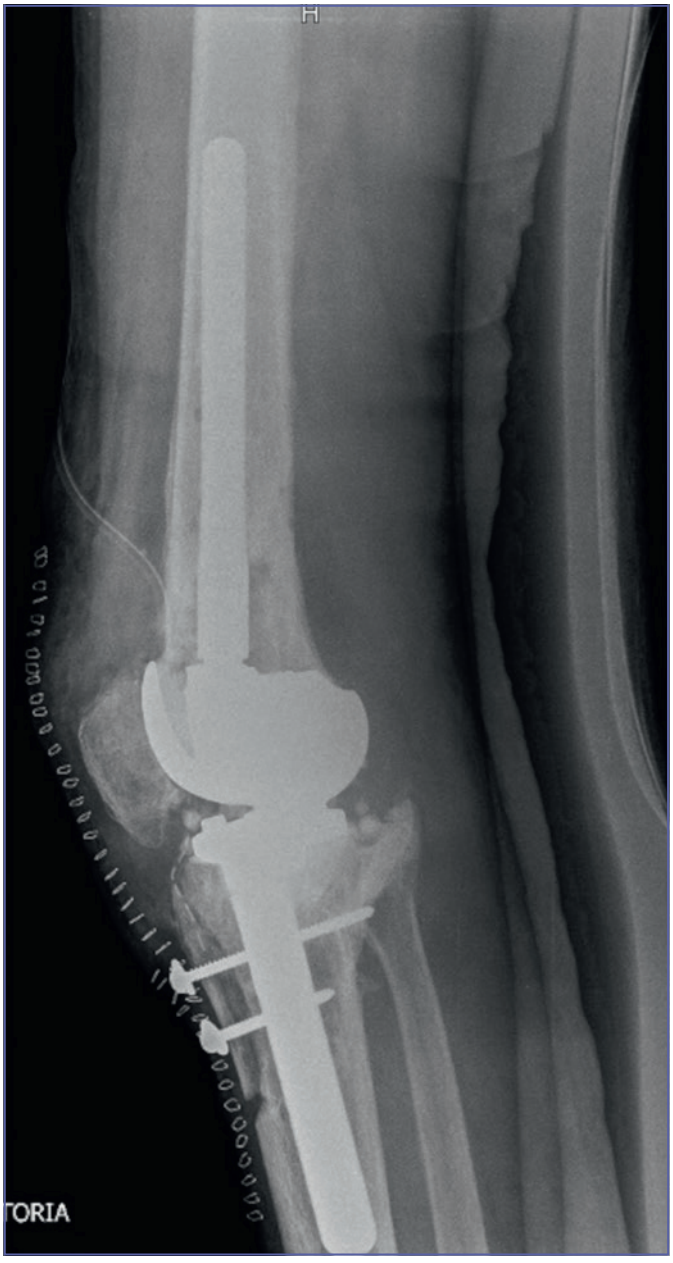

Figure 4. Lateral subvastus approach distally extended with tibial tubercle osteotomy.

Figure 5. Prior transverse incision of the knee and loss of soft tissue that required demo-epidermal graft.

The Keblish approach was first described in 1991 and the author emphasized the advantages in the valgus knee [23]. It allows a direct approach into the deformity and simplifies the patellar tilt and ligament balancing. Using this approach in PTOA patients, with multi-operated knees, the osteotomy of tibial tuberosity is often necessary due to stiffness or patella baja which limit exposure of articulation and increase the risk of patellar tendon injury [24].
Moreover, in case of femur hardware, it can be removed by a lateral subvastus approach that can be extended distally in conjunction with a tibial tubercle osteotomy [4] (Fig. 4).
In the presence of double incision, usually antero-lateral and postero-medial or posterior approach, a new median incision should be made. The distal part of the new median incision should merge in one of the previous two incisions [6]. In case of prior transverse incision, due to an exposed fracture or previous cover flap, crossing previous incisions at angle > 60° and maintaining full thickness skin bridges of at least 7 cm are recommended to maintain adequate tissue perfusion (Fig. 5) [25,26]. Alternatively, especially with previous pedicle flap or based on perforating arteries flap, it can be indicated to completely raise the previous flap from the underlying tissues to expose the joint surface without damaging vascularization (Fig. 6).

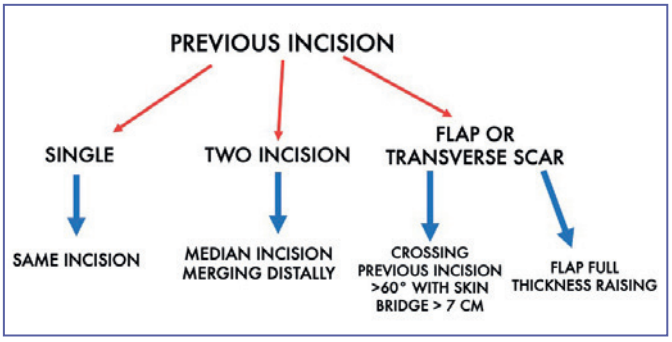

Figure 6. Decision making of adequate surgical approach (flow-chart).

Figure 7. Prior hardware for knee fracture could hinder the total knee arthroplasty procedure (Antero-Posterior X-Ray).

Problem wound: coverage option

In rarely complex situations, wound closure may be difficult due to retracting scars and a tissue expander or primary flap coverage is required (Fig. 7).
Soft tissue expansion, introduced in 1950s, is based on stretching the skin beyond its physiologic limit to induce higher mitotic activity and collagen synthesis. The effect is an increased surface area of the skin which allows tension-free wound closure. Usually, a tissue expander is inserted into subcutaneous pocket near the planned incision for 8 weeks [27-29]. Skin grafting requires a well vascularized bed, no prosthesis exposure, and good soft tissue

bulk that usually are not present in these types of patients. Instead, with wide soft tissue loss and exposure of the prosthesis, local flaps may be the best reconstructive option. Local flaps are raised on a vascular pedicle rotated in the required position [30].

Defects of the medial proximal tibia, tibia tubercle, patellar tendon, and patella can be covered by medial gastrocnemius muscle or musculo-cutaneous pedicle flap. The gastrocnemius has two heads, medial and lateral, with separated bloody supply and the medial one is the longer [31]. Several authors evaluated the role of the gastrocnemius flap. Casanova et al. [18] stated that it provides a good quality soft tissue coverage for most of the defects; it also provides blood supply and increases the concentration of antibiotics. Furthermore, it can be easily mobilized to the knee region and fills the empty space around the prosthesis. The functional consequences at the harvest site are minimal, allowing for early mobilization and a reduced rate of arthrodesis after TKA failure [18]. Ries et al. demonstrated that this flap has a high success rate for soft tissue coverage and a lower risk of failure compared to free flap [32].

More proximal defect may be treated with additional lateral gastrocnemius or fascio-cutaneous flap transposition, but the lack of muscle tissue is not good for local drainage.

In this case, an alternative can be the vastus lateralis muscle flap with distal pedicle. This is a salvage flap suitable for extensive longitudinal loss of knee tissue or reconstruction of extensor apparatus [33] Wang et al. [34] showed the constancy of the three perforating arteries from the superolateral geniculate artery in the distal quarter of the vastus lateralis, which makes it a reliable flap. It does not require microsurgery, but this type of flap is accompanied by a limitation of function of the harvest limb. If the defect is too large and presents inadequate peripheral soft tissue, a free flap is more appropriate.

Limitations of tissue mobility, multiple previous incision and additional plastic surgery can lead to under-sizing the total knee prosthesis and reduction in active muscular strength and range of motion [35]. The flap coverage gives the possibility to restore the correct joint volume and use an adequate size of TKA.

Remove or retain hardware?

The presence of hardware from previous surgery is a risk factor of post-TKA infection, along with male gender and high BMI [36]. The removal of this has always been a debated topic and, currently, no clear indications are present in literature. Some surgeons prefer hardware removal, if possible, due to the lower risk of infection and mechanical instability [36,37].

Moreover, in these kinds of patients the presence of retained hardware of the prior surgery can hinder the intramedullary guides of TKA and the possibility of removing them should be considered [38] (Figs. 7-8). Hardware removal could be performed in either a staged or concurrent manner, and both have benefits and defects. Staged removal usually improves tissue healing and revascularization, as well as improved bone stock before arthroplasty [16]. On the other hand, two different operations increase the risk of infection and compromise wound healing [39]. However, the screw holes left from the hardware removal increases the stress riser and the risk of post-operative fracture in the concurrent removal manner with TKA. This can result in the need to use more complex and stable implants, limits post-surgery weight bearing, and delays the adequate rehabilitation protocol [40].

Figure 8. Prior hardware for knee fracture could hinder the total knee arthroplasty procedure (Lateral X-Ray).

Smith et al. [39], in a retrospective review from 1998 to 2018, identified no significant difference in complications, reoperations, or revision between conversion TKA patients who underwent either concurrent hardware removal or staged hardware removal. Klatte et al. [41] reported on a group of conversion patients who underwent concurrent hardware removal and TKA, reporting a post-operative infection rate of 3% and mechanical complications in 5% of cases. However, in this study and many others, the data reflect a heterogenous group with different type, size, and location of hardware [3,42,43].

In our experience, we suggest hardware removal if it hinders the TKA positioning, such as in the case of proximal posterior tibia plate, and therefore on the planned surgical approach.

In case of young patients, it is also preferable to remove hardware in two stages, as early as possible, or with the first sign of osteoarthritis in order to achieve the best possible wound healing [44].

Furthermore, in case of multiple plate or screws, we do not suggest removing those far from the future surgical access, to prevent soft tissue devascularization and if they do not preclude the TKA implant. Accurate TKA pre-operative planning with a computer navigation system can be useful to understand which hardware can be left in place. Manzotti et al. [44] evaluated the use of computer navigation system for one-stage TKA without removal in post-traumatic knee arthritis with prior femoral fracture. They found that, with computer assistance, the results are reproducible and similar to primary routine TKA.

In the current literature, the final decision to remove or retain the hardware is still debated, especially in asymptomatic patients, and should be based on individual patient factors [45,46] (Fig. 9).

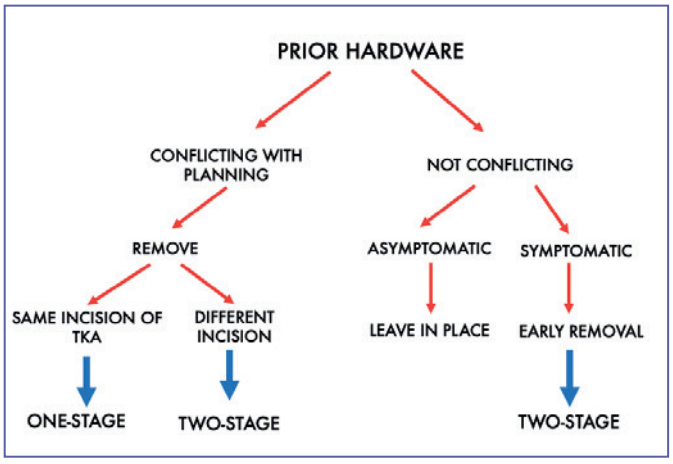

Figure 9. Decision making of management for post-traumatic knee with prior hardware in place.

Conclusions

Post-traumatic osteoarthritis (PTOA) management of the knee is demanding for surgeons. Each patient must be carefully evaluated to choose the adequate surgical strategy on a case-by-case basis. Accurate radiographic and CT study, pre-operative planning, and selection of prosthesis type is critical, and should be decided according to the bone defect and knee stability. However, these cases have higher rate of possible complications compared with primary total knee arthroplasty due to the previous surgery and scarring, prior hardware, poor bone quality, and ligament incompetence. It is essential to assess which surgical approach should be used to reduce the risk of wound and decide to remove or retain prior implants to reduce the risk of post-operative infection. Unfortunately, there is no consensus in the literature, so that the management of these complex cases relies on the surgeon's experience and patient characteristics.

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Conflict of interest statement

The Authors declare no conflict of interest.

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Authors' contributions

DB and PdB as designers of the study. MS, GS e PdB as revisors of the study.

All Authors have read and approved the manuscript.

Ethical consideration

This study was approved by the Istitutional Ethics Committe of AOU Careggi, Florence, Italy. The research was conducted ethically, with all study procedures being performed in accordance with the requirements of the World Medical Association's Declaration of Helsinki. Written informed consent was obteined from each patients for study participation and data publication.

References

1 Houdek MT, Watts CD, Shannon SF, et al. Post-traumatic total knee arthroplasty continues to have worse outcome than total knee arthroplasty for osteoarthritis. J Arthroplasty 2016;31:118-123. https://doi.org/10.1016/j.arth.2015.07.022

2 Weiss NG, Parvizi J, Trousdale RT, et al. Total knee arthroplasty in patients with a prior fracture of the tibial plateau. J Bone Jt Surg - Ser A 2003;85:218-221. https://doi.org/10.2106/00004623-200302000-00006

3 Papadopoulos EC, Parvizi J, Lai CH, et al. Total knee arthroplasty following prior distal femoral fracture. Knee 2002;9:267-274. https://doi.org/10.1016/S0968-0160(02)00046-7

4 Lonner JH, Pedlow FX, Siliski JM. Total knee arthroplasty for post-traumatic arthrosis. J Arthroplasty 1999;14:969-975. https://doi.org/10.1016/S0883-5403(99)90012-8

5 Muthuri SG, McWilliams DF, Doherty M, et al. History of knee injuries and knee osteoarthritis: a meta-analysis of observational studies. Osteoarthr Cartil 2011;19:1286-1293. https://doi.org/10.1016/j.joca.2011.07.015

6 Benazzo F, Rossi SMP, Combi A, et al. Knee replacement in chronic post-traumatic cases. EFORT Open Rev 2016;1:211-218. https://doi.org/10.1302/2058-5241.1.000025

7 Schenker ML, Mauck RL, Mehta S. Pathogenesis and prevention of post-traumatic osteoarthritis after intra-articular fracture. J Am Acad Orthop Surg 2014;22:20-28. https://doi.org/10.5435/JAAOS-22-01-20

8 Tochigi Y, Buckwalter JA, Martin JA, et al. Distribution and progression of chondrocyte damage in a whole-organ model of human ankle intra-articular fracture. J Bone Joint Surg Am 2011:93:533-539. https://doi.org/10.2106/JBJS.I.01777

9 Kornah BA, Safwat HM, Abdel-Hameed SK, et al. Managing of post-traumatic knee arthritis by total knee arthroplasty: case series of 15 patients and literature review. J Orthop Surg Res 2019;14:1-9. https://doi.org/10.1186/s13018-019-1180-3

10 Anderson DD, Marsh JL, Brown TD. The pathomechanical etiology of post-traumatic osteoarthritis following intra-articular fractures. Iowa Orthop J 2011;31:1-20.

11 FPNI. Swedish Knee Arthroplasty Register, 2020.

12 Jordan KM, Arden NK, Doherty M, et al. EULAR Recommendations 2003: an evidence based approach to the management of knee osteoarthritis: report of a Task Force of the Standing Committee for International Clinical Studies Including Therapeutic Trials (ESCISIT). Ann Rheum Dis 2003;62:1145 LP-1155. https://doi.org/10.1136/ard.2003.011742

13 Crawford DC, Miller LE, Block JE. Conservative management of symptomatic knee osteoarthritis: a flawed strategy? Orthop Rev 2013;5:2. https://doi.org/10.4081/or.2013.e2

14 Lunebourg A, Parratte S, Gay A, et al. Lower function, quality of life, and survival rate after total knee arthroplasty for post-traumatic arthritis than for primary arthritis. Acta Orthop 2015;86:189-194. https://doi.org/10.3109/17453674.2014.979723

15 Kanamiya T, Naito M, Hara M, Yoshimura I. The influences of biomechanical factors on cartilage regeneration after high tibial osteotomy for knees with medial compartment osteoarthritis: clinical and arthroscopic observations. Arthroscopy 2002;18:725-729. https://doi.org/10.1053/jars.2002.35258

16 Lizaur-Utrilla A, Collados-Maestre I, Miralles-Muñoz FA, et al. Total knee arthroplasty for osteoarthritis secondary to fracture of the tibial plateau. A prospective matched cohort study. J Arthroplasty 2015;30:1328-1332. https://doi.org/10.1016/j.arth.2015.02.032

17 Nahabedian MY, Orlando JC, Delanois RE, et al. Salvage procedures for complex soft tissue defects of the knee. Clin Orthop Relat Res 1998;356:119-124. https://doi.org/10.1097/00003086-199811000-00017

18 Casanova D, Hulard O, Zalta R, et al. Management of wounds of exposed or infected knee prostheses. Scand J Plast Reconstr Surg Hand Surg 2001;35:71-77. https://doi.org/10.1080/02844310151032637

19 Wang XS, Zhou YX, Shao HY, et al. Total knee arthroplasty in patients with prior femoral and tibial fractures: outcomes and risk factors for surgical site complications and reoperations. Orthop Surg 2020;12:210-217. https://doi.org/10.1111/os.12610

20 Scott CEH, Davidson E, Macdonald DJ, et al. Total knee arthroplasty following tibial plateau fracture: a matched cohort study. Bone Jt J 2015;97-B:532-538. https://doi.org/10.1302/0301-620X.97B4.34789

21 Colombel M, Mariz Y, Dahhan P, Kénési C. Arterial and lymphatic supply of the knee integuments. Surg Radiol Anat 1998;20:35-40. https://doi.org/10.1007/BF01628113

22 Johnson DP, Eastwood DM, Bader DL. Biomechanical factors in wound healing following knee arthroplasty. J Med Eng Technol 1991;15:8-14. https://doi.org/10.3109/03091909109015442

23 Tonelli Filho JR, Passarelli MC, Brito JAS, et al. Keblish's lateral surgical approach enhances patellar tilt in valgus knee arthroplasty. Rev Bras Ortop 2016;51:680-686. https://doi.org/10.1016/j.rboe.2016.10.010

24 Zayni R, Bonnin M. The lateral approach in the valgus knee. Knee Jt Surg Tech Strateg 2012;9782287993:901-906. https://doi.org/10.1007/978-2-287-99353-4_85

25 Windsor RE, Insall JN, Vince KG. Technical considerations of total knee arthroplasty after proximal tibial osteotomy. J Bone Joint Surg Am 1988;70:547-555.

26 Garbedian S, Sternheim A, Backstein D. Wound healing problems in total knee arthroplasty. Orthopedics 2011;34:e516-e518. https://doi.org/10.3928/01477447-20110714-42

27 Stoffel K, Blauth M, Joeris A, et al. Fracture fixation versus revision arthroplasty in Vancouver type B2 and B3 periprosthetic femoral fractures: a systematic review. Arch Orthop Trauma Surg 2020;140:1381-1394. https://doi.org/10.1007/s00402-020-03332-7

28 Wilhelmi BJ, Blackwell SJ, Mancoll JS, et al. Creep vs stretch. A review of the viscoelastic properties of skin. Ann Plastic Surg 1998;41:215-219.

29 Huang X, Qu X, Li Q. Risk factors for complications of tissue expansion: a 20-year systematic review and meta-analysis. Plast Reconstr Surg 2011;128:787-797. https://doi.org/10.1097/PRS.0b013e3182221372

30 Scott WN, Ed. Insall and Scott surgery of the knee, Sixth Ed. New York, NY: Elsevier 2017, pp. 2360.

31 Moscona RA, Fodor L, Har-Shai Y. The segmental gastrocnemius muscle flap: Anatomical study and clinical applications. Plast Reconstr Surg 2006;118:1178-1182. https://doi.org/10.1097/01.prs.0000221259.13173.1d

32 Ries MD, Bozic KJ. Medial gastrocnemius flap coverage for treatment of skin necrosis after total knee arthroplasty. Clin Orthop Relat Res 2006;446:186-192. https://doi.org/10.1097/01.blo.0000218723.21720.51

33 Auregan JC, Bégué T, Tomeno B, et al. Lambeau de muscle vaste latéral à pédicule distal: technique conservatrice de sauvetage des pertes de substance du genou. Rev Chir Orthop Traumatol 2010;96:214-219. https://doi.org/10.1016/j.rcot.2010.02.013

34 Wang Y, Begue T, Masquelet AC. Anatomic study of the distallt based vastus lateralis muscle flap. Plast Reconstr Surg 1999;103:101-103. https://doi.org/10.1097/00006534-199901000-00017

35 Bégué T, Mebtouche N, Levante S. One-stage procedure for total knee arthroplasty in post-traumatic osteoarthritis of the knee with wound defect. Usefulness of navigation and flap surgery. Knee 2012;19:948-950. https://doi.org/10.1016/j.knee.2012.03.012

36 Suzuki G, Saito S, Ishii T, et al. Previous fracture surgery is a major risk factor of infection after total knee arthroplasty. Knee Surg Sport Traumatol Arthrosc 2011;19:2040-2044. https://doi.org/10.1007/s00167-011-1525-x

37 Manrique J, Rasouli MR, Restrepo C, et al. Total knee arthroplasty in patients with retention of prior hardware material: what is the outcome? Arch Bone Jt Surg 2018;6:23-26. https://doi.org/10.22038/abjs.2017.19759.1513

38 Baldini A, Adravanti P. Less invasive TKA: extramedullary femoral reference without navigation. Clin Orthop Relat Res 2008;466:2694-2700. https://doi.org/10.1007/s11999-008-0435-9

39 Smith EJ, Katakam A, Box HN, et al. Staged vs concurrent hardware removal during conversion total knee arthroplasty. J Arthroplasty 2020;35:3569-3574. https://doi.org/10.1016/j.arth.2020.06.055

40 Johnson BA, Fallat LM. The effect of screw holes on bone strength. J Foot Ankle Surg 1997;36:446-451. https://doi.org/10.1016/S1067-2516(97)80097-X

41 Klatte TO, Schneider MM, Citak M, et al. Infection rates in patients undergoing primary knee arthroplasty with pre-existing orthopaedic fixation-devices. Knee 2013;20:177-180. https://doi.org/10.1016/j.knee.2013.02.004

42 Kreitz TM, Deirmengian CA, Penny GS, et al. A current procedural terminology code for "Knee Conversion" is needed to account for the additional surgical time required compared to total knee arthroplasty. J Arthroplasty 2017;32:20-23. https://doi.org/10.1016/j.arth.2016.06.040

43 Bergen MA, Ryan SP, Hong CS, et al. Conversion total knee arthroplasty: a distinct surgical procedure with increased resource utilization. J Arthroplasty 2019;34:S114-S120. https://doi.org/10.1016/j.arth.2019.01.070

44 Manzotti A, Pullen C, Cerveri P, et al. Post-traumatic knee arthritis: navigated total knee replacement without hardware removal. Knee 2014;21:290-294. https://doi.org/10.1016/j.knee.2012.06.008

45 Busam ML, Esther RJ, Obremskey WT. Hardware removal: indications and expectations. J Am Acad Orthop Surg 2006;14:113-120. https://doi.org/10.5435/00124635-200602000-00006

46 Prediger B, Mathes T, Probst C, et al. Elective removal vs retaining of hardware after osteosynthesis in asymptomatic patients – a scoping review. Syst Rev 2020;9:1-9. https://doi.org/10.1186/s13643-020-01488-2