Knee Arthrodesis

Bernd Preininger, Georg Matziolis, and Carsten Perka

Contents

B. Preininger (✉) • G. Matziolis
Department of Orthopaedics, Center for Musculoskeletal Surgery, Charité-Universitätsmedizin Berlin, Berlin, Germany
e-mail: Bernd.Preininger@charite.de

C. Perka
Department of Orthopaedics and Department of Accident and Reconstructive Surgery, Centre for Musculoskeletal Surgery, Charité – University Medicine, Berlin, Germany
e-mail: carsten.perka@charite.de

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Introduction

Today, permanent fusion of the knee joint – knee arthrodesis – is primarily performed as a leg-sparing salvage procedure in the case of persistent joint infection after total knee arthroplasty. Persistent infections after repeated joint-sparing surgical interventions and insufficiency of the extensor apparatus accompanied by infection are the main indications for this procedure.

Arthrodesis was described as such a salvage procedure after persistent prosthesis infection by Nelson and Evarts as early as 1971 [50]. If an arthrodesis is successful, it represents a therapeutic option for effectively restoring stability to the knee joint with a minimum degree of leg function, thus retaining the patient's mobility.

Indications

The main indications for knee fusion today are persistent infections after repeated revision interventions following knee arthroplasty [2, 72]. However, the assessment of a persistent infection

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can sometimes be difficult and must be done individually for each patient, in order to evaluate which treatment strategy will offer the best overall outcome for the patient. Thus, joint fusion must be considered if the re-implantation of an endoprosthesis is to be regarded as unsuccessful with a high degree of probability [2, 26, 30, 37, 72].

Apart from this, general indications for joint fusion include the presence of infections that do not respond to antibiotics or are very difficult to treat, immune-deficient patients, pronounced skin and soft-tissue defects, destruction of the periarticular tendon and ligament structures, especially of the extensor apparatus, as well as the patient's wish not to have any further prosthesis revisions performed. Above all in young, active patients after extensive tumour resection [17] or in the case of Charcot's joint, joint fusion should be considered. However, the progressive improvement of endoprosthetic treatment options means that good results can also be achieved on patients aged under 50 years after total knee replacement (TKR) [23, 40, 48].

Historically, fusion of the knee joint was performed for the primary therapy of post-traumatic arthritis of the knee in young patients and for the treatment of knee infections, especially joint involvement in tuberculosis, as well as for the primary therapy of rheumatoid arthritis and osteoarthritis. As a result of the drastic reduction of the incidence of tuberculosis and the development of knee arthroplasty, the distribution of the indications has changed markedly and these primary indications have declined.

Successful outcomes after knee arthrodesis depend on the residual bone mass and bone quality [4, 37, 59, 63, 71, 75], as well as on the number of prior interventions [25]. Against this background, it may appear difficult to find the right therapeutic strategy in co-operation with the patient. Nevertheless, it should be taken into account that a fused, relatively pain-free leg still brings better quality of life than above-knee amputation [10, 73], which may become increasingly probable the more endoprosthetic revisions are performed. In addition, it has been shown that knee arthrodeses are associated with a lower infection rate after recurrent TKR infections and mostly lead to a pain-free, stable leg [5, 12, 37, 65].

Table 1 Indications and contra-indications for knee arthrodesis

Indications	Destruction of the extensor apparatus
	Persistent infection after repeated TKA-revision
	Soft tissue defects
	"Difficult to treat" micro-organisms (TBC)
	Immunologically-deficient patients
	Charcot's joint disease
	Post-traumatic arthritis
Contra-indications	Existing impairment of ipsilateral hip or ankle joint and pathologies at the lower spine

Contra-Indications

In patients who only benefit from knee fusion to a limited degree, due to accompanying circumstances, the indication should be reconsidered critically.

In order to achieve a good functional outcome, increased compensatory movement in the adjacent joints and increased loading on the contralateral side are necessary. Thus, in patients with existing impairments in the ipsilateral ankle and hip joint, as well as pathological changes in the region of the lower spine, poorer functional results must be expected after knee fusion. Knee fusion should not be performed in patients after contralateral amputation at the knee or proximally thereof, or in patients with contralateral knee or hip arthrodesis. Indications and Contra-indications are summarized in Table 1.

Pre-Operative Considerations, Preparations and Planning

Many of the patients in whom knee fusion is considered are suffering from a systemic primary disease, such as diabetes mellitus, cardiovascular disease, endocrinological diseases, or an

impaired immune response. Such patients should be prepared optimally for such an intervention from the point of view of their primary disease, to help them cope as well as possible with the subsequent healing and rehabilitation process. After tumour resection, chemotherapy and radiotherapy should have been completed, in order to avoid the associated bone- and wound-healing disorders as far as possible.

A thorough examination of the limb, especially concerning the neurological and vascular status, must be conducted. The local soft-tissue and circulatory situation is particularly critical for the success of joint fusion. Most of the patients who come into question have already had numerous prior interventions at this point [26, 32], so that particular attention must be paid to the site of the previous incisions and scars. In the knee region supplied medially by nerves and vessels, the approach situated as far as possible laterally should always be chosen.

The majority of patients under consideration for arthrodesis have a reduce soft-tissue coverage, which is associated with poorer results after joint fusion [58]. Thus, it is recommended to carefully evaluate this soft-tissue situation preoperatively and, if necessary, to consider interdisciplinary treatment with the aid of plastic surgery techniques.

In radiological examinations, the available bone and any bone defects are determined. On whole-leg radiographs, the leg axis and any possible preoperative difference in leg length are investigated. If the postoperative shortening of leg length to be expected is greater than 5 cm [6, 13, 57, 75, 45, 10, 54], concurrent osteotomy with consecutive callus distraction can be considered and planned [29, 45, 64]. At the same time, such radiographs can be used to consider the surgical options to perform the arthrodesis and to estimate the size and placement of the implants to be used for fixation.

Such planning especially is essential after tumour resection with considerable bone loss. In such cases, it may be necessary to use autologous iliac crest cancellous bone, pedicled vascularised fibula grafts, femur and/or tibia slide osteotomies, as well as allografts.

Prior to surgery, immobilisation of the knee by means of a removable splint or a leg cylinder cast can help the patient to experience the postoperative condition to be expected and to learn how to cope with everyday situations in this condition.

Energy Consumption

Studies have shown that the oxygen consumption when walking with a knee arthrodesis is roughly 30 % higher compared with normal walking, while oxygen consumption when walking after above-knee leg amputation is on average a further 25 % higher [67, 73]. In other studies, however, no differences in energy consumption were observed after arthrodesis and amputation [27]. In an investigation by McClenaghan et. al in a patient population with malignant tumours of the knee, patients achieved slower gait velocities accompanied by an increased oxygen requirement after arthrodesis or amputation vs. rotationplasty [46]. Compared with revision endoprostheses and ablative therapies, arthrodesis brings advantages with regard to physical loading capacity [27]. This aspect should be taken into account when considering knee arthrodesis in elderly patients and those weakened by various other primary diseases.

Goals of Surgery

The goal of knee arthrodesis is a good load-bearing and rapidly established osseous union between femoral and tibial parts of the joint. This follows the general rules of bone healing and requires sufficient bone contact, mechanical stabilisation and greatest possible preservation of circulation in the tissue as well as sufficient soft-tissue coverage. The resections are necessary for a debridement of both the femur and the tibia and should be performed as sparingly as possible to avoid further bone loss.

As goals for alignment of the leg, a straight leg axis in the frontal plane (5–7° valgus between the femoral and tibial stem) and fixation in flexion between 0° and 15° have been described

[10, 35, 57], whereas there is no consensus regarding the best position in the sagittal plane. While a position more or less in extension minimises the loss of leg length, a slight flexion improves comfort when seated and improves the gait pattern [66].

The leg position described above can be achieved ideally by using modular, intramedullary nails, external fixation systems and plates. It is difficult to achieve such a leg position using long intramedullary nails, since they usually have to be bent into shape intraoperatively, as they otherwise produce a straight anatomical axis, i.e. a varus mechanical whole-leg axis.

One- or Two-Stage Procedure

The knee arthrodesis can be performed in one or two sittings [22, 62].

Arthrodesis performed in one stage consists of radical septic debridement of bone and the adjacent soft-tissues and stabilisation of the tibial and femoral bone ends. Assuming no massive pus collection or "difficult to treat" micro-organisms (Gram negative microorganism, Enterococcus, MRSA, ESBL) are found locally, knee arthrodesis can also be performed in one stageafter TKR infection as long as the microorganism is identified and resitogram-adopted antibiotic treatment can be performed [19, 38, 57].

In the case of a one-stage procedure in arthrodeses following tumour resection, a two-phase procedure is recommended. After completion of resection and debridement, the surgical instruments, gowns, gloves and covers are changed and replaced with a clean set [10].

Knee arthrodesis following repeated prior surgical interventions, due to persistent infection after knee arthroplasty or with present "difficult to treat" micro-organisms should ideally be conducted in two stages [34, 37, 38] (Table 2).

Table 2 One-stage versus two-stage procedure

One-stage	Two-stage
Identified micro-organism	Recurrent (TKA-) infection
No "difficult to treat" micro-organism	"Difficult to treat" micro-organism
Tumour resection → 2-phase procedure	

In the first stage, all in situ implants are removed and thorough surgical debridement is performed. Then, a temporary arthrodesis is applied using a cement spacer loaded with antibiotics, with or without axial intramedullary stabilisation. The patient is treated adjuvantly for a further 6 weeks with systemic antibiotics established according to antibiogram. The antibiotics are then paused for 2 weeks and systemic and local inflammatory parameters are determined (CRP, BSR, joint aspiration). The definitive knee fusion can then be conducted in a second intervention.

Surgical Methods

Fixation Methods

The success of arthrodesis is dependent on both an adequate fixation technique and patient-specific factors. The choice of implants that can be used for arthrodesis includes external fixations, intramedullary nails (long, short), internal fixation methods employing plates, as well as combinations of the above. Fixation methods are summarized in Table 3.

Internal Fixation Methods

Intramedullary Methods: Nails

The method most commonly used for stabilisation in knee arthrodesis is the Küntscher intramedullary nail [14–16, 19, 22, 31, 37].

Intramedullary systems for arthrodesis are currently available as modular nails and as non-modular nail systems. The advantage of these intramedullary force bearers is the good,

Table 3 Surgical methods for knee arthrodesis

	Advantages	Disadvantages
Internal Fixation		
Intramedullary Fixation (Nails)	Good fixation stiffness	Intramedullar contact with in situ hip implants
	Early mobilisation	Risk of intramedullary infection-diversion
	"Wearing comfort"	
Extramedullary Fixation (Plates)	Permanent compression over arthrodesis	Difficult soft tissue coverage
External Fixation		
	Good soft tissue management	Poor "wearing comfort"
	External axial compression	Pathological gait pattern
	Coping with reduced bone quality	Pin infection
		Poorer fusion results

permanent stiffness of fixation by a load-bearing implant, the possibility of early mobilisation of the patient and the good "wearing comfort" compared with extramedullary fixation systems.

Arthrodesis nails can be inserted with and without bone cement, whereby the use of bone cement provides the option of topical, if necessary resistogram-adapted antibiosis and thus local infection therapy. Non-cemented nails do not release local antibiotics and may thus favour the development of a re-infection. A hollow cavity remains in the area of the knee, which may be filled by a haematoma and thus also favour the development of a post-operative re-infection. The indication for cemented nails should be restricted in the event of a lack of sufficient cancellous bone and the concurrent use of biological augmentation methods. The first situation offers the bone cement little possibility for interlinking and thus paves the way for loosening of the fixation. The heat released by the cement during the curing phase can damage both free and pedicled vascularised bone grafts. As an alternative to the use of cement as a filling material, "impaction grafting" with allogeneic bone can be considered, although no data have been published concerning the success of this procedure in arthrodesis. The surgical procedure implanting a modular arthrodesis nail is depicted in Figs. 1–3. Please note that a complete removal of all cement particles is considered mandatory in 1- or 2-stage procedures before inserting the new implants.

Modular Nails

Modular nail systems have been widely used for performing knee arthrodesis in recent times [39, 60]. Such systems can be used in the case of an in situ ipsilateral hip endoprosthesis as well as in the case of intramedullary anomalies of the femur and/or tibia. The coupling mechanism and the coupling angle integrated in the implant enables the adjustment of the desired leg position, accompanied by a relatively simple implantation technique. Such nails are generally inserted at the femoral and tibial isthmus, filling the medullary space, and project beyond it by several centimetres.

The greater space requirement of the coupling mechanism compared with non-modular nails is sometimes considered a disadvantage, in turn requiring a more extensive bone defect in the area of the arthrodesis in the course of implantation and perhaps endangering osseous fusion. However, since such implants are often used after repeated revisions of infected endoprostheses, the bone loss caused by the coupling mechanism of the nail is proportionally small.

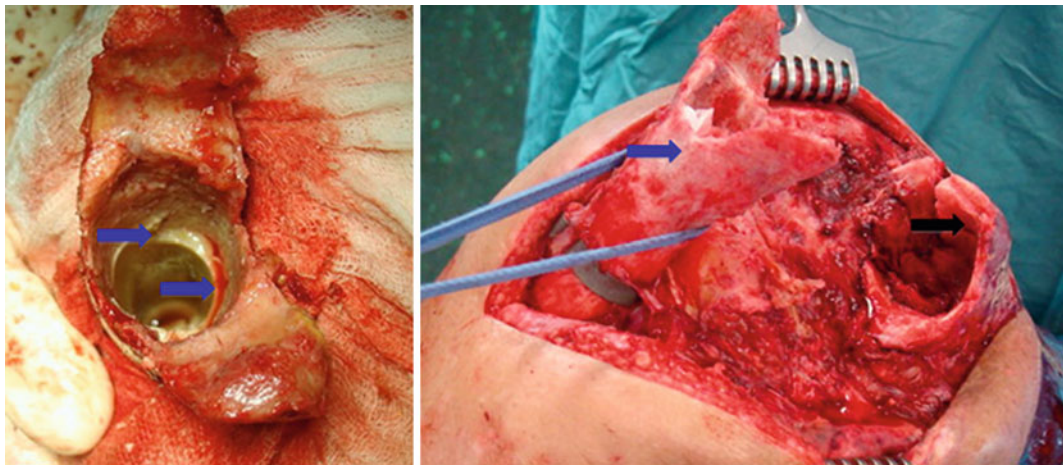

Fig. 1 The femur from distally after complete synovial and bony debridement is shown. A complete removal of all cement particles (blue arrows) is mandatory (left). Intra-operative setting for complete femoral (blue arrow) and tibial (black arrow) exposure before the positioning of the definite implant (right)

Modular nail systems can be inserted using cemented or cementless techniques. (Fig. 4)

Long Nails

The use of long arthrodesis nails, which extend from the proximal femur into the distal tibia, offer the advantage of excellent stability in the knee region as a result of the long intramedullary contact and thus force transmission distance of the nail. Excellent fusion results are the result [31]. However, the disadvantages to be mentioned are the complicated and long surgical technique and increased blood loss [15, 38, 57]. Implantation is either anterograde via the piriform fossa [1, 15] or retrograde through the knee, exiting in the area of the buttocks, and then anterograde again into the tibia. As a result of the size and design of the implant, sterilisation may be problematical, while the nail can migrate and intraoperative fractures of the femur or tibia can occur, as can neurovascular injuries and postoperative gluteal pain.

Contraindications for the use of a long nail are in situ hip implants and a florid infection in the ipsilateral leg.

Extramedullary Methods: Plates

The advantage of using plate fixations for knee fusion is that it enables the application of permanent compression over the arthrodesis. Different techniques have been described for arthrodesis by means of plate fixation; they include single plate techniques [49, 56] and double plate techniques [51] with good results. Disadvantages of this method are the more difficult soft-tissue coverage and possible pain that can arise from the "application" of the plate, especially of the fixed-angle internal fixation systems (Fig. 5).

External Fixation Methods

External fixation methods for knee arthrodesis with the application of two femoral and two tibial pins for maintenance of the compression pressure over the arthrodesis were published by Charnley et al. at an early stage [9]. The indications in this patient population were knee osteoarthritis and tuberculous arthritis.

Advantages of external fixation methods are the good soft-tissue management and the possibility of exerting axial compression on the arthrodesis. Through the variable positioning and diameter variants of the pins,

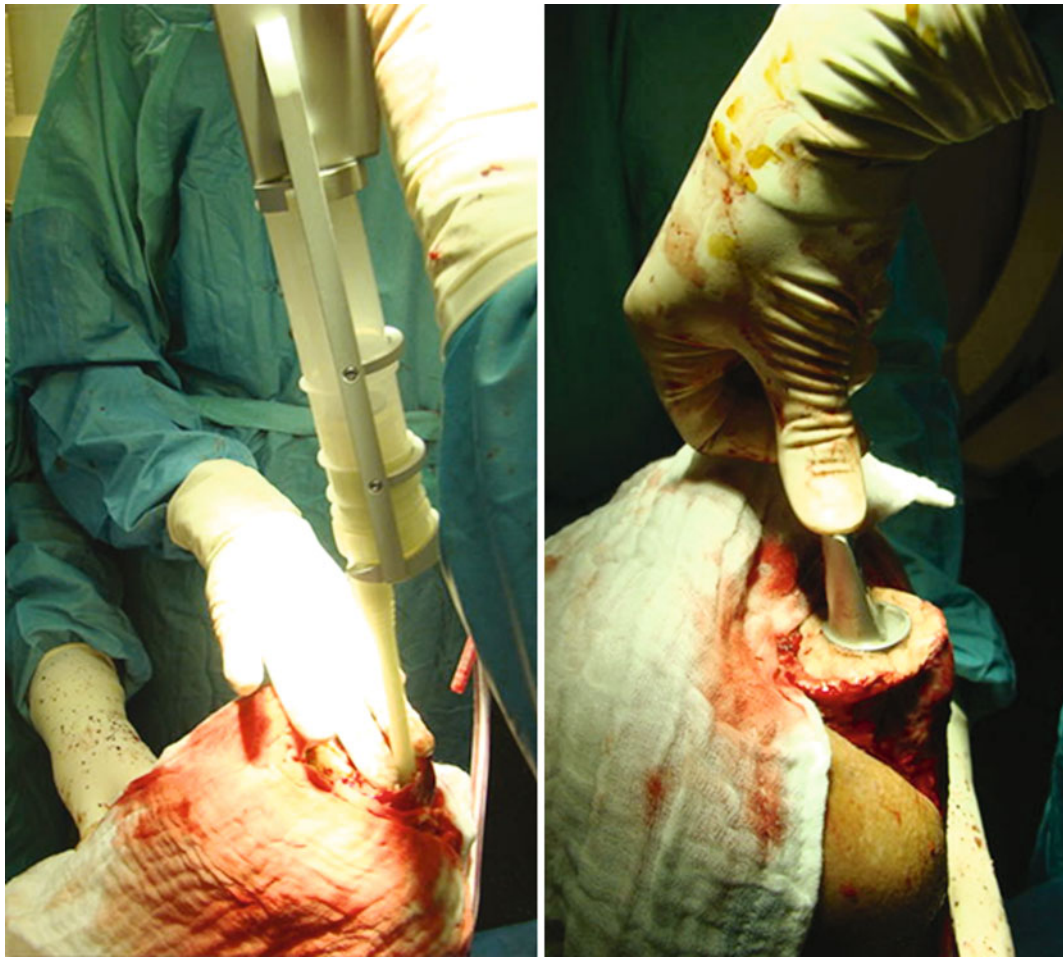

Fig. 2 Pressurizing intramedullary cementing technique (left) and subsequent implantation of the tibial part of the arthrodesis nail is shown (right)

external fixation systems are ideal for infection situations and in the case of generally reduced bone quality [62].

Disadvantages of all fixation methods are the risk of pin infection, poorer fusion results than after internal fixation [41], as well as the difficulty of correctly interpreting the healing outcome and thus of correctly planning removal of the fixation.

Application of the fixation can be mono- or bi-planar, uni- or bi-lateral. Circular frame fixations, such as the Ilizarov ring fixation, are additionally available. The pins of the fixation should be placed bi-cortically in healthy bone and avoid any neurovascular disturbance. The duration of fixation can range from weeks [9] to several months [7, 20, 37]. In studies, the increase in stiffness through bi-planar fixation methods resulted in better fusion results than in monoplanar fixations [7, 24, 25] (Fig. 6).

Ilizarov ring fixation is used for knee arthrodesis, where fusion rates of 68–100 % are reported here [13, 21, 43, 44, 35, 54, 68, 70]. The advantage of this technique is the possibility of the exclusive use of wires for bone anchorage, which means that it can also be applied if bone quality is reduced and offers the possibility of immediate full load-bearing of the affected leg.

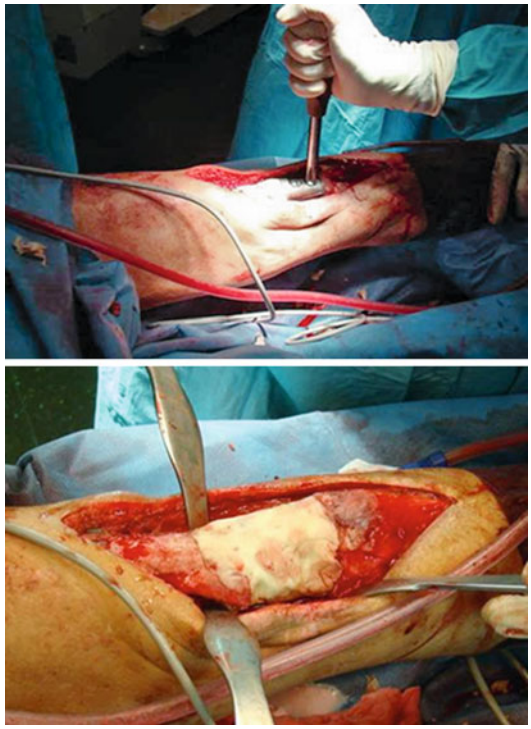

Fig. 3 After complete hardening of the cement the implant connection is performed using 2 screws (above). Finally a cement plug is formed around the connection site avoiding bare metal exposure (below)

Fig. 4 Arthrodesis performed with an intramedullary, cemented, modular nail

Disadvantages of ring fixation methods are the more demanding surgical technique as well as their restricted use in adipose patients, due to the correspondingly larger ring diameter. In addition, the required circular extensions hinder the patient from walking with closed legs and thus results in a pathological gait pattern.

Oostenbroek et al. [54] reported on their experience in 15 patients in whom 93 % achieved a successful osseous union with the Ilizarov technique. 53 % of these patients had previously undergone attempted arthrodesis, whereby the patient population was as a whole older and many had been suffering from osteomyelitis for many years. The complication rate was 80 %, although the authors attributed this to poor bone quality and quantity. The mean duration of treatment was 51 weeks. In cases of difficult to treat recurrent infections, treatment always lasted more than 1 year.

Augmentation in the Case of Bone Defects

Biological Augmentation

Massive loss of bone substance after tumour resection as well as after extensive infection-related debridement often make it necessary to use bone grafts and/or autologous and allogenic bone replacement materials [3, 42]. The general principles for applying such

Fig. 5 Arthrodesis performed with a double plate technique (LCP-plates). Note the integration of the patella performed with a screw fixation

methods must be adhered to precisely here, too; for example, their use is not indicated in acute infectious stages or in the event of strongly limited circulation of the adjacent tissue. Some studies have reported on the successful use of autologous iliac crest cancellous bone after an initially delayed course of healing. The application was made on average 4 months after the index operation [17, 61, 74].

Pedicled Vascularised Fibular Graft

The use of a vascularised ipsilateral fibula graft in addition to one of the above-mentioned fixation techniques represents a biological option in cases with a large defect length [53, 61, 69].

This method is technically demanding and requires microsurgical abilities as well as well-functioning postoperative monitoring. Usui et al. [69] report on successful osseous union in 16 of 17 patients in a patient population with on average 14 cm loss of bone substance by means of locally pedicled fibula transfer. The average duration of surgery was 8.5 h, with a mean blood loss of 2,322 mL. In the follow-up investigation presented by Rasmussen et al. (on average 6 cm bone defect), osseous union of the defect was observed in 12 of 13 patients after an average follow-up of 51 months; one patient had to undergo amputation [61].

Complications

The complication rate after knee arthrodesis is high and is estimated to be between 12 % and 85 % [11, 33, 37, 54, 63]. Complications are in particular infection or tumour recurrence, pseudarthroses and peroneal nerve lesions.

Fig. 6 Arthrodesis performed with a biplanar external fixation device using carbon connection rods

Implant-specific complications, such as periprosthetic pain at the ends of intramedullary implants, implant loosening and periprosthetic fractures are treated analogously to those of endoprostheses.

A lesion of the peroneal nerve can be addressed secondarily by surgical neurolysis [47, 52]. Symptomatic pseudarthroses are mostly treated with a change in procedure. The use of alternative, additional fixations (external fixation) as well as the local application of bone and bone replacement materials are to be mentioned here.

Persistent infections must be surgically revised if systemic suppressant therapy fails. Pin infections must be treated by replacing the affected pins.

Alternative Treatment Options

Alternative therapy options to arthrodesis are chronic antibiotic infection suppression, artificial arthrodesis – without osseous union by means of intramedullary nails and cement spacers, resection arthroplasty or amputation.

Antibiotic infection suppression shows only limited effectiveness, with a success rate of 25 % [10, 57].

Amputation or resection arthroplasty should be reserved for the treatment of particularly severe cases. Among others, they include life-threatening infections, infections that persist after repeated attempts to treat them, untreatable soft-tissue defects, extensive bone losses, and the patient's wishes after repeated attempts at reconstructive surgery which have failed.

Resection arthroplasties are best tolerated by patients with low functional demands who already have limited mobility involving several joints. Advantages of resection arthroplasty for the patient are a better sitting position, while the great disadvantage is pain and instability when walking [18].

The last therapeutic option is amputation proximal to the knee. However, this option leads to poor functional results [32, 55], so it should

primarily only be offered to already immobile patients. Nevertheless, amputation is indicated in the case of strongly limited vascular status of the limb, in the case of extensive tumour involvement and/or strongly virulent micro-organisms.

Conversion of the Arthrodesis to a Total Knee Arthroplasty

The implantation of a knee replacement after a previous arthrodesis operation is associated with a considerable complication rate and often repeated arthrodesis application [8, 28, 36]. The main problems of such a procedure are a deficient extensor apparatus, mostly in combination with atrophic quadriceps musculature and shrunk peri-articular soft-tissue (joint capsule, skin). Such an intervention is usually performed upon the patient's insistence; the indication should be considered carefully on an individual basis.

Summary

Knee arthrodesis serves as a salvage procedure after knee replacement infections or tumour resections that can no longer be treated by endoprosthetic (revision) interventions. The success of such an arthrodesis depends primarily on the available bone and soft-tissue quality. The technical conduct of the surgical intervention is difficult. Only surgeons who can manage the multiple complications that may occur should perform this intervention. Patients with a fully healed knee arthrodesis are in a position to walk effectively and have functional advantages over patients who have undergone amputation proximal to the knee.

References

1. Bargiotas K, Wohlrab D, et al. Arthrodesis of the knee with a long intramedullary nail following the failure of a total knee arthroplasty as the result of infection. J Bone Joint Surg Am. 2006;88(3):553–8.
2. Barrack RL, Butler RA, et al. Managing the infected knee: as good as it gets. Orthopedics. 2000;23(9):991–2.
3. Bassiony AA, Abdelrahman M, et al. Resection arthrodesis for the management of aggressive giant cell tumor of the distal femur. Indian J Orthop. 2009;43(1):67–71.
4. Behr JT, Chmell SJ, et al. Knee arthrodesis for failed total knee arthroplasty. Arch Surg. 1985;120(3):350–4.
5. Bengston S, Knutson K, et al. Treatment of infected knee arthroplasty. Clin Orthop Relat Res. 1989;245:173–8.
6. Brodersen MP, Fitzgerald Jr RH, et al. Arthrodesis of the knee following failed total knee arthroplasty. J Bone Joint Surg Am. 1979;61(2):181–5.
7. Brooker Jr AF, Hansen Jr NM. The biplane frame: modified compression arthrodesis of the knee. Clin Orthop Relat Res. 1981;160:163–7.
8. Cameron HU, Hu C. Results of total knee arthroplasty following takedown of formal knee fusion. J Arthroplasty. 1996;11(6):732–7.
9. Charnley J, Lowe HG. A study of the end-results of compression arthrodesis of the knee. J Bone Joint Surg Br. 1958;40-B(4):633–5.
10. Conway JD, Mont MA, et al. Arthrodesis of the knee. J Bone Joint Surg Am. 2004;86-A(4):835–48.
11. Cunningham JL, Richardson JB, et al. A mechanical assessment of applied compression and healing in knee arthrodesis. Clin Orthop Relat Res. 1989;242:256–64.
12. Damron TA, McBeath AA. Arthrodesis following failed total knee arthroplasty: comprehensive review and meta-analysis of recent literature. Orthopedics. 1995;18(4):361–8.
13. David R, Shtarker H, et al. Arthrodesis with the Ilizarov device after failed knee arthroplasty. Orthopedics. 2001;24(1):33–6.
14. De Vil J, Almqvist KF, et al. Knee arthrodesis with an intramedullary nail: a retrospective study. Knee Surg Sports Traumatol Arthrosc. 2008;16(7):645–50.
15. Donley BG, Matthews LS, et al. Arthrodesis of the knee with an intramedullary nail. J Bone Joint Surg Am. 1991;73(6):907–13.
16. Ellingsen DE, Rand JA. Intramedullary arthrodesis of the knee after failed total knee arthroplasty. J Bone Joint Surg Am. 1994;76(6):870–7.
17. Enneking WF, Shirley PD. Resection-arthrodesis for malignant and potentially malignant lesions about the knee using an intramedullary rod and local bone grafts. J Bone Joint Surg Am. 1977;59(2):223–36.
18. Falahee MH, Matthews LS, et al. Resection arthroplasty as a salvage procedure for a knee with infection after a total arthroplasty. J Bone Joint Surg Am. 1987;69(7):1013–21.
19. Fern ED, Stewart HD, et al. Curved Kuntscher nail arthrodesis after failure of knee replacement. J Bone Joint Surg Br. 1989;71(4):588–90.
20. Fidler MW. Knee arthrodesis following prosthesis removal. Use of the Wagner apparatus. J Bone Joint Surg Br. 1983;65(1):29–31.

21. Garberina MJ, Fitch RD, et al. Knee arthrodesis with circular external fixation. Clin Orthop Relat Res. 2001;382:168–78.
22. Garcia-Lopez I, Aguayo MA, et al. Knee arthrodesis with the Vari-Wall nail for treatment of infected total knee arthroplasty. Acta Orthop Belg. 2008;74(6):809–15.
23. Gill GS, Chan KC, et al. 5- to 18-year follow-up study of cemented total knee arthroplasty for patients 55 years old or younger. J Arthroplasty. 1997;12(1):49–54.
24. Hagemann WF, Woods GW, et al. Arthrodesis in failed total knee replacement. J Bone Joint Surg Am. 1978;60(6):790–4.
25. Hak DJ, Lieberman JR, et al. Single plane and biplane external fixators for knee arthrodesis. Clin Orthop Relat Res. 1995;316:134–44.
26. Hanssen AD, Trousdale RT, et al. Patient outcome with reinfection following reimplantation for the infected total knee arthroplasty. Clin Orthop Relat Res. 1995;321:55–67.
27. Harris IE, Leff AR, et al. Function after amputation, arthrodesis, or arthroplasty for tumors about the knee. J Bone Joint Surg Am. 1990;72(10):1477–85.
28. Henkel TR, Boldt JG, et al. Total knee arthroplasty after formal knee fusion using unconstrained and semiconstrained components: a report of 7 cases. J Arthroplasty. 2001;16(6):768–76.
29. Hessmann M, Gotzen L, et al. Knee arthrodesis with a unilateral external fixator. Acta Chir Belg. 1996;96(3):123–7.
30. Husted H, Toftgaard Jensen T. Clinical outcome after treatment of infected primary total knee arthroplasty. Acta Orthop Belg. 2002;68(5):500–7.
31. Incavo SJ, Lilly JW, et al. Arthrodesis of the knee: experience with intramedullary nailing. J Arthroplasty. 2000;15(7):871–6.
32. Isiklar ZU, Landon GC, et al. Amputation after failed total knee arthroplasty. Clin Orthop Relat Res. 1994;299:173–8.
33. Johannsen HG, Skov O, et al. Knee arthrodesis with external ring fixator after infected knee arthroplasty. Ugeskr Laeger. 2005;167(35):3295–6.
34. Jorgensen PS, Torholm C. Arthrodesis after infected knee arthroplasty using long arthrodesis nail. A report of five cases. Am J Knee Surg. 1995;8(3):110–3.
35. Jung KA, Lee SC, et al. Arthrodesis of the knee using computer navigation in failed total knee arthroplasty. Orthopedics. 2009;32(3):209.
36. Kim YH, Kim JS, et al. Total knee arthroplasty after spontaneous osseous ankylosis and takedown of formal knee fusion. J Arthroplasty. 2000;15(4):453–60.
37. Knutson K, Lindstrand A, et al. Arthrodesis for failed knee arthroplasty. A report of 20 cases. J Bone Joint Surg Br. 1985;67(1):47–52.
38. Lai KA, Shen WJ, et al. Arthrodesis with a short Huckstep nail as a salvage procedure for failed total knee arthroplasty. J Bone Joint Surg Am. 1998;80(3):380–8.
39. Letartre R, Combes A, et al. Knee arthodesis using a modular customized intramedullary nail. Orthop Traumatol Surg Res. 2009;95(7):520–8.
40. Lonner JH, Hershman S, et al. Total knee arthroplasty in patients 40 years of age and younger with osteoarthritis. Clin Orthop Relat Res. 2000;380:85–90.
41. Mabry TM, Jacofsky DJ, et al. Comparison of intramedullary nailing and external fixation knee arthrodesis for the infected knee replacement. Clin Orthop Relat Res. 2007;464:11–5.
42. MacDonald JH, Agarwal S, et al. Knee arthrodesis. J Am Acad Orthop Surg. 2006;14(3):154–63.
43. Manzotti A, Pullen C, et al. Knee arthrodesis after infected total knee arthroplasty using the Ilizarov method. Clin Orthop Relat Res. 2001;389:143–9.
44. Manzotti A, Pullen C, et al. The Ilizarov method for failed knee arthrodesis following septic TKR. Knee. 2001;8(2):135–8.
45. Manzotti A, Pullen C, et al. Knee arthrodesis and limb lengthening in the treatment of infected total knee arthroplasty: case report. J Trauma. 2002;52(2):359–63.
46. McClenaghan BA, Krajbich JI, et al. Comparative assessment of gait after limb-salvage procedures. J Bone Joint Surg Am. 1989;71(8):1178–82.
47. Mont MA, Dellon AL, et al. The operative treatment of peroneal nerve palsy. J Bone Joint Surg Am. 1996;78(6):863–9.
48. Mont MA, Lee CW, et al. Total knee arthroplasty in patients </=50 years old. J Arthroplasty. 2002;17(5):538–43.
49. Munzinger U, Knessl J, et al. Arthrodesis following knee arthroplasty. Orthopade. 1987;16(4):301–9.
50. Nelson CL, Evarts CM. Arthroplasty and arthrodesis of the knee joint. Orthop Clin North Am. 1971;2(1):245–64.
51. Nichols SJ, Landon GC, et al. Arthrodesis with dual plates after failed total knee arthroplasty. J Bone Joint Surg Am. 1991;73(7):1020–4.
52. Nogueira MP, Paley D, et al. Nerve lesions associated with limb-lengthening. J Bone Joint Surg Am. 2003;85-A(8):1502–10.
53. Nouri H, Meherzi MH, et al. Knee arthrodesis using a vascularized fibular rotatory graft after tumor resection. Orthop Traumatol Surg Res. 2010;96(1):57–63.
54. Oostenbroek HJ, van Roermund PM. Arthrodesis of the knee after an infected arthroplasty using the Ilizarov method. J Bone Joint Surg Br. 2001;83(1):50–4.
55. Pring DJ, Marks L, et al. Mobility after amputation for failed knee replacement. J Bone Joint Surg Br. 1988;70(5):770–1.
56. Pritchett JW, Mallin BA, et al. Knee arthrodesis with a tension-band plate. J Bone Joint Surg Am. 1988;70(2):285–8.

57. Puranen J, Kortelainen P, et al. Arthrodesis of the knee with intramedullary nail fixation. J Bone Joint Surg Am. 1990;72(3):433–42.
58. Rand JA, Bryan RS. The outcome of failed knee arthrodesis following total knee arthroplasty. Clin Orthop Relat Res. 1986;205:86–92.
59. Rand JA, Bryan RS, et al. Failed total knee arthroplasty treated by arthrodesis of the knee using the Ace-Fischer apparatus. J Bone Joint Surg Am. 1987;69(1):39–45.
60. Rao MC, Richards O, et al. Knee stabilisation following infected knee arthroplasty with bone loss and extensor mechanism impairment using a modular cemented nail. Knee. 2009;16(6):489–93.
61. Rasmussen MR, Bishop AT, et al. Arthrodesis of the knee with a vascularized fibular rotatory graft. J Bone Joint Surg Am. 1995;77(5):751–9.
62. Riouallon G, Molina V, et al. An original knee arthrodesis technique combining external fixator with Steinman pins direct fixation. Orthop Traumatol Surg Res. 2009;95(4):272–7.
63. Rothacker Jr GW, Cabanela ME. External fixation for arthrodesis of the knee and ankle. Clin Orthop Relat Res. 1983;180:101–8.
64. Rozbruch SR, Ilizarov S, et al. Knee arthrodesis with simultaneous lengthening using the Ilizarov method. J Orthop Trauma. 2005;19(3):171–9.
65. Schoifet SD, Morrey BF. Persistent infection after successful arthrodesis for infected total knee arthroplasty. A report of two cases. J Arthroplasty. 1990;5(3):277–9.
66. Siller TN, Hadjipavlou A. Knee arthrodesis: long-term results. Can J Surg. 1976;19(3):217–9.
67. Somayaji HS, Tsaggerides P, et al. Knee arthrodesis – a review. Knee. 2008;15(4):247–54.
68. Spina M, Gualdrini G, et al. Knee arthrodesis with the Ilizarov external fixator as treatment for septic failure of knee arthroplasty. J Orthop Traumatol. 2010;11(2):81–8.
69. Usui M, Ishii S, et al. Arthrodesis of knee joint by vascularized fibular graft. Microsurgery. 1996;17(1):2–8.
70. VanRyn JS, Verebelyi DM. One-stage debridement and knee fusion for infected total knee arthroplasty using the hybrid frame. J Arthroplasty. 2002;17(1):129–34.
71. Wade PJ, Denham RA. Arthrodesis of the knee after failed knee replacement. J Bone Joint Surg Br. 1984;66(3):362–6.
72. Wasielewski RC, Barden RM, et al. Results of different surgical procedures on total knee arthroplasty infections. J Arthroplasty. 1996;11(8):931–8.
73. Waters RL, Perry J, et al. Energy cost of walking of amputees: the influence of level of amputation. J Bone Joint Surg Am. 1976;58(1):42–6.
74. Weiner SD, Scarborough M, et al. Resection arthrodesis of the knee with an intercalary allograft. J Bone Joint Surg Am. 1996;78(2):185–92.
75. Wilde AH, Stearns KL. Intramedullary fixation for arthrodesis of the knee after infected total knee arthroplasty. Clin Orthop Relat Res. 1989;248:87–92.