ORIGINAL ARTICLE

Knee arthrodesis using a customised modular intramedullary nail in failed infected total knee arthroplasty

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KEYWORDS
Knee;
Arthrodesis;
Nailing;
Infection;
Total knee arthroplasty

Summary

Background: Knee arthrodesis is used to treat patients with failed infected total knee arthroplasty (TKA). Among fixation methods, intramedullary nailing increases the chances of bone union but may carry a risk of infection around the nail. This risk is not well understood, because available case-series studies were not confined to patients with knee infection.

Hypothesis: Infection recurrence rates after knee arthrodesis with intramedullary nailing used to treat failed infected TKA are similar to those seen with other fixation methods.

Methods: We retrospectively reviewed 31 cases of knee arthrodesis with fixation by a modular intramedullary nail performed at a subspecialized center treating complex osteoarticular infections (CRIoAC). The antibiotic regimen was determined based on multidisciplinary discussions and microbiological studies of preoperative and intraoperative specimens. Mean follow-up was 50 ± 22 months (range, 28–90 months). Arthrodesis was performed in one stage (n = 6) or two stages (n = 25). Success was defined as presence, after a postoperative follow-up of at least 24 months, based on the following criteria: normal erythrocyte sedimentation rate and/or C-reactive protein, no wound inflammation or sinus tract, no revision surgery, and no antibiotic treatment. Bone union was not a criterion for a successful arthrodesis procedure.

Results: Removal of the fixation material was required in three patients and long-term palliative antibiotic therapy in three patients (fixation material in place with repeated positive specimens)
Introduction

Knee arthrodesis is an option in patients with refractory infection of a total knee arthroplasty (TKA) [1]. Knee arthrodesis is viewed as a salvage procedure, which may serve to avoid amputation, in patients with uncontrollable infection and/or extensor apparatus deficiency or extensive skin lesions [2]. Of the various available fixation methods, the two most widely used are compression by an external fixator [3] and intramedullary nailing [4].

With intramedullary nailing, a gap can be left to avoid a major leg-length discrepancy in the event of severe bone loss. This point constitutes an important advantage, as shortening after knee arthrodesis is often poorly accepted by the patients [5–7]. Several case-series studies of intramedullary nailing for knee arthrodesis have been published [5,8]. However, the studied population included patients with or without infection [5–7] and the cohorts with infection comprised fewer than 20 patients [5,6,8–10]. Consequently, the success rate in terms of eradication of the infection is unclear. In contrast to external fixation [2], nailing may promote persistence or recurrence of the infection [5–10]. In addition, the antibiotic regimens used in these studies are not always described in detail [6–10], despite their crucial role in eradicating the infection [11,12].

We hypothesised that, provided the patients received an appropriate antibiotic regimen determined in multidisciplinary discussions, the infection recurrence rate after intramedullary nailing was similar to that seen with external fixation. We tested this hypothesis in a population of patients with chronic TKA infection managed by a single surgical team using a standardised treatment protocol to ensure uniformity in quality of care. Our secondary objective was to assess function and patient satisfaction using a patient self-administered evaluation score.

Materials and methods

Patients

We retrospectively reviewed the medical charts of patients managed at the reference centre for complex osteo-articular infections (CRIÖAC) for north-western France (Lille-Tourcoing / Rouen / Caen / Amiens area). Of 152 chronic TKA infections (meeting the criteria of Tsukayama et al. [9]) managed between 2005 and 2008, 39 were managed with knee arthrodesis. Fixation was by an external fixator in eight cases and intramedullary nailing in 31 patients. These 31 patients form the basis for the present study. Arthrodesis was performed either after failure of TKA replacement in one stage (n = 1) or two stages (n = 25) or immediately in the event of a disrupted extensor apparatus (n = 6).

Mean age at arthrodesis was 67 ± 12 years (range, 48–80 years) and mean number of revision procedures before arthrodesis was 2.1 ± 0.8 (1–4). Arthrodesis was performed in one stage (n = 6) or two stages (n = 25). In all 31 cases, microbiological documentation was obtained via the examination of intraoperative specimens (Table 1). *Staphylococcus aureus* (SA) was the only organism in 10 cases (including 1 case with methicillin-resistant SA [MRSA]) and a coagulase-negative staphylococcus (CNS) was the only organism in six cases (including 1 with methicillin-resistant CNS [MRCNS]). In seven (22.5%) patients, several organisms were found (Table 1). Of the 31 patients, 13 had diabetes mellitus. The ASA score [12] was 3 in seven patients, 2 in 22 patients, and 1 in two patients.

Operative technique

A customised dual-component arthrodesis nail (Link EndoModel™, Boves, France) was fashioned based on radiographic measurements (Figs. 1 and 2). Each patient was first discussed in a multidisciplinary meeting (infectiologist, anaesthesiologist, and surgeon), during which the antibiotic regimen was defined based on a protocol derived from recommendations by Zimmerli et al. [13]. No tourniquet was used in any of the patients. The first step was removal of the TKA in six cases and removal of a previously implanted cement spacer in 25 cases. Microbiological specimens were collected and probabilistic antibiotic therapy was then started intravenously (vancomycin + cefotaxime or cefepime). The antibiotic regimen was adjusted according to the microbiological results, with 5 days of intravenous treatment followed by 3 months of oral treatment with two antibiotics.

The femur was reamed to the diameter of the nails, which were implanted without cement by press-fit (surface-sanded...
titanium without hydroxyapatite) into the diaphyses. The two components were then linked to each other. In patients with limited bone loss (gap < 2 cm), autologous bone grafting was performed (n = 23: 20 with patellar bone and 3 with iliac bone). In the remaining eight patients, the gap was greater than 2 cm and no attempt was made to fill it. After surgery, no immobilisation was used. All patients were encouraged to resume full weight bearing on the operated limb.

• self-evaluation of pain and function using the Oxford score [14];
• detection and measurement of leg-length discrepancy requiring compensation;
• and patient satisfaction index. The radiographs were assessed for signs of bone union between the femur and tibia (Fig. 3). Finally, the erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP) level were measured.

### Outcome evaluation

Clinical, radiological, and laboratory follow-up data were collected over a mean of 50 ± 22 months (28–90 months). The following clinical criteria were assessed:

- condition of the scar, signs of local and/or systemic infection (intra-articular effusion, local heat and/or erythema, sinus tract, fever);

Postoperative follow-up was at least 2 years. A full recovery was defined as presence of all the following [15]: normal ESR and/or CRP, no evidence of inflammation of the scar and no sinus tract, no further antibiotic therapy, and no revision surgery. Bone union was not among our objectives, given the severe bone loss in some of our patients. Patients who died within the first 2 years after the arthrodesis were classified as not fully recovered.

### Table 1  Microorganisms recovered in 31 patients treated with knee arthrodesis and intramedullary nailing.

<table>
<thead>
<tr>
<th>Patient</th>
<th>Bacteria identified</th>
<th>Bacteria found in the event of recurrent/persistent infection (during removal of the nail or before initiating palliative antibiotic therapy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1, a, b</td>
<td>MSCNS and Enterobacter cloacae</td>
<td>MSCNS</td>
</tr>
<tr>
<td>2</td>
<td>SARM</td>
<td></td>
</tr>
<tr>
<td>3 a</td>
<td>MSSA and MSCNS</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>MSSA</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>MSSA</td>
<td></td>
</tr>
<tr>
<td>6 a</td>
<td>Escherichia coli and Enterococcus faecalis</td>
<td>Same organism + SASM</td>
</tr>
<tr>
<td>7</td>
<td>MSSA</td>
<td>Same organism</td>
</tr>
<tr>
<td>8 c</td>
<td>Enterococcus faecalis</td>
<td>SCNMS</td>
</tr>
<tr>
<td>9</td>
<td>MSSA</td>
<td></td>
</tr>
<tr>
<td>10 f</td>
<td>SCNMR</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Pseudomonas aeruginosa</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>MSCNS</td>
<td></td>
</tr>
<tr>
<td>13 a</td>
<td>MSSA and streptococcus</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>MSCNS</td>
<td></td>
</tr>
<tr>
<td>15 a</td>
<td>MSCNS and Staphylococcus capitis</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Streptococcus</td>
<td></td>
</tr>
<tr>
<td>17 a</td>
<td>MSCNS and Enterococcus faecalis</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>MSCNS</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>MSCNS</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Streptococcus agalactiae</td>
<td></td>
</tr>
<tr>
<td>21 b a</td>
<td>Fusobacterium spp.</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>Pseudomonas aeruginosa</td>
<td></td>
</tr>
<tr>
<td>23 a</td>
<td>Staphylococcus warneri and MSCNS</td>
<td></td>
</tr>
<tr>
<td>24 f</td>
<td>MSSA</td>
<td>SARM</td>
</tr>
<tr>
<td>25</td>
<td>MSSA</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>MSCNS</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>MSSA</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>MSSA</td>
<td></td>
</tr>
<tr>
<td>29 b a</td>
<td>MSSA</td>
<td>Same organism</td>
</tr>
<tr>
<td>30</td>
<td>Escherichia coli</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>Streptococcus</td>
<td></td>
</tr>
</tbody>
</table>

CNS: coagulase-negative staphylococcus; SA: Staphylococcus aureus; MS: methicillin-susceptible; MR: methicillin-resistant.

* Polymicrobial infections.
* Palliative antibiotic therapy.
* Removal of the nail.
Figure 1  Cement spacer used for two-stage arthrodesis. The anteroposterior view (shown here) and lateral view equipped with a graduated ruler were used to fashion the customised implant.

Statistical methods

The statistical analysis was done by the biostatistics unit in Lille, France, using Statview™ and SAS™ (SAS Institute Inc., Cary, NC, USA). Univariate analyses were performed using the Chi² test for categorical variables, with Yates' correction for small samples and Fisher’s F test. Regression analysis was used for quantitative variables. Kaplan-Meier survival curves were plotted, with the 95% confidence intervals (95% CIs), for revision surgery with nail removal and for revision surgery because of persistent infection in patients who failed to meet one of the criteria for eradication of the infection. Values of $P < 0.05$ were considered significant.

Results

Revision surgery and death

Revision surgery for recurrent infection was required in three patients who had draining sinus tracts and laboratory evidence of inflammation. The organisms recovered in these three patients are reported in Table 1:

- in one patient with a fracture and septic non-union between the nail and a hip prosthesis, surgery was required 18 months after the knee arthrodesis procedure for implantation of a massive hip-knee prosthesis with knee arthrodesis (replacement with a "total femur"). This treatment was successful in controlling the infection, but bone union was not achieved;
- another patient required removal of the nail after 17 months followed by arthrodesis with external fixation. Bone union was obtained but only at the price of limb shortening;
- in the third patient, bone union was not obtained and the nail was removed after 14 months. After implantation of a spacer, another nail was placed. The severe bone loss precluded bone healing, but no further surgery was required over the 26-month follow-up.

Three patients died more than 24 months after the knee arthrodesis (after 26, 34, and 55 months, respectively) from causes unrelated to the procedure. None of the patients required amputation for uncontrolled infection.

Figure 2  Customised intramedullary nail used in the study patients (Link, Boves, France).

Figure 3  Bone union.
surgical procedures left a gap that was difficult to fill. Of the 23 patients in whom the gap was filled, 19 exhibited bone union, compared to only two of the eight patients without filling (F test, 0.005); the initial gap measured 2 to 3 cm in these two patients and more than 3 cm in the remaining six patients. Bone union was not obtained in the three patients who required revision surgery because of recurrent infection. Failure of the material did not occur in any of the patients without recurrent infection and without bone union.

Laboratory data and infection eradication rate

Recurrent or persistent infection was noted in six (19.4%) patients, the three patients with recurrent infection and three patients in whom chronic palliative vibramycin therapy was started on day 90 because of laboratory marker elevation without clinical or radiological evidence of infection. In these last three patients, the microbiological specimens obtained before vibramycin initiation showed either persistence of the same pathogen (n=1) or a new pathogen alone or with the previous organism (Table 1). None of these 3 patients had required revision surgery at last follow-up (28, 40, and 44 months, respectively).

Survival analysis

Mean follow-up for this analysis was 50±22 months. Arthrodesis survival without revision surgery for nail removal was 77.8±4% (Fig. 6). Arthrodesis survival without revision surgery for recurrent or persistent infection was 74.6±4.2% (Fig. 7).

Discussion

The primary objective of this study was to determine the rate of recurrent or persistent infection after knee arthrodesis with fixation by a dual-component intramedullary nail (6/31, 19.4%) in patients managed in a reference centre with a protocol that included appropriate antibiotic therapy. Many previous case-series studies of knee arthrodesis included small numbers of patients [6,8], were not confined to patients with failed infected TKA [5,6] and, in contrast to our study, used heterogeneous infection management protocols that were more or less well defined [5,6,8,10,16,17] (Table 2). We studied a uniform population of patients with failed infected TKA treated using a standardised protocol. This study design allowed us to obtain a fairly accurate estimate of the risk of infection after arthrodesis with nail fixation, which was 19.4% in our patients. However, we did not obtain comparative data, since the indications for intramedullary nailing and external fixation are different in our centre.

The risk of recurrent infection after arthrodesis with intramedullary nail fixation is unclear in the literature. Volpi et al. [6] reported two instances among 14 patients. In a population of patients who underwent knee arthrodesis for a variety of reasons, most of which did not involve infection, Lai and Huang [16] recorded only three cases of infection among 68 patients managed with arthrodesis and

Clinical outcomes

In the three above-mentioned patients, sinus tracts developed in the setting of recurrent clinical infection. Residual pain with no evidence of recurrent infection was noted in 14 patients. Mean leg-length discrepancy was 10±10 mm (5–34 mm), and 20 patients required compensation. Mean Oxford score was 41±11 (23–58); 9 patients had scores between 20 and 30 and 22 had scores greater than 30, indicating poor outcomes and reflecting the noticeable dissatisfaction among patients, who initially accepted to undergo TKA as a means of relieving their pain.

Dissatisfaction with the procedure was reported by 22 patients. The mean reason for dissatisfaction was loss of mobility. The small leg-length discrepancy was considered a favourable feature by 25 patients.

Radiological outcomes

In 10 (33%) patients, union of the femur and tibia was not obtained. This absence of union had no negative impact on the result, since the nail acted as a fixed prosthesis (Figs. 4 and 5). The often severe bone loss after several
intramedullary nailing. Crockarell and Mihalko [8] estimated that the risk of recurrent infection after knee arthrodesis with intramedullary nailing ranged from 0.5 to 15%. All eight patients with arthrodesis and intramedullary nailing studied by Lee et al. [17] experienced bone union and remained free of recurrent infection. These case-series are difficult to compare, as the sample sizes are often smaller than in our study [6,14,16–18] and, more importantly, these series were not limited to TKA infections [6,7,16] (Table 2).

Among other arthrodesis techniques, plate fixation is not widely used [19] and external fixation is generally preferred [3,20]. External fixation is associated with a lower risk of recurrent infection, although complications related to the pins may occur. Parratte et al. [20] observed no cases of recurrent infection among 14 patients managed with external fixation. In a comparative study by Mabry et al. [18], the risk of recurrent infection was 8.3% with intramedullary nailing compared to only 4.9% with external fixation. However, these studies were not confined to patients with failed infected TKA, and comparisons are therefore difficult, although external fixation seems associated with lower infection rates [9,18]. The revision procedures in our case-series consisted in either implantation of another nail or external fixation, demonstrating that another technique can be used after failed intramedullary nailing.

The second objective of this study was to evaluate patient satisfaction. The information delivered to the patients before the procedure did not always include a

![Figure 6](image_url) Survival curve for revision surgery with removal of the nail (77.8 ± 4%).

![Figure 7](image_url) Survival curve for infection (74.6 ± 4.2%).
Table 2 Comparison of recurrent infection rates and bone union rates in various case-series studies of arthrodesis with intramedullary nailing for failed infected total knee arthroplasty.

<table>
<thead>
<tr>
<th>Study</th>
<th>Technique</th>
<th>Number of patients</th>
<th>Infected TKA</th>
<th>Recurrent infection, n (%)</th>
<th>Bone union, n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volpi et al. [6]</td>
<td>Customised nail</td>
<td>14</td>
<td>12</td>
<td>2 (16.6)</td>
<td>13/14 ±92%</td>
</tr>
<tr>
<td>Incavo et al. [7]</td>
<td>Nail with interlocking screw</td>
<td>22</td>
<td>17</td>
<td>1 (5.8)</td>
<td>17/21 ±80%</td>
</tr>
<tr>
<td>Bargiotas et al. [9]</td>
<td>Nail with interlocking screw</td>
<td>12</td>
<td>12</td>
<td>2 (16.6)</td>
<td>10/12 ±83%</td>
</tr>
<tr>
<td>Lai et Huang [16]</td>
<td>Nail with interlocking screw (3 different techniques)</td>
<td>68</td>
<td>40</td>
<td>3 (7.5)</td>
<td>Not specified for the three techniques</td>
</tr>
<tr>
<td>Lee et al. [17]</td>
<td>Nail</td>
<td>8</td>
<td>8</td>
<td>0 (0)</td>
<td>100%</td>
</tr>
<tr>
<td>Mabry et al. [18]</td>
<td>Nail (customised and standard)</td>
<td>24</td>
<td>24</td>
<td>2 (8.3)</td>
<td>23/24 ±95%</td>
</tr>
<tr>
<td>Current study</td>
<td>Customised modular nail</td>
<td>31</td>
<td>31</td>
<td>6 recurrences including 3 managed by nail removal (19.4)</td>
<td>21/31 ±67% and 19/23 (82.6%) with grafting</td>
</tr>
</tbody>
</table>

Discussion of functional outcomes compared to preoperative function. We believe this point is crucial, particularly as knee arthrodesis is being used at increasingly young ages. Patient dissatisfaction was ascribable in part to leg-length discrepancy related to the arthrodesis (use of canes for walking, major compensation, orthopaedic footwear) and in part to knee stiffness, which were not expected outcomes of the initial surgical procedure (former indication for TKA). Arthrodesis with external fixation is associated with greater leg-length discrepancy than arthrodesis with intramedullary nailing [20]. Mean loss of limb length in a study by Parratte et al. [20] was 4.5 ± 1.3 cm, i.e., twice the length lost in our study. The Oxford score values in our study indicate only a moderate level of patient satisfaction. The main reasons were stiffness of the knee and failure of an apparently well-planned functional procedure.

Finally, our study allowed us to evaluate the rate of bone union after arthrodesis with intramedullary nailing to treat infected TKA. In previous studies, the mean bone union rate after arthrodesis with nailing ranged from 80 to 100% [2,7]. We obtained bone union in only 21 (67%) of our 31 patients. Volpi et al. [6] and Lee et al. [17] reported high bone union rates after arthrodesis with nailing, but their sample sizes were limited (Table 2). The bone union rate was low in our population, but our priorities were optimisation of knee function and control of the infectious process via the use of a nail that served as a fixed prosthesis allowing immediate weight bearing. Thus, bone union was not our primary treatment goal. Our results support the widespread use of bone grafting, which was associated with a higher bone union rate (19/23 vs. 2/8). Namdari et al. [21] used intramedullary nailing and a modular intercalary prosthesis in a patient with massive bone loss. After 20 months, there was no evidence of failure of the material. Finally, our case-series included 12 patients from the study by Letartre et al. [5] of arthrodesis with the same type of intramedullary nail fixation. The longer follow-up in this last study [5] shows that absence of bone union has no adverse effects in the mid-term. We recorded no cases of mechanical failure (nail breakage, faulty osteointegration of the surface-sanded nail), but the duration of our follow-up is still too short to conclude that the use of a modular nail has no long-term adverse mechanical effects in patients with severe bone loss and no bone union.

Conclusion

Arthrodesis with fixation by a modular customised intramedullary nail used to treat failed infected TKA is associated with an acceptable rate of recurrent infection that is higher, however, than with external fixation. Intramedullary nailing allows immediate weight bearing and minimises the leg-length discrepancy, thereby providing satisfactory functional outcomes even in the absence of bone union.

Disclosure of interest

No direct conflicts related to this work. HM is an occasional research and education consultant for Zimmer and Tornier. ES is an occasional speaker for Novartis and Sanofi-Aventis and has received support for conventions from Pfizer, MSD, and Novartis.
Acknowledgements

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