Femorotibial bone loss during revision total knee arthroplasty

D. Huten*

Service d’orthopédie-traumatologie, hôpital Sud, CHU de Rennes, 16, boulevard de Bulgarie, 35203 Rennes cedex 2, France

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Summary Bone loss (BL) is frequent during revision total knee arthroplasty (TKA). It is underestimated in X-rays. Most classifications distinguish contained from uncontained BL but the most frequently used classification is that of Engh, which does not take into account this element. Reconstruction should result in resistant support for the revision TKA. It helps correct malalignment, restore satisfactory ligament tension and height of the joint line. Several techniques have been suggested: cement, augments, bone grafts, modular metaphyseal sleeves and cones and megaprostheses. Cement is only used with small BL, especially in elderly patients. Augments allow rapid filling of small peripheral BL with good mid-term results but frequent radiolucent lines. Morselized allografts can be incorporated and remodeled. They are a good alternative in young patients. Structural allografts are resistant but there is a risk of fracture and resorption. Modular metaphyseal sleeves and cones incorporate with host bone and are attached to the prosthesis by a mechanical interface or cement. They may also be more durable. Megaprostheses are only indicated in severe BL in elderly subjects. Reconstruction is just one aspect of revision TKA and it should respect the technical requirements of the procedure in particular fixation with a stem, which is important in determining the outcome of reconstruction.

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Bone loss (BL) is frequent during revision TKA, because of previous bone resections, migration of hardware, osteolysis, difficult extraction of components, infection or periprosthetic fracture. Epiphyseal osteopenia may also be present.

The most frequently used classification of BL is that of Engh [1].

Reconstruction should result in strong stable support of the new prosthesis and harmonious transfer of load to the bone. It helps correct malalignment, restore satisfactory tension in soft tissues and level of the joint line (JL).

Numerous techniques exist: cement, augments, bone grafts, modular metaphyseal sleeves and cones, and megaprostheses.

Classification

BL is underestimated on X-rays, especially of the femur. Osteolysis is visualized more effectively with oblique view X-rays and CT scan which is required in every case. Therefore,

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greater bone loss should be expected during revision surgery than that seen on imaging.
BL can be contained (or central) or uncontained (or peripheral).

**Engh classification**

Engh classified BL into three types for the tibia (T1, T2, T3) and femur (F1, F2, F3), based on X-rays and surgical findings (Fig. 1):

- type 1: minimum BL, normal height of the JL, normal development of the posterior condyles, tibial component proximal to the fibular head;
- type 2: cancellous BL involving only one tibial or femoral condyle (type 2A) or both (2B): too proximal JL and/or reduced development of the profile of the posterior condyles and/or tibial component above the fibular head;
- type 3: BL involving most of the tibial or femoral condyle, which may detach the patellar ligament or a collateral ligament.

This is the most frequently used classification but does not take into account the contained or uncontained aspect of BL or diaphyseal BL.

**SOFCOT 2000 symposium classification**

This classification evaluates bone stock based on bone cuts (Fig. 2) using three parameters [2]:

- grades A, B, or C depending on the level of the area of bone where the new prosthesis will be placed. Grade is followed by M if prosthesis support is medial in this zone (A, B or C), L if lateral or ML;
- condition of the bone surface: contained BL, central (1 point) or excentric (2 points), or uncontained BL (6 points);
- depth index of uncontained BL: if it is in the same area as that for the grade, it is a for grade A… If it is more distal, it is b or c for grade A…
- d for diaphyseal involvement.

For the femur there is also a score for the posterior condyle: 0 (no BL), 1 (uncontained BL) or 2 points (uncontained BL with distal BL).

**Diaphyseal BL by Steens et al.**

Steens et al. has proposed a classification of diaphyseal BL, adapted to stem revision prostheses [3].

![Figure 1](image_url) **Engh classification:** a: T1, F1; b: T2B, F1; c: T1, F2B; d: T3, F3.

![Figure 2](image_url) **SOFCOT classification.**

Principles of revision TKA

Reconstruction of bone loss is just one step in revision surgery, and certain technical requirements must be respected for long-term implant survival:

- satisfactory alignment;
- creating (except for hinged prostheses) two equal rectangular flexion and extension gaps with balanced ligament tension;
- choice of the smallest possible prosthetic constraint;
- stable fixation with a stem that transfers load to the diaphysis.

Experimentally:

- a 70-mm cemented stem carried 28–38% of the load of the metaphysis [4];
- in a comparison of 40 and 75 mm stems, Stern et al. [5] showed that:
  - cement provides the greatest stability,
  - the longer the stem, the greater the magnitude of micromovements of the tibial tray, but cementing resolves this phenomenon.

There is a choice between:

- cementless press-fit stems engaged into the femoral canal, associated with cementing of the epiphyseal portion of the component up to the stem junction (hybrid fixation, Fig. 3). This requires good quality bone;
- and cemented stems in case of large BL, more constrained prostheses, in patients with a large canal and a thin cortex, very elderly patients, or a diaphysis which is not adapted to a canal filling stem (bayonet deformity, S-shaped...). If the stem is to be cemented, the design and

the condition of the surface should be adequate, and it should also be as short as the condition of the bone allows, to facilitate removal in case of re-revision.

Offset stems may be necessary to prevent component overhang (Fig. 3), malalignment or to balance a flexion gap by translating the femoral component forwards or backwards.

Eliminating BL

Resecting the base of the BL eliminates it. This technique can be considered in the tibia where components of various widths and thicknesses are available.

However:

- the prosthesis rests on less resistant bone;
- the resection is less wide and the base plate will be smaller;
- the bone cut becomes round, creating a risk of a rotational error;
- there is less cancellous bone, so cementing will be less effective.

After a 15-mm bone resection, tibial baseplate (smaller and more posterior) transfers loads to the tibia that are 2–3 times greater than after a 5-mm resection [6].

In case of peripheral BL, translation results in an undersized tibial baseplate resting on a continuous surface. An offset stem, allows translation of 4.5 mm [7] or more with certain systems. The size of the baseplate should be compatible with that the femoral component.

Because there is only one thickness for femoral components, it cannot compensate for significant bone resorption (too proximal joint line). Translation of the component is possible (Fig. 4) but in this case, an undersized component...
must be chosen, increasing the risk of instability during flexion and/or femoral notches.

Medial translation (tibial or femoral), which is a factor of patellar instability, should be avoided.

**Filling with cement**

This inexpensive method is adapted to all types of BL. However, during revision surgery, there are very few bone irregularities for the cement to grip, and it is difficult to pressurize it in large and/or uncontained BL.

In an experimental study, Chen et Krackow [8] showed the mechanical results of filling block shaped BL was better than wedge shaped BL in proportion to the obliquity of the wedge angles. However, to give BL a block shape, bone stock must be sacrificed and the revision components then rest on less resistant cancellous bone, because it is further from the JL.

**Technique**

The technical principles are as follows:

- interposed tissue is removed;
- holes are drilled (3.5 mm) into the condensed bone;
- blood and debris are removed by pulsatile lavage;
- cement can be reinforced by screws that are sunk until their heads are a slightly below the implant (if there is contact with the component, the cement cannot be pressurized and there is metal-metal contact). The screws, 5 or 6.5 mm in diameter, are placed 5–10 mm apart (Fig. 4);
- in peripheral BL, during pressurization the cement should be contained by a finger.

**Results**

Elia and Lotke [9], used cement (19 cases), bone graft (12 cases) or customized prostheses (9 cases) in 40 revision TKA. At 3.5 years of follow-up (2–9) the rate of loosening was 10% with radiolucent lines of more than 1 mm in 52.5% and no difference among the three techniques. The authors increasingly used grafts over time, and stopped cementing the stems.

In 40 revision, TKA Murray et al. [10] cemented long stems while filling small bone defects. After 58 months of follow-up (24–111), a partial, non-progressive radiolucent line of 1 mm was found in 32% of the cases in the tibia, in 10% in the femur and there was one complete femoral radiolucent line.

**Discussion**

The results of cement alone or reinforced with screws are mediocre [4,8]. Its resistance to shear stress and compression is low. Thermal bone necrosis can also occur, as well as 2% shrinkage during polymerization and lamination when used in large quantities.

This technique is used less and less often because of loosening and frequent immediate and secondary radiolucent lines, which are especially visible in the tibia (Fig. 5).

Cement is only indicated in shallow, limited bone defects especially in elderly patients.

**Metal augments**

They differ depending on the systems:

- block tibial augments (4/8/12/16 mm, or 5/10/15/20 mm blocks) or wedge augments (wedge or half wedges 5/10/15/20/25). The base of the thickest block augments should be beveled at the base to prevent bulging under the skin;
- distal femoral block augments (the same thickness as tibial augments) and posterior (4/8 or 5/10 mm) augments.

They allow rapid filling of bone defects that have been geometrically shaped with instruments. They provide stable support and transfer loading forces to the bone.

In the tibia:

- tibial augments make it possible to use a baseplate that is larger than the bone cut at the distal part of the BL, because the tibia narrows from the top to the bottom;
- there are monoblock base plates including two block augments (Fig. 6b) from 5–25 mm, beveled distally [11,12].

Posterior femoral augments make it possible to use a prosthesis that is large enough to obtain stability during flexion, and their bony support opposes rotational forces. A lateral posterior augment increases external rotation of the femoral component and distal augments restore JL level.

Augments are screwed or cemented to components.
Experimental results

Brooks et al.
Brooks et al. [4] compared different types of filling (cement, reinforced cement, metal augments, custom-made prostheses) of a wedge shaped BL of the tibia plateau. Bending of the base plate after cement filling was used as a reference (100%). During axial loading, it was 70% with cement reinforced with screws, 17% with the metal augment, 9% with the customized prosthesis and for a varus load 72%, 31% and 17% respectively. Thus cement alone or reinforced with screws is less effective than metal augments.

Chen and Krackow
Chen and Krackow [8] compared the rigidity of the tibial baseplate after filling a wedge shaped BL of 20° with a wedge shaped or a block shaped augment. Results were slightly better with the block, but the differences were not significant.

Fehring et al. [13]
Fehring et al. [13] compared the distribution of tibial strains to the tibia from a stemmed tibial baseplate with wedge or block augments, and did not find any significant difference between the two. Nevertheless, the baseplate and block augments resisted torsional forces better and there was less distribution of loads to the tibia.

Results

The results of tibial wedges, first used for primary TKA were satisfactory at mid-term follow-up although there were frequent radiolucent lines [12].

Augments are often used in revision TKA.
In the published series [10,12,14,15] (Table 1):

- they are more frequently used in the femur where only one component is available, and where the risk of non-union of the bone graft is high (bone cut surfaces are reduced);
- it addressed moderate peripheral BL (types 1 and 2);
- a stem was always associated with the augments;
- mid-term results were satisfactory, with frequent radiolucent lines [15], especially in the tibia because they are more visible. The are often found early, which suggests poor penetration of the cement into bone that is dense and without irregularities.

Hockman et al. [16] showed the limits of augments in a study of 54 TKA revisions with more than 5 years of follow-up. BL were large (48% type 3). Augments were used in 89% of the cases and structural allografts in 48%, always with stems. Failures (9 repeat revisions and 8 non-revised failures) were more frequent in the absence of a structural allograft (42.9% versus 19.2%). This may be explained by the smaller cancellous bone-cement surface interface when there is no allograft.

Figure 6  a: posterior femoral augment with radiolucent line; b: thick tibial base plate.
Table 1

<table>
<thead>
<tr>
<th>Revisions BL</th>
<th>Number of augment</th>
<th>Stems</th>
<th>Follow-up (years)</th>
<th>Repeat revision</th>
<th>Radiolucent lines</th>
<th>Survival</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haas et al., 1995 [14]</td>
<td>?</td>
<td>Tibia: 25 Femur: 23</td>
<td>Cementless</td>
<td>3.6 (2—9)</td>
<td>6 including Infection: 3 Loosening: 2</td>
<td>?</td>
</tr>
<tr>
<td>Rand, 1996 [15]</td>
<td>41</td>
<td>Tibia: 10 Femur: 30</td>
<td>Cementless or cemented</td>
<td>3.1 (2.5—5)</td>
<td>0</td>
<td>61%</td>
</tr>
<tr>
<td>Gotfon et al., 2002 [11]</td>
<td>Types 1 and 2</td>
<td>Tibia: 15 Femur: 65</td>
<td>Cementless</td>
<td>5.9 (4.1—8.6)</td>
<td>5 including Infection: 1 Loosening: 2</td>
<td>Femur: 6.3% Tibia: frequent</td>
</tr>
<tr>
<td>Patel et al., 2004 [12]</td>
<td>Type 2</td>
<td>Tibia: 20 Femur: 151</td>
<td>Cementless</td>
<td>7 (5—11)</td>
<td>6 including Infection: 2 Loosening: 3</td>
<td>Femur: 7.3% Tibia: 15%</td>
</tr>
</tbody>
</table>

BL: bone loss.

a Event: repeat revision, or recommended repeat revision.
b Event: repeat revision.

Discussion

Augments facilitate revisions with limited peripheral BL, and fears of separation and corrosion are unfounded. The limitation of this option is fixation with cement in mediocre bone. There is no consensus on the maximum size: less than 20 mm [7], or even less than 10 mm [11,12]. And yet thicker augments exist, up to 3 cm [17] but in the tibia there is a risk of a painful subcutaneous bulge, and in the femur, thick distal augments can prevent bone-intercondylar spacer contact, and thus limit stable rotation.

It would be wise to limit the use of augment to BL of 5—10 mm and for more extensive BL in older or less active patients.

Bone grafts

The goal of bone grafts is to reconstruct bone stock. They require preparation of host bone: debridement, preserving the peripheral rim of bone including ligament insertions, and drilling condensed bone.

Autografts

The availability of autografts is extremely limited, (resected bone, preparation of the intercondylar notch).

Sometimes, certain bone cavities and small peripheral bone defects can be filled with an autograft. Dorr et al. [18] provided a good description of this procedure in the tibia, with two failures/14 revisions (without stems) performed with 13 autografts (9 resected bone and 4 harvested from the iliac crest) and one allograft.

The autografts are only used to fill very small bone defects, or to graft the allograft-host bone interface. Harvesting from the iliac crest may be indicated when grafting metaphyseo-diaphyseal fractures.

Allografts

Frozen allografts provide solid grafts that are available and easy to work with but are associated with numerous risks:

- transmission of viral diseases;
- risk of infection which is reduced by 25 kGy radiation treatment that barely affects the solidity of a frozen allograft [19];
- immunological reaction, whose risk is reduced by ablation of the bone marrow by lavage.

Freeze dried bone maintains its original mechanical properties, but is more fragile because of radiation and more difficult to work with.

Union can be obtained between the allograft and host bone. The cement penetrates the cancellous bone, which helps fixation of the prosthesis after union. Nevertheless [19]:

- allografts are not incorporated (less than 10%), especially cortical allografts;
- the risk of infection is 6—13% and of non-union and fracture is 15—20%;
- there is a risk of macrophagic resorption.

Morselized allografts have no immediate resistance but they can be incorporated and are remodelled in reaction to surrounding loading pressures.

Morselized grafts

Grafts approximately 5 mm (3—10) in size can be packed around an implant fixed by mean of a stem or strongly packed into the BL before placing the implant. Filling around a prosthesis. Whiteside [20] reported the results of 110 revision TKA with long stem cementless components (150—200 mm) press-fit into the isthmus, in type 3 tibial (42) and femoral (35) BL or both (28), with at least
one third of the peripheral rim intact. Once the components were in place the BL was filled with bone fragments combined with bone marrow and bone obtained by reaming. Weight bearing was partial for 6–12 weeks. After 60–127 months of follow-up, two revisions were necessary and loosening of the tibial component occurred in 1 patient. Bone graft density had increased after one year in 31 patients in the tibia and in 28 in the femur. Fourteen biopsies of these grafts [21] showed the presence of new bone after 3 weeks, enchondral ossification at 6 months and lamellar bone after 18 months. Hanna et al. [22] used this technique in 56 revision TKAs with manually packed freeze dried grafts mixed with autologous blood. The graft seemed to be incorporated in 96% of the cases. After 7.3 years (4–10), five revisions were necessary but this was not related to the graft. Graft survival at 10 years was 98% (event: revision with change or removal of the implant).

**Impacted allografts.** This is the equivalent of the Exeter technique. Animal and cadaver studies reported by Toms et al. [23] have shown that morselized grafts impacted into epiphyseal BL result in excellent immediate stability with a cemented component. This is also true after graft impaction in BL contained by a metallic mesh. Nevertheless, the best stability was obtained with an augmentation wedge (study of tibias in resin [24]).

**Results.** The first series reported by Toms et al. [23] included very few cases. Two of the more recent series (Table 2) describe the use of porous coated implants (under the tibial base plate and on the proximal parts of the stems), cemented [25] or uncemented [26] on the surfaces of the of the bone cuts [25]. The others [3,27–29] involve cemented stem prostheses.

The graft was contained [28,29] or not [27] by a mesh. The results were satisfactory at mid-term follow-up. The rate of repeat loosening was low and bone reconstruction was apparently obtained. The authors [27] described visible remodeling of the graft at 1 year and its capacity to support the components. In the rare cases of revision surgery the graft had consolidated and the biopsy [26] showed newly formed bone in the graft.

**Discussion.** Metallic meshes, plates and bone struts can help contain peripheral BL. Residual BL can be filled with augment [27]. Experience and specific instruments are needed for this. This technique is a good option in young patients (Fig. 7).

**Structural grafts**

**Engh technique.** A partially or completely contained BL is transformed into a hemispheric cavity by reaming in the direction of loading forces until cancellous bone is reached. It is filled with a debrided femoral head with a female reamer, which exposes cancellous bone. The diameter is 1–2 mm larger than the male reamer, so that the graft can be embedded, attached with pins that do not interfere with bone resection or preparation of the stem insertion. Residual BL can be filled with an augment. There is union of the graft and host bone and the cement penetrates the cancellous bone of the graft, thus stabilizing the prosthesis at the metaphysis.

Engh and Ammeen [1] reported their results in 49 revisions with tibial type 3 BL. The stems usually filled the canal and were cementless (hybrid fixation). At 97 months (61–91) there were nine revisions including four with repeat revision (61–191), none were due to reconstruction. Only the uncontained peripheries of grafts were partially resorbed. Survival at 10 years was 93% (event: removal/change of the tibial component).

Table 2  Impact bone-grafting.

<table>
<thead>
<tr>
<th></th>
<th>Number of cases</th>
<th>BL</th>
<th>Stems</th>
<th>Follow-up</th>
<th>Repeat revision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bradley, 2000 [26]</td>
<td>21</td>
<td>?</td>
<td>LCS revision</td>
<td>33 months</td>
<td>1 loosening</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(85–105 mm): 18/21</td>
<td>(6–62)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cementless: 16/21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Benjamin et al., 2001 [27]</td>
<td>33</td>
<td>Type 2 usually</td>
<td>Cementless stems (95–140 mm)</td>
<td>10–72 months</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cemented stems (50–105 mm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lonner et al., 2002 [28]</td>
<td>17</td>
<td>?</td>
<td>Cemented in the graft</td>
<td>21 months</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>contained by metallic mesh</td>
<td>(6–40)</td>
<td></td>
</tr>
<tr>
<td>Barden et al., 2004 [25]</td>
<td>20</td>
<td>Hinged revision</td>
<td>LCS revision</td>
<td>5.3 years</td>
<td>1 loosening</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(85–105 mm): 19/40</td>
<td>(2.3–10.5)</td>
<td>1 infection</td>
</tr>
<tr>
<td>Lotke et al., 2006 [29]</td>
<td>48</td>
<td>Types 2 and 3</td>
<td>Cemented in the graft</td>
<td>3.8 year</td>
<td>1 infection</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>contained by a cage par</td>
<td>(2–6.5)</td>
<td>(arthrodesis)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>un grillage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steens et al., 2008 [3]</td>
<td>34</td>
<td>Hinged revision</td>
<td>Cemented hinged</td>
<td>4 years (2–9)</td>
<td>5 loosening</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>prostheses</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

BL: bone loss; LCS: low contact stress.
After 41 months (20–62) of follow-up Parks and Engh [30] studied the histology of seven of these allografts and two autografts (primary TKA). These were postmortem studies (5 allografts and 2 autografts) or biopsies (2 allografts). All the bone was living in the two autografts. The allografts were intact but not vascularized. There was bone apposition at the interface of the host bone except in areas where subchondral bone had been left.

**Massive allografts.** In case of BL in a tibial or femoral condyle, the graft (femoral head from the bone bank or massive bone allograft) and the host bone are modified to obtain a stable interface. Despite its inconveniences screwing (weakening) is the best fixation technique (Fig. 8).

In case of BL in both condyles a massive bone allograft is indispensable:

- length is estimated by creating axial traction on the extended knee;
- stability is obtained by fitting or step-cutting which takes into account rotation. The cancellous graft should be in contact with the host bone. The graft should not be carved too much, it will weaken it and favor resorption (perforations and exposed cancellous bone should be cemented);
- ideally the allograft should be attached to the host bone by the stem alone but additional internal fixation may be necessary (screws, plate). To avoid using a plate, cortical

Figure 7  Filling of central BL (a) with a morselized graft (b).

Figure 8  BL of the medial tibial plate (a and b). Allograft with screw fixation (c).

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allograft struts wrapped in cerclage wires may be used. Plates and struts can compromise closure;
• the size of the implant will be chosen according to the size of the host epiphysis (be careful of large implants which can prevent closing);
• the implant and stem are cemented to the graft (without any cement between the graft and host bone interface). The stem is cemented into the shaft of the host or press-fit. Long stems which extend beyond the isthmus should be used;
• the interface is grafted;
• the remaining bone fragments and their attached ligaments are attached to the graft;
• an articulated knee brace controls knee rehabilitation. Weight bearing is partial for 6 weeks and full after union (3–4 months).

It is difficult to compare the results of published series [17,31–35] (Table 3) because they differ in type of BL, graft fixation, length and type of stem fixation, constraint of the prosthesis and follow-up. Considering the complexity of these revisions, short and mid-term results are good. Nevertheless, the rate of complications (infection, loosening with collapse of the graft, non-union, fracture, laxity) is high. The most severe risk is infection, which may have different causes.

The recent series by Bauman et al. clearly showed the limits of this technique [32]. Seventy cases were followed up for more than 5 years (or until revision or death of the patient). Repeat revision was necessary in 22.8% after 42 months (1–68). Graft survival (event: any revision) was 75.9% at 10 years. The authors concluded that structural allografts should be reserved to very large contained BL.

**Metaphyseal sleeves and cones**

Unlike bone grafts which adapt to the host bone, with these components the remaining bone must be adapted to the device.

![Figure 9](http://dx.doi.org/10.1016/j.otsr.2012.11.009)
Pourous titanium metaphyseal sleeves

They are cone shaped with various sizes and lengths and adapted to the metaphysis. The surface texture is stepped and coated with porous titanium. The interface between the sleeve and the stem is a morse taper. After it has been incorporated the sleeve transfers loading forces to the bone and opposes rotation.

Bone preparation is centered on the stem and performed with a rasp whose form is the same as the sleeve and the stem. The periphery of the BL should be strong enough to stabilize the augment. Rotation of the sleeve can be different from that of the stem. After 49 months (24–74) results of the use of the sleeve with the hinged implant S-ROM and cement on bone cut surfaces, were satisfactory [36].

This component can only be used with implants from one company (Fig. 9).

Tantalum cones

Tantalum is a resistant metal whose elasticity is between that of cortical and subchondral bone. Its friction coefficient is high. It is available in tibial and femoral cones of different shapes. The porosity (70–80%) allows incorporation by the host bone and penetration of the cement to strengthen fixation to implant components (Fig. 10).

The bone is prepared with a rasp and/or a burr so the selected cone can be fitted using an impactor and the trial component with its stem but preparation is not necessarily

![Figure 10](image_url)
centered on the stem. In peripheral BL, only the distal part of the cone is fitted. Once a stable position has been found the gaps between the bone and the cone are filled (allograft, bone substitute) to avoid penetration by cement. Often the prosthesis is only resting on part of the cone whose rotation is different from the prosthesis.

Results
Meneghini et al. [37] reported results in 15 tibial reconstructions with cones in type 2B or 3 BL. After 34 months (24–47), there was reactive osseous trabeculation between the bone and the cone, with no radiolucent lines or loosening. Three immediate partial radiolucent lines were found around the stem (30–155 mm) which did not progress. Osteointegration was confirmed in four revisions (2 infections, 1 femoral loosening, 1 fracture).

Long et Scuderi [38] described 16 tibial reconstructions of the same type, in type 2 or 3 tibial BL. At 31 months (24–38), there were signs of osteointegration of the cones. Two infections required removal of a well-fixed cone.

Howard et al. [39] concluded that femoral cones were effective in 24 revisions after 33 months of follow-up (24–56).

Discussion
Sleeves and cones have several advantages over allografts: a simpler technique, no risk of transmitting viral or bacterial infection, shorter surgery, and possibly more durable fixation. They can be associated with augments and/or bone grafts. However, they may be difficult to remove.

Cones are compatible with most TKA systems and their placement can differ from that of the implant. Their rough surface can impinge upon soft tissues. The tendency is to combine them with short cemented stems to ensure the necessary stability for osteointegration of the cone [37]. Once this is obtained, the implant is in fact solidly attached to the metaphysis via the cone and a long stem is not necessary. This is also true for sleeves.

Megaprostheses
They have the best mechanical properties [4]. Customized prostheses are expensive, require specific measurements, take several weeks to manufacture, and may still end up not fitting. They have been replaced by modular systems, with a large choice of femoral and tibial components and stems:

- Springer et al. [40] reported results in 26 rotating hinged modular systems (including 22 for revision). At 58.5 months, 8 patients presented with complications including five infections and one ruptured axis;
- Pour et al. [41] reported an even higher complication rate after 1.7 years of follow-up with the same system in 44 revisions (3 infections, 4 loosenings and 1 periprosthetic fracture).

The surgical procedure and rehabilitation are rapid. The rate of infection, which is often followed by amputation, and the risk of short term mechanical complications should limit this choice to elderly patients with very large BL or complex periprosthetic fractures.

Conclusions
The treatment of BL depends on the type, the size, the quality of bone, and the patient’s age and level of activity. Bone resection should eliminate bone that is too fragile, while sacrificing as little healthy bone as possible. This choice is a compromise.

Contained BL respects the periphery of the components. Cementing is only indicated in small BL, especially in elderly patients. Otherwise there is a choice between moroselized grafts (young patients) and a femoral head, while metaphyseal sleeves and cones also play an important role in central BL.

Uncontained BL are more difficult to manage:

- cement alone or reinforced with screws may be used in very small BL;
- metal augments can fill BL no larger than 1 cm, or 2 in elderly subjects;
- as long as one third of the peripheral rim and a good part of the metaphyseal cortex is intact, moroselized or structural allografts can be used for reconstruction. Graft reconstruction is easier, and the contact surface with the graft is larger in the tibia. Metaphyseal sleeves and cones are increasingly replacing allograft use. They both increase the interface of fixation between the prosthesis and remaining metaphyseal bone, so that fixation is not limited to the stem;
- when the epiphysis is nearly inexistent, there is a choice between a massive allograft (young patients) and a megaprosthes (elderly patients) as a salvage technique;
- diaphyseal BL is filled with an auto/allograft wrapped in cerclage wires.

Different techniques are often combined (augment + bone graft or metaphyseal sleeve or cone...).

Durability of the reconstruction depends on other essential parameters: alignment, ligament balance, constraint of the prosthesis, stem fixation. Research is based on developing a system of resistant metaphyseal fixation (with an allograft, or a component which can be incorporated [sleeves, cones...]), combined with a short stem.

Disclosure of interest
The author declares that he has no conflicts of interest concerning this article.

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