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# Custom Endoprostheses for Limb Salvage: A Historical Perspective and Imaging Evaluation

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Historically, primary bone malignancies were treated with amputation. Since the mid 1970s, several limb salvage reconstruction techniques have been developed, including resection arthrodesis, allografts and allograft composites, endoprostheses, and rotationplasty [1–3]. These have evolved in conjunction with radiation therapy and adjuvant chemotherapy protocols that have dramatically improved patient survival [3, 4].

Limb salvage reconstruction has three goals: The local recurrence rate should be no greater than that with amputation, the procedure should not delay the administration of adjuvant or neoadjuvant therapy, and the reconstruction should be enduring and not associated with many local complications [1, 2].

Endoprosthetic limb salvage is most often undertaken for primary bone sarcomas. Less frequent indications include aggressive or multiply recurrent benign bone tumors; bone metastases; soft-tissue sarcoma involving bone; failed primary joint replacement; and recalcitrant, chronic nonunions [2–4] (Fig. 1).

## Evolution of Prosthetic Design

The first endoprosthesis was implanted in 1940, but this technique was not used routinely until the late 1970s. Original prostheses were custom-designed single-piece components of cast steel alloys. Early titanium single-piece components were machined (Fig. 2). Early knee devices were rigid hinges [1] (Fig. 2).

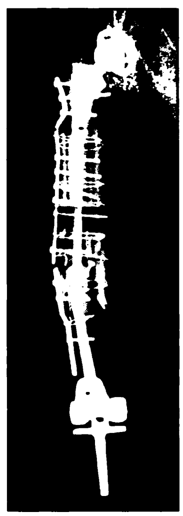

**Fig. 1.**—Indications for total femoral endoprosthesis in 73-year-old woman who had previously undergone six procedures for arthroplasty fixation. Although endoprosthetic reconstruction is usually performed for primary bone tumors, other indications include chronic nonunions that are recalcitrant to conventional treatment. Anteroposterior radiograph of femur shows nonunion at level of mid shaft.

Since the late 1980s, the single-component endoprosthesis has been replaced by modular systems that use a rotating-hinge knee joint

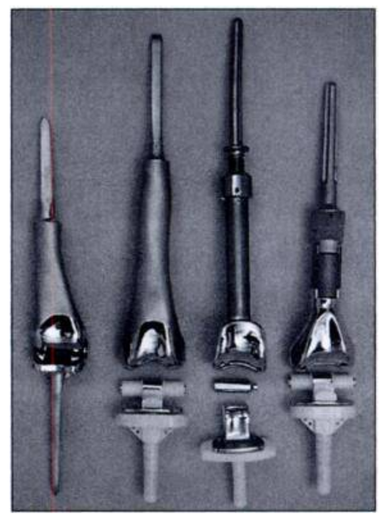

**Fig. 2.**—Evolution of distal femoral endoprostheses. From left to right: Waldius (Howmedica, Rutherford, NJ) distal femoral replacement made with cast cobalt chromium alloy and rigid metal-on-metal hinge knee mechanism (this device is no longer used); cast cobalt chromium distal femoral replacement with Kinematic Rotating Hinge Knee (Howmedica) mechanism; Lewis Expandable Adjustable Prosthesis distal femoral replacement (Wright Medical, Arlington, TN); modular distal femoral replacement with forged cobalt chromium femoral stem, 360° porous ingrowth material, modular titanium segment, and cobalt chromium condylar component using rotating hinge knee mechanism (Howmedica).

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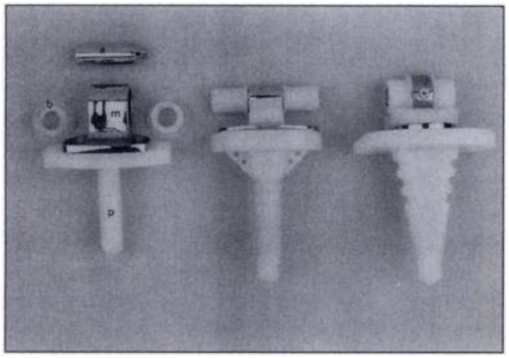



**Fig. 3.**—Rotating hinge knee mechanisms. From left to right: Lacey Rotating Hinge Knee mechanism (Wright Medical, Arlington, TN), Kinematic Rotating Hinge Knee (Howmedica, Rutherford, NJ), Noyles Rotating Hinge Knee (Intermedics, Austin, TX). a = axle, b = bushing, m = metal tibial bearing component, p = polyethylene tibial bearing component.

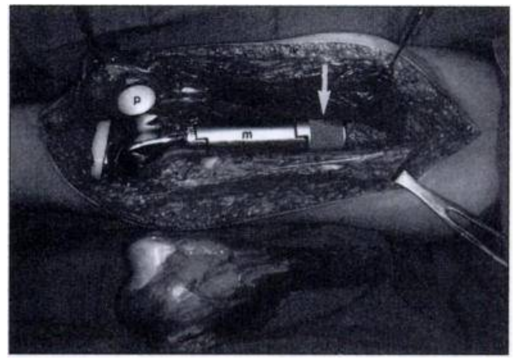



**Fig. 4.**—Photograph of implanted distal femoral endoprosthesis in 16-year-old boy with osteosarcoma. Note 360° proximal porous coating (*arrow*) and modular segment (m). p = patellar button.

(Fig. 3), titanium modular segments, and a variety of stem designs of machined titanium or forged cobalt chromium (Figs. 2 and 4). All use a 360° ring of extramedullary porous ingrowth material (Figs. 2 and 4) in an attempt to achieve either fibrous or bony ingrowth [5]. Such ingrowth provides stability and isolates the periprosthetic joint fluid from the bone–prosthesis or bone–cement–prosthesis interface.

Femoral stems are available with an anterior bow for better fit and fill of the shaft. Humeral and tibial reconstructions use only straight stems. Cross pin fixation (Fig. 5) has been used to enhance stabilization and promote bone incorporation in press-fit tibial and femoral components and to enhance the rotatory stability of short stems [6].

In 1985, expandable endoprostheses of various designs were introduced to permit endoprosthetic reconstruction of skeletally immature individuals (Fig. 2). The initial Lewis Expandable Adjustable Prosthesis (Wright Medical, Arlington, TN) mechanism consisted of a central threaded stem that could be lengthened with a chuck key. With the advent of modular prostheses, exchange of the modular segment for a longer component is now used to achieve expansion [3, 4, 7].

## Imaging Before Surgery

Once the decision has been made to undertake endoprosthetic reconstruction, cross-sectional imaging (MR imaging or CT) is used to define the extent of tumor within the bone and soft tissue, determine the feasibility of limb salvage, and plan the surgery.

Imaging for prosthetic design relies on MR imaging and scanograms. The MR image is a longitudinal T1-weighted scan that includes the entire bone. The images are used to determine the extent of the tumor and detect possible skip lesions. Measurements are made on the scanner console at the time of image acquisition (Fig. 6A). Specific attention is paid to the distance from the nearest joint to the furthest extent of the lesion. Although axial images are key in the assessment of the extent of soft-tissue involvement, they are not needed if this information is already available from prior cross-sectional imaging.

The scanogram is a full-length radiograph that includes a ruler on the image to allow accurate measurement without concern for scale distortion due to magnification [1, 2]. Measurements made on longitudinal T1-weighted images are transferred to the scanogram (Fig. 6B) to determine the level of a safe osteotomy. Scanograms are also used to measure the width of the medullary canal in the shaft to determine stem size; in the femur, they are used to measure the anterior bow of the shaft (Figs. 6C and 6D).

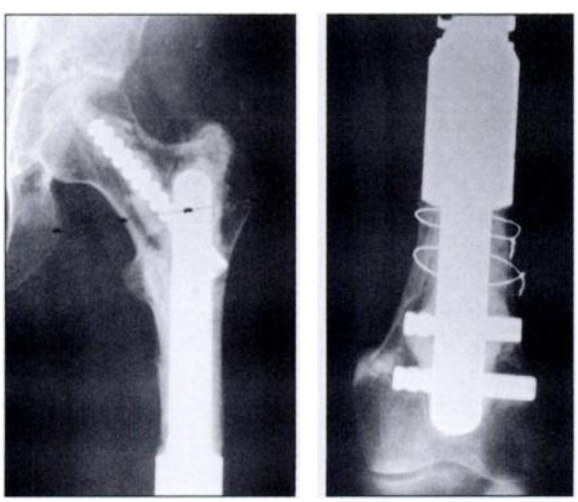
## Imaging After Surgery

In the lower extremity, postoperative scanograms can be used to assess whether the legs are of equal length (Fig. 7). Radiographic analysis should include evaluation of three possible complications: recurrent or residual tumor, mechanical failure (bone or prosthesis), and deep infection.

Stress shielding, or bone resorption around the implant (Fig. 8), should not be mistaken for loosening or infection. This phenomenon results from redistribution of forces along the bone such that most of the axial load is transmitted through the stem. The bone that is no longer subjected to the stress thus resorbs (Wolff's law). Stress shielding is seen in the early postoperative period and usually stabilizes after 1 year [5].

As with conventional joint arthroplasty, titanium debris may be radiographically evident in the soft tissues around the prosthesis (Fig. 9). This dense material should not be mistaken for tumor recurrence.

In skeletally immature individuals, continued growth of the proximal tibia may be seen after reconstruction of the distal femur, even though the central portion of the growth plate has been breached (Fig. 10). The peripheral portions of the physis remain intact. With continued skeletal maturation, the cement mantle around the liner will fracture and the



A B

**Fig. 5.**—Cross pins help to enhance rotatory stability of relatively short stem.
**A**, Radiograph of 43-year-old man with malignant fibrous histiocytoma of bone shows proximal femoral cross pin in conjunction with distal femoral endoprosthesis.
**B**, Radiograph of 15-year-old girl with Ewing's sarcoma shows distal femoral cross pins in conjunction with intercalary femoral endoprosthesis.

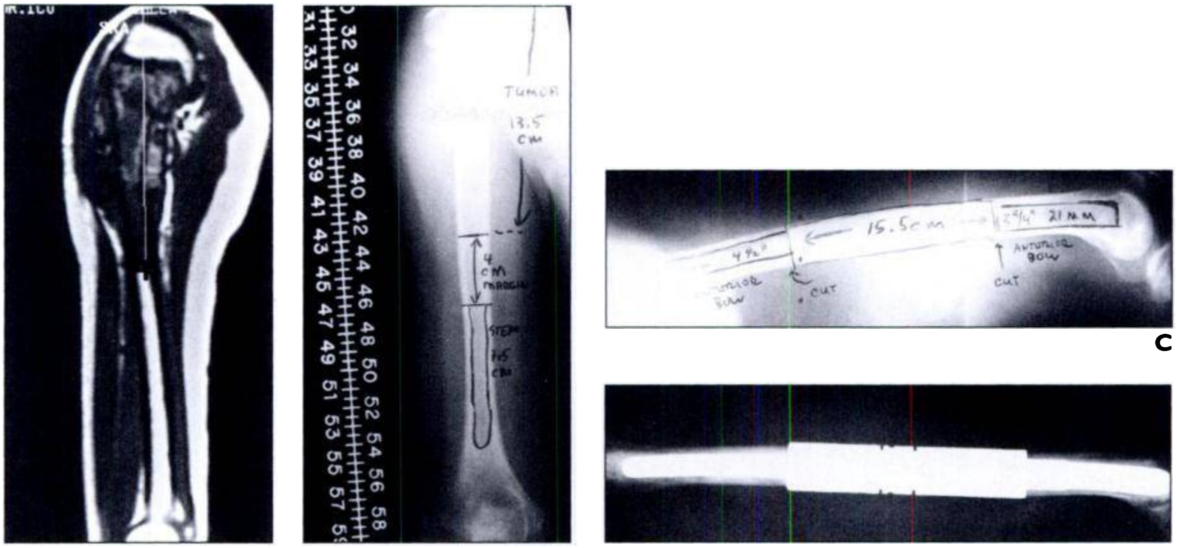



**Fig. 6.**—Endoprosthesis design.
**A**, Sagittal T1-weighted MR image covering entire length of humerus in 14-year-old girl with osteosarcoma. Measurements of distance from humeral head to inferior margin of tumor are made at console.
**B**, Measurements from MR image in **A** are transferred to scanogram. In this case, osteotomy was made 4 cm distal to inferior margin of tumor to ensure tumor-free margin.
**C**, Scanogram template for intercalary femoral endoprosthesis in 28-year-old man with osteosarcoma. Note anterior bow for femoral stems.
**D**, Radiograph of implanted endoprosthesis in same patient as in **C**.

tibia will grow symmetrically, resulting in equal or near-equal tibia lengths [7].

## Complications

Most limb salvage reconstructions carry a 35–50% risk of local complications.

### *Local Recurrence*

Tumor recurrence in the bone is extremely uncommon because osteotomy margins are usually well removed from the edge of the tumor. Local recurrence in the soft tissue is often difficult to detect radiographically, except in the case of bone- or cartilage-forming tumors (Fig. 11).

### *Infection*

Deep infection can occur acutely as a result of contamination at the time of operation or as a late complication from hematogenous seeding. Traditional imaging techniques for the diagnosis of infection are generally not helpful. Triple-phase technetium bone scans and indium scans will show increased tracer activity related to the surgery for several months, and MR imaging is precluded by virtue of periprosthetic metallic artifacts. Ultimately, aspiration is needed to confirm the presence or absence of periprosthetic infection.

### *Mechanical Failure*

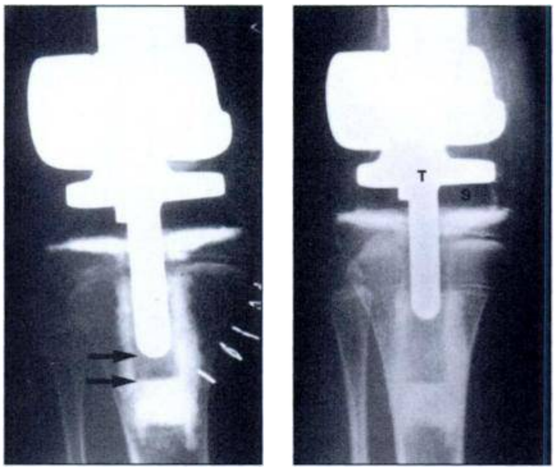
Aseptic loosening is the most common cause of endoprosthetic failure. At 10 years, the risk that a cemented distal femoral replacement




**Fig. 7.**—Postoperative radiography of 13-year-old boy with osteosarcoma. In lower extremity, scanograms are used to ensure equal leg lengths.

**Fig. 8.**—Radiograph of 13-year-old boy with osteosarcoma shows stress shielding along stem of expandable proximal humeral endoprosthesis. Bone resorption (*arrow*) reflects redistribution of forces along bone. This finding is expected and should not be mistaken for prosthetic loosening or infection. Note superior migration of humeral head. Soft tissues are stretched and attenuated with expansion, allowing head to subluxate.

**Fig. 9.**—Radiograph of 22-year-old man with osteosarcoma shows titanium debris. Lining of pseudocapsule that surrounds distal femoral endoprosthesis is evident by virtue of extensive imbedded titanium.




10A 10B

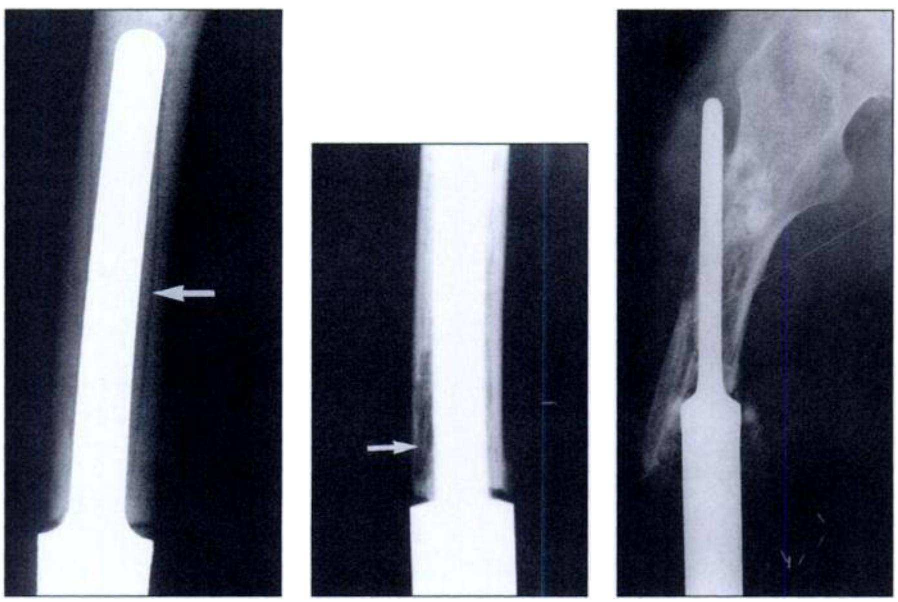
11

**Fig. 10.**—Radiographs of 8-year-old girl with osteosarcoma show continued growth of proximal tibia after distal femoral limb salvage.

**A**, Immediately after operation, note distance between tibial stem tip and lower aspect of polyethylene (*arrows*).

**B**, Two years later, tibial polyethylene sleeve with metal tibial bearing component has been pushed proximally by continued circumferential growth of physis. S = sleeve, T = tray.

**Fig. 11.**—Radiograph of 18-year-old man with osteosarcoma shows local recurrence 3 years 6 months after proximal tibia limb salvage. Soft-tissue mineralization anterior to distal femur (*arrow*) represents recurrent osteosarcoma.



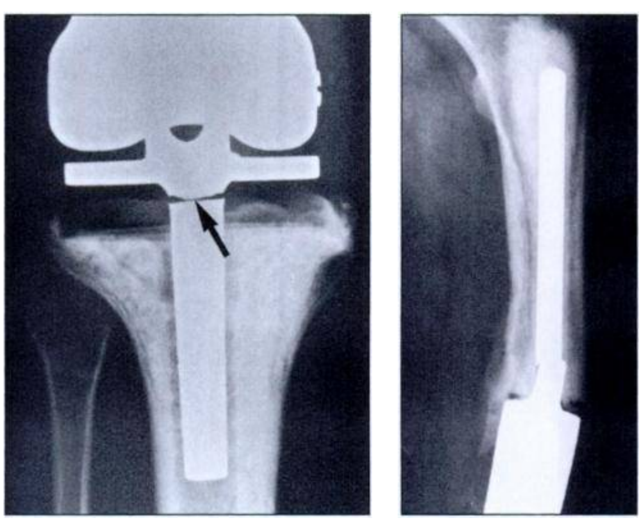
A B C

**Fig. 12.**—Radiographs show a septic loosening.

**A**, In 35-year-old man with osteosarcoma, thin radiolucency is present at bone–cement interface of distal femoral endoprosthesis (*arrow*). In presence of thigh pain, this finding is diagnostic of aseptic loosening.

**B**, In 20-year-old man with osteosarcoma, focal cortical osteolysis (*arrow*). This process may be limited or may be rapidly progressive.

**C**, In 24-year-old man with osteosarcoma, gross aseptic loosening of distal femoral stem with protrusion through femoral cortex. Patient presented for revision. Failure was due to undersizing of stem as compared with diameter of femoral canal.



13A 13B

14

**Fig. 13.**—Radiographs show fatigue fracture.

**A**, In 15-year-old boy with osteosarcoma, proximal tibial component stem fracture (*arrow*) of distal femoral endoprosthesis.

**B**, In 43-year-old man with malignant fibrous histiocytoma of bone, proximal stem fracture of distal femoral endoprosthesis.

**Fig. 14.**—Radiograph shows bushing failure in 22-year-old man with osteosarcoma. Nine years after initial surgery, axle has migrated laterally.

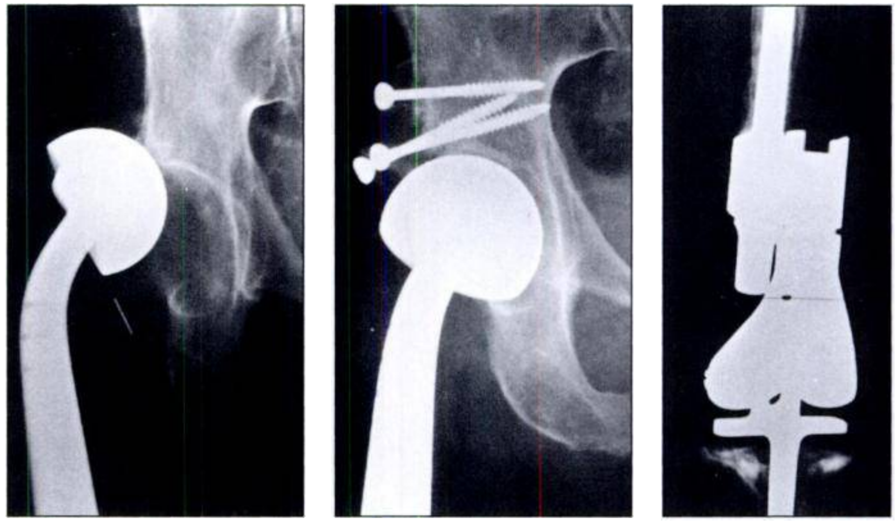



**Fig. 15.**—Radiographs show dislocation and component dissociation.
**A**, Severe subluxation of bipolar proximal femoral endoprosthesis occurred 1 year after initial surgery in 61-year-old woman with chondrosarcoma.
**B**, Grafting superolateral acetabulum prevented subsequent instability in same patient as in **A**.
**C**, Component dissociation in 61-year-woman with bone loss after supracondylar fracture and infection. Cemented proximal portion of distal femoral endoprosthesis has become dissociated from proximal portion of modular component. This dissociation occurred 2 weeks after reassembly of components after debridement of hematogenously spread periprosthetic infection that occurred 1 year 6 months after initial surgery.

will fail from aseptic loosening ranges from 15% to 40% [5, 6]. The radiographic presence of progressive radiolucent lines at the bone–prosthesis or bone–cement interface (Fig. 12A) suggests aseptic loosening and is diagnostic in the presence of thigh pain. Additional imaging is not necessary. Aseptic loosening may also appear as cortical osteolysis adjacent to the endoprosthesis (Figs. 12B and 12C).

Fatigue fracture of the metal components is not rare (Fig. 13). Stem fracture may be apparent clinically before radiographic confirmation because a well-cemented stem will appear normal until translation between the fragments takes place. Once the fragments have become displaced, the radiographic appearance can be dramatic. Factors leading to fatigue failure of a metal endoprosthesis include failure to fill and fit the bony canal satisfactorily and undersizing of the stem relative to the resected segment length or the patient's weight [2, 4, 6].

As with conventional arthroplasty, the polyethylene components of an endoprosthesis may wear. Polyethylene bushing failure (Fig. 14) is uncommon with rotating-hinge mechanisms. Only when malalignment of the components occurs can the diagnosis be made radiographically.

Prosthesis dislocation (Figs. 15A and 15B) or subluxation is uncommon. Very rarely, the components of a modular endoprosthesis will dissociate [4]. This complication is readily evident radiographically (Fig. 15C).

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