Reconstruction of the Extensor Mechanism After Major Knee Resection

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abstract

In periarticular knee resections, the relative lack of soft tissue coverage and need to reattach the extensor mechanism after en bloc resection of the tibial tuberosity with the tumor specimen complicate reconstructions and decrease postoperative function and stability of the knee joint. Distal femoral reconstructions are less problematic; muscular attachments are relatively few, neurovascular structures are not immediately adjacent to bone, and the knee extensor mechanism is usually not compromised from bone tumors. In the proximal tibia, the close proximity of the neurovascular structures in the popliteal fossa and peroneal nerve at the lateral aspect of the leg make reconstruction more difficult. Poor function is mostly related to unreliable options for knee extensor mechanism reattachment and poor soft tissue coverage. Successful and reliable attachment of the soft tissues has been a significant advance that improved functional outcomes.

This article describes techniques for the reconstruction of the extensor mechanism of the knee after proximal tibia resections. Combined reconstruction techniques using direct reattachment of the patellar tendon with synthetic materials to megaprosthetic or allograft reconstructions for immediate stability, augmentation with autologous bone graft or substitutes at the attachment site, and coverage with the medial gastrocnemius muscle flap and supplementary flaps for long-term stability of the reattachment are currently considered the gold standard.

Figure: Intraoperative photographs showing wide resection of the proximal tibia and fibula (A), proximal tibia megaprosthetic reconstruction (B), and direct attachment of the extensor mechanism to the megaprosthesi augmented with acellular dermal allograft (C).

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Advances in surgery, imaging, and adjuvant treatments have enabled limb salvage for sarcomas around the knee without compromising survival. Distal femoral reconstructions are less problematic: muscular attachments are relatively few, neurovascular structures are not immediately adjacent to bone, and the knee extensor mechanism is usually not compromised from bone tumors. However, in the proximal tibia, the close proximity of the neurovascular structures in the popliteal fossa and peroneal nerve at the lateral aspect of the leg, the relative lack of soft tissue coverage, and the need to reattach the extensor mechanism after en bloc resection of the tibial tuberosity with the tumor specimen complicate reconstruction and decrease postoperative function and stability of the knee joint.

Poor soft tissue coverage and primary wound-healing problems have been associated with an incidence of infection ranging up to 31%, wound-healing problems ranging up to 38%, and failure of proximal tibial reconstruction. Function is inferior compared with reconstructions in other joints; Musculoskeletal Tumor Society functional scores for patients undergoing proximal tibia reconstructions were approximately 65%, An inability to walk and climb stairs and extensor lag with compromised active extension of the knee are common. Poor function is mostly related to unreliable options for knee extensor mechanism reattachment and poor soft tissue coverage.

Successful and reliable attachment of the soft tissues and routine use of muscle flaps for wound closure have been significant advances that reduce complications rates and improve functional outcomes.

This article describes the available options for knee extensor mechanism reconstruction (eg, direct attachment, augmentation with synthetic materials, autologous bone graft or substitutes, and tendon transfers and muscle flaps) with respect to the different types of bone reconstructions (eg, megaprosthetic, osteoarticular, and allograft–prosthesis composite) after major knee resection.

**RECONSTRUCTION OF THE EXTENSOR MECHANISM**

Numerous options for the reconstruction of the extensor mechanism of the knee following proximal tibia and extraarticular knee resections have been reported. These include direct reattachment of the patellar tendon to a megaprosthesis, osteoarticular allografts, and allograft–prosthesis composites, and augmentation techniques with synthetic materials. Combined techniques have also been described, including direct suture to the prosthesis or allograft and osteotomy of the fibula with attachment to the lateral collateral ligament, medial gastrocnemius flap with transposition of the fibula, and direct reattachment of the patellar tendon to a megaprosthesis augmented with autologous bone graft, medial gastrocnemius muscle flap, and synthetic materials.

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### Table

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<thead>
<tr>
<th>Name</th>
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<td>Dacron</td>
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<td>Gore-Tex</td>
<td>W.L. Gore &amp; Associates, Inc, Newark, Delaware</td>
<td>Polytetrafluoroethylene</td>
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<td>Graftjacket</td>
<td>Wright Medical Technology, Inc, Arlington, Tennessee</td>
<td>Human cadaveric dermis</td>
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<tr>
<td>Ligament Advancement Reinforcement System (LARS)</td>
<td>Surgical Implants and Devices, Arc-sur-Tille, France</td>
<td>Terephthalic polyethylene polyester</td>
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<td>Leeds-Keio</td>
<td>Xiros, Leeds, United Kingdom</td>
<td>Polyethylene terephthalate</td>
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<tr>
<td>Vicryl mesh</td>
<td>Ethicon, Somerville, New Jersey</td>
<td>Polylactin 910</td>
</tr>
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<td>OrthADAPT</td>
<td>Pegasus Biologic, Inc, Irvine, California</td>
<td>Equine pericardium xenograft</td>
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*References 23, 24, 30, 35, 36, 43, 44, 48-50.
The reconstruction method of the extensor mechanism is influenced by the extent of surgical resection and the type of bone reconstruction, namely megaprosthetic or allograft. Biomechanical studies have reported that by reattachment of the extensor mechanism to a megaprosthesis with augmentation with a synthetic material and a gastrocnemius muscle flap, a strong continuity of the patellar tendon is obtained, whereas the gastrocnemius flap and leg extensors decrease the postoperative extensor lag; however, the patellar tendon stretches over time. In contrast, by reattachment of the extensor mechanism to a tibial allograft, the patellar tendon remains stable with no elongation between pre- and postoperative measurements. Reconstruction must provide adequate mechanical compression results in poorer graft retention, mechanical compression on tissue healing may lead to ischemia from increased pressure, reduced microvascular flow, limited delivery and removal of cellular substrates and metabolites, and reduced oxygen tension limiting cell proliferation, proteoglycan, and protein synthesis, thereby leading to reconstruction failure.

**DIRECT REATTACHMENT TO A MEGAPROSTHESIS**

Screws, sutures, loops, metallic or polyethylene plates, absorbable and nonabsorbable synthetic materials and artificial ligaments, biological reconstructions, and combinations of these have been reported to reattach the extensor mechanism to a megaprosthesis.

Direct attachment of the extensor mechanism to the proximal tibia megaprosthesis provides the initial mechanical stability needed for healing and scarring. However, common complications with direct fixation are wound-healing problems, infection, and increased extensor lag or failure of the patellar tendon–metal junction requiring secondary repair. A residual extensor lag of >20° may occur in 9% to 33% of patients who undergo direct attachment to a megaprosthesis, and in 20% to 44% of patients in whom a pedicled gastrocnemius flap is used to reinforce the repair.

Previous studies have reported the formation of an immature patellar tendon–implant neoenthesis when compressive forces are applied to the patellar tendon–prosthesis junction with a mechanical clamp device. Although lack of mechanical compression results in poorer graft retention, mechanical compression on tissue healing may lead to ischemia from increased pressure, reduced microvascular flow, limited delivery and removal of cellular substrates and metabolites, and reduced oxygen tension limiting cell proliferation, proteoglycan, and protein synthesis, thereby leading to reconstruction failure.

**DIRECT REATTACHMENT TO AN OSTEOARTICULAR ALLOGRAFT**

Compared with megaprosthetic reconstruction, osteoarticular allografts allow restoration of bone stock and direct biological reattachment of the host tendons, ligaments, and capsule. However, osteoarticular allograft reconstructions are technically more difficult, involve a longer period of immobilization for healing and union to occur among the capsulotendinous structures and bone, and are associated with higher complication rates, including infection, nonunion, fracture, subchondral collapse, articular cartilage degeneration, and instability. Allograft-related complications are more common in the setting of chemotherapy and radiation therapy.

**DIRECT REATTACHMENT TO AN ALLOGRAFT–PROSTHESIS COMPOSITE**

Allograft–prosthesis composites combine the potential advantages of osteoarticular allografts, including restoration of bone stock and biological reattachment of the soft tissues, with the advantages of a prosthesis, including range of motion, load-sharing properties, and articular stability. The short-term survival of allograft–prosthesis composites in the proximal tibia is approximately 73% at 5 years, with excellent and good Musculoskeletal Tumor Society function, which is comparable with that of megaprosthetic reconstructions.
in tubes and cords. In vivo and in vitro studies have shown that complete fibrous ingrowth can be seen after 6 months. However, after 6 months, the mechanical properties of Trevira deteriorate.

Gore-Tex (W.L. Gore & Associates, Inc, Newark, Delaware) is a type of polytetrafluoroethylene initially used in 1971 for human vascular grafts and plastic surgery. Because vascular ingrowth is limited, this polymer has been shown to be minimally integrated with the surrounding tissues. Moreover, the pore sizes range from 0.5 to 30 µm, which is not an ideal diameter for macrophage migration and tissue ingrowth but can be a favorable environment for bacterial invasion and infection. Kollender et al reported a technique for secondary reconstruction of failed knee extensor mechanism reconstruction using 2 Gore-Tex strips sutured to the reconstructed patellar tendon for reinforcement, in addition to medial gastrocnemius muscle flap coverage for mechanical and biological reinforcement of the reconstructed extensor mechanism.

GraftJacket (Wright Medical Technology, Inc, Arlington, Tennessee) regenerative tissue matrix is an acellular dermal allograft used to augment repairs of the rotator cuff, Achilles tendon, and the extensor mechanism of the knee (Figure 1). It was first shown to act as a scaffold for host cell repopulation, revascularization, and tissue remodeling in experimental models. Subsequent work in sports medicine has shown superior biomechanical performance and increased load to failure strength of GraftJacket matrix when compared with other biologic tendon graft substitutes and augmentation grafts.

Ligament Advancement Reinforcement System (LARS; Surgical Implants and Devices, Arc-sur-Tille, France) is a polyester artificial ligament used for augmentation or replacement of the extensor apparatus after tumor resection. Its use did not increase the risk of infection; however, ligament failure may occur in up to 23% of patients. This highlights the fact that although secure mechanical fixation and soft tissue ingrowth or scarring may be achieved with a prosthetic material, healing does not occur at the patellar tendon–implant junction.

Leeds-Keio (Xiros, Leeds, United Kingdom) is an artificial ligament used for the reconstruction of knee ligaments, particularly the anterior cruciate ligament, but also in hip, ankle, shoulder and spine surgery. In tumor surgery, it has been used as an artificial periosteum for soft tissue reattachment to the prosthesis, with minimum inflammatory reaction.

Vicryl (polyglactin 910) mesh (Ethicon, Somerville, New Jersey) is a polyester artificial ligament used for augmentation or replacement of the extensor apparatus after tumor resection.
biodegradable material used to attach the extensor mechanism to a megaprosthesi
s augmented with autologous bone and marrow grafts. It has been shown to pro-
vide an environment more conducive to tendon–bone–implant healing than a comp-
ressive clamp system. Despite the poten-
tial detrimental effects of the mesh degra-
dation products, a neoenthesis developed
with regions of direct and indirect types
of healing at 12 weeks. Early mechanical
stability with Vicryl mesh was similar to a
mechanical clamp reconstruction.44

The disadvantage of artificial liga-
ments is that they often result in syno-
vitis, infection, and loosening or loss of mechanical strength of the reconstructed
tensor mechanism.30 In vivo and in vitro
studies have shown that complete fibrous
ingrowth can be seen after 6 months of
reconstruction using artificial ligaments.57
However, after 6 months, the mechanical
properties of the synthetic materials and
their capacity in providing durable stabil-
ity deteriorates, and extensor function can
be assumed only by newly formed scar
tissue.50,53,58-60 Therefore, these materials
are recommended for immediate postop-
erative stability of the reconstructed ex-
tensor mechanism for an adequate period
of time to allow strong scar tissue forma-
tion. For long-term stability, artificial liga-
ments and synthetic materials should be
combined with biological augmentation and reconstruction techniques.56

Autologous Bone Graft, Demineralized
Bone Matrix, and Bone Morphogenetic
Protein-7

Biological augmentation and recon-
struction techniques have been described
to overcome the problems of healing
of extensor mechanism reconstruc-
tions.35,36,46,55,68-71 Many prostheses in-
clude a porous or hydroxyapatite-coated
surface on the tibial component to pro-
vide ingrowth and mechanical reinforce-
ment. However, fibrous tissue rather than
tendon ingrowth occurs on the porous-
coated surface of the megaprosthetic72; a
tendon–hydroxyapatite attachment devel-
opps with collagen fibers orientated parallel
to the implant surface, indicative of fibrous
encapsulation.35,36

Malawer et al23 described a technique
of extracortical bone fixation, in which a
bone graft is laid and secured over the ex-
tramedullary porous-coated surface of the
prosthesis, and reported incorporation of
the bone graft in 60% of patients. By
attaching the extensor mechanism to the
extramedullary porous-coated surface of
the prosthesis and reinforcing it with an au-
tologous bone graft, a fibrous–bone bridge
can result.4 Other studies report that by
using bone autograft to augment the patel-
lar tendon–prosthesis interface, a layered
tendon–fibrocartilage–bone interface can
be seen at 12 weeks, which is similar to a
normal tendon insertion.35,36 Bone block
augmentation of patellar tendon–implant
interface may result in more reliable re-
tention of the graft on the implant surface,
enhanced biological integration, and more
consistent functional outcomes compared
with morselized graft augmentation tech-
niques (Figure 2).4,73,74 Augmentation of
the tendon–implant interface with deminer-
alized bone matrix or bone morphogenetic
protein-7 results in regeneration of a more
direct-type of neoenthesis, with regions of
fibrocartilage, mineralized fibrocartilage,
and bone.39,41 Demineralized bone matrix
is osseoinductive, providing a slow release
system for growth factors, including bone
morphogenetic proteins,75 and has the po-
tential to improve attachment of the ten-
don to the implant.40 With stable mechani-
cal fixation of the extensor mechanism, a
direct-type neoenthesis can be created
using combinations of a bioactive implant
surface, such as hydroxyapatite, and bio-
logical augmentation with bone autograft
or substitutes and muscle flap.4,35-39,44

Transpositional Fibula Flap

Pedicled transpositional fibula flap with
its tendon attachments may provide a biolog-
ical attachment of the extensor mechanism
without the use of synthetic material.69,70
Comparing the transpositional fibula flap,
including suturing of the patellar tendon to
the biceps tendon and lateral collateral liga-
ment, the medial gastrocnemius muscle
flap, and a combination of both techniques
for extensor mechanism reconstruction after
proximal tibia resection, results were better
when both techniques were combined.46

Tendon Transfers

Tendon transfers have been described
for extensor mechanism reconstruction
after major knee resections with con-
flicting results. Some authors reported a
Musculoskeletal Tumor Society functional
score of 50% and significant loss of extensor
strength following flexor-to-extensor tendon
transfer after knee resection.96 The decreased
function was presumed to be the effect of
extensive scarring, which led to decreased
extensor strength and knee stabilization.92
The authors discouraged tendon transfers
for extensor mechanism reconstructions.92
Other authors used gastrocnemius and pes
anserinus tendon transfers for reconstruc-
tion of the extensor mechanism, with satis-
factory overall function, mean knee flexion
of 62°, and extension lag of 12°. The authors
concluded that this technique provides ex-
cellent tissue coverage and a strong extensor
mechanism and is therefore a viable alterna-
tive to arthrodesis.58

Muscle Flaps

Pedicled transpositional or free mus-
cle flaps, including the medial or lateral
Supplementary muscle flaps, such as the medial gastrocnemius muscle flap (B), coverage of the prosthesis with the medial gastrocnemius and soleus muscle flap, and attachment of the extensor mechanism with sutures to the medial gastrocnemius flap (C).

Figure 3: Illustrations showing proximal tibia resection (A), distal detachment and rotation of the medial gastrocnemius muscle flap (B), coverage of the prosthesis with the medial gastrocnemius and soleus muscle flap, and attachment of the extensor mechanism with sutures to the medial gastrocnemius flap (C).

Figure 4: Ultrasonography in active knee extension showing the medial gastrocnemius muscle flap (arrows) in a patient with proximal tibia resection and megaprosthetic reconstruction.

The medial gastrocnemius muscle flap remains the most widely used adjunct for wound coverage and reconstruction of the extensor mechanism of the knee. First used by Dubousset et al., the medial head of the gastrocnemius muscle can be raised as a muscle or myocutaneous unit. Two techniques have been described: (1) as a transpositional flap: when an intact patella tendon and patella exist, the medial gastrocnemius is transposed anteriorly without division of its proximal or distal attachments; and (2) as a rotational flap: when the patella tendon is absent, the muscle is detached distally, rotated anteriorly over the fibula, and sutured to the joint capsule and the patella or the remaining patellar tendon, forming a complete soft tissue envelope around the prosthesis (Figures 3, 4). Supplementary muscle flaps, such as the soleus, gracilis, and semimembranosus, can be used to augment coverage provided by the gastrocnemius muscle flap in situations where wound coverage is deficient or when a significant amount of the vastus medialis or gastrocnemius muscle was resected. Technical refinements include primary skin grafting to relieve tension during skin closure and excision of the aponeurosis over the transferred muscle to increase the reach and surface area of the muscle flap.

Conclusion

Reconstruction of the extensor mechanism after major resection and reconstruction around the knee is challenging. Combined reconstruction techniques using direct reattachment of the patellar tendon with synthetic materials to megaprosthetic or allograft reconstructions for immediate stability, augmentation with autologous bone graft or substitutes at the attachment site, and coverage with the medial gastrocnemius muscle flap or supplementary flaps for long-term stability of the reattachment are currently considered the gold standard.

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Feature Article


