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Biological Reconstruction in Musculoskeletal Oncology: Have We Reached a Turning Point?

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ABSTRACT

In the field of musculoskeletal oncology, there has been a shift in ideology from local management of tumours with amputations to limb salvage surgery. Musculoskeletal oncology entered a new age of limb salvage due to advances in the fields of chemotherapy and radiation oncology, as well as in alloys, metals, and composites (Shojaie et al., 2023; Andrade et al., 2016). However, limb salvage is indicated only when we can achieve R0 margins and ensure that the major neurovascular structures remain uninvolved or reconstructible; salvage at all costs is a fallacy. Extensive soft tissue loss or a limb rendered insensate and ischemic is a contraindication to limb salvage surgery, where amputation would be a better functional choice.

The "void" left behind after the resection of the diseased bone was filled with a metallic prosthesis. This gave our patients almost immediate freedom of motion, a stark contrast to the older philosophy of amputation/disarticulation. However, this came at a cost; we are not gods to provide bountiful gifts that last forever. The bones we replaced with metal had an expiration date, as initial results were good but were associated with multiple complications. We were essentially placing a mechanical part into a biological system and hoping the two would coexist. Hence, we argue that we have reached a definitive turning point and are moving out of the "Age of Mechanics" and into the "Age of Biologics." Can we consider one method as superior to the other?.

What Is Biological Reconstruction?

Biological reconstruction, as used in musculoskeletal oncology, is the technique of reconstructing a bone defect following tumour removal, utilising processed or living biological tissues rather than synthetic implants (Puri, 2021; Tiwari *et al.*, 2019). Techniques consist of autografts (vascularised fibula transfer, Capanna technique, epiphyseal preservation); allografts (donor bone); radiated or liquid nitrogen treatment of tumour bone; or distraction osteogenesis of bone (Shankhdhar *et al.*, 2018).

These techniques seek to re-establish the natural structure of the bone, integrate with the host bone, and, if successful, provide long-term durability and advantages when union is achieved. Additionally, there is no risk of implant breakage or implant wear, which is seen in long-term follow-up of prosthetic replacements.

Type of Graft	Advantages	Disadvantages
Vascularized Autograft (Free Fibula)	Higher biological activity Faster union time Lower infection rates	Requires microvascular anastomosis Fixed length of bone available Longer surgical time
Non-Vascularized Autograft	Simpler surgery Shorter surgical time	Fixed length of bone available Lower biological activity Longer time for union
Allograft	Any length of bone can be procured No additional donor site morbidity	Higher risk of infection Longer time for union
Combination	Allograft provides strength Vascularized Fibula provides life	Requires microvascular anastomosis Longer surgical time
Sterilised Tumor Bone	Anatomical fit No additional donor site morbidity	Will require ECRT / Liquid nitrogen dipping risk of non-union if segment length increases

In the past, resected tumour bone was discarded, and the void had to be filled by a prosthesis, autograft from a different site, or allograft. However, with advancements in oncology, surgeons can now recycle the resected bone by sterilising the specimen, either by radiation (extracorporeal radiation therapy) or liquid nitrogen dipping (Tiwari *et al*., 2019). These methods can be performed during surgery, and the surgeon also obtains an anatomically fitting bone to fill the defect.

However, these techniques are not without disadvantages, such as the risk of non-union or malunion, which may warrant a second surgery. When used in weight-bearing bones, they require a longer postoperative period to achieve full weight-bearing compared to prostheses. The prosthetic 5- and 10-year survival rates for distal femoral prostheses in previous studies ranged from 57% to 93% and 0% to 88%, respectively (Puri, 2021). The 5-year limb-preservation rates ranged from 86% to 96%. Despite these advances, up to 50% of patients encounter complications that may require revision surgery (Grimer *et al*., 2016; Jeys *et al*., 2009). Additionally, patients with diabetes mellitus at the time of initial surgery have a higher risk of developing complications.

Appropriate patient selection is one of the most important factors affecting the outcome of biological reconstruction. It is necessary to carefully consider factors such as age, life expectancy, tumour biology, treatment response, and functional demands. Biological reconstruction is most beneficial for younger patients with limited disease, particularly when cost constraints preclude the use of expandable prostheses in children with residual growth and long survival potential. In contrast, prosthetic replacement, which provides quicker functional recovery, is beneficial for patients with advanced disease or short life expectancy. While periarticular resections remain challenging because of significant mechanical stress and the need to preserve joint function, intercalary diaphyseal defects are especially well suited to biological methods. Although indications for biological reconstruction have expanded due to developments in joint-preserving resections and implants, prosthetic options still predominate in complex periarticular situations.

According to recent research, in carefully selected patients, biological reconstruction can yield MSTS scores comparable to prosthetic reconstruction. A major advantage is long-term durability, particularly in younger patients with good survival prospects, in whom biological integration may reduce the need for revision surgery. The future of biological reconstruction lies in the integration of tissue engineering, regenerative medicine, and precision surgery. Recent developments in bioactive scaffolds, stem cell augmentation, and growth factor delivery show potential in accelerating healing and reducing complications. Advances in navigation and 3D planning also support joint-preserving and biological reconstruction strategies (Puri, 2021).

Conclusion

Biological reconstruction has reached a stage where it can be applied more frequently in selected patients, particularly younger individuals with a good life expectancy. It represents a significant shift in ideology toward biologically integrated, patient-specific limb salvage techniques, although it cannot entirely replace prosthetic reconstruction. It is not universally superior, and decision-making remains individualized, depending on patient characteristics, tumour location and biology, and surgical expertise. Rather than competing ideologies, biological and prosthetic reconstructions should be viewed as complementary tools within a personalised treatment algorithm.

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