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Review article

Osteotomy and fracture fixation in children and teenagers

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ABSTRACT

Significant changes have occurred recently in fixation methods following fracture or osteotomy in children and teenagers. Children have benefited the most from these advances. A child's growth is anatomically and physiologically ensured by the growth plate and periosteum. The need to keep the periosteum intact during trauma cases has led to the introduction of flexible intramedullary nailing. We will review the basic principles of this safe, universally adopted technique, and also describe available material, length and diameter options. The problems and the limitations of this method will be discussed extensively. In orthopedics, the desire to preserve the periosteum has led to the use of locking compression plates. Because of their low profile and high stability, they allow the micromovements essential for bone union. These new methods reduce the immobilization period and allow autonomy to be regained more quickly, which is especially important in children with neurological impairment. The need to preserve the growth plate, which is well known in pediatric surgery, is reviewed with the goal of summarizing current experimental data on standard fracture and osteotomy fixation methods. Adjustable block stop wires provide better control over compression. These provide an alternate means of fixation between K-wires and screws (now cannulated) and have contributed to the development of minimally invasive surgical techniques. The aim of this lecture is to provide a rationale for the distinct technical features of pediatric surgery, while emphasizing the close relationship between the physiology of growth, bone healing and technical advances.

1. Introduction

Many changes have occurred in pediatric osteotomy and fracture fixation over the past few years. The objective of this lecture is to discuss all these changes in the context of scientific advances in the fields of biomechanics and biology, and to highlight the most essential elements related to children and their growth. Recent data on bone healing will be reviewed first as an introduction to current options for pediatric osteotomy and fracture fixation and their biological basis. Joint fusion, common in "adult" orthopedics and spinal fixation will not be discussed here, as they comprise entire fields on their own.

2. Current data on fracture healing

There are few recent publications specific to fracture healing in children. The basis of fracture healing in children using flexible intramedullary nailing (FIN) was described in 1987 by Téot, who performed extensive experiments [1]. Biological aspects such as preserving the fracture hematoma and periosteum, the fundamental role of the periosteum and the importance of medullary vascularization were highlighted. The role of bone morphogenic proteins (BMPs), osteoblast-osteoclast interactions, contribution of ischemia and hypoxia, and electric induction phenomenon were revealed. Parallels were drawn between the process of bone healing and the various stages of endochondral bone formation in the embryo. A description of the four stage of bone healing is given in Table 1 along with an overview of the growth factors and cells involved.

But biological factors are only some of the elements needed for bone healing. Bone regeneration requires three fundamental components [2]:

- progenitor cells;
- growth factors (osteoinduction);
- appropriate scaffold (osteoconduction).

Giannoudis added the mechanical environment to this list and arrived at the diamond concept of fracture healing (Fig. 1) [3,4]. But to fully understand individual variations in bone healing, genetic variations [5], use of drugs such as NSAIDs, ageing and smoking must also be taken into consideration.

Biomedical engineering can come into play with each of these four components.

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Table 1
Stages of bone healing.

Stage of bone healing	Event	Molecules expressed
Inflammation	Hematoma Inflammation Recruitment of MSC	IL-1, IL-6, TNF-alpha trigger biological cascade TGF-ß, BMP-2, PDGF activate callus formation GDF-8 expressed at day 1, cell division
Cartilage formation Periosteal response	Chondrogenesis and endochondral ossification Cell division, intramembranous ossification Vascular proliferation Angiogenesis (periosteum)	TGF-ß2 and ß3, GDF-5 peak expression BMP-5 and BMP-6 VEGFs
Cartilage resorption Primary bone callus	Active osteogenesis Appearance of osteoblasts, woven bone Osteoclasts, cartilage resorption Angiogenesis	TNF-alpha, cartilage resorption, MSC recruitment, chondrocyte apoptosis RANKL and MCSF, cartilage resorption BMP-3, -4, -7 and -8 expressed recruitment of cells having osteoblastic lineage BMP-5 and -6, likely regulating endochondral and intramembranous ossification
Final callus Remodelling	Remodelling Appearance of bone marrow	IL-1 and IL-6, bone remodelling TGF-ß, RANKL and MCSF levels reduced

Based on a course on osteoinductive materials, Bone Morphogenic Proteins, F. Sailhan, http://www.getbo.com.
MSC: mesenchymal stem cells; BMPs: bone morphogenic proteins.

Internal fixation of mid-shaft fractures greatly evolved under the auspices of the AO Foundation. The concept of rigid anatomical fixation was transformed to a more biology-friendly design, resulting in locking compression plates [6].

The desire to maintain the mechanical environment through muscle balancing and bone vascularization led to the idea of minimally invasive surgery.

Mesenchymal stem cell-based therapies and osteoinductive factors are now being used clinically [7,8].

Since children rarely have bone-healing deficiencies, the pediatric orthopedics world is a spectator to these developments, for now. But without true pediatric studies on bone healing, we are left to extrapolate recent scientific findings to children.

As for fracture fixation, the following points are already well known, but will be discussed in a biological context:

- keep the periosteum intact;
- do not disturb the fracture hematoma;
- flexibility is required during fixation;
- development of percutaneous surgery.

Although biomedical engineering applies only to a limited number of cases, some of the initial applications were autologous bone marrow grafting and osteopetrosis [7]. Recent applications consist of BMP treatment of congenital pseudarthrosis, bone marrow-derived mesenchymal cells in osteogenesis imperfecta [9], application of the induced membrane technique to children [10], avascular necrosis related to corticosteroid therapy, and by analogy, treatment of mucopolysaccharidosis diseases [11].

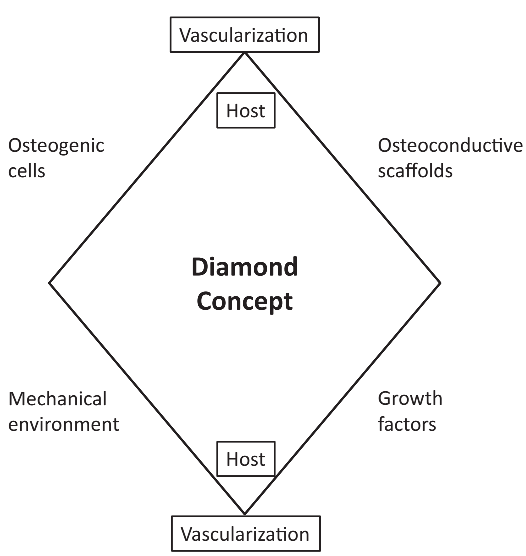

Fig. 1. Diamond concept capturing the four elements of fracture healing.
From Giannoudis.

3. Role of fixation in children and teenagers

It is restating the obvious that childhood is characterized by growth and that this process is driven by two specific structures: the growth plate (or physis) and periosteum, which is a true ally for the pediatric orthopedic surgeon. Each of these structures has its own complications and problems during osteotomy and fracture fixation.

Although growth conveniently corrects many cases of malunion, it would be wrong to believe that it solves everything. Conversely, automatically reducing and fixing every fracture can also lead to problems. One must always remember that conservative (non-surgical) treatment leads to faster and more reliable healing than fracture fixation. This procedure is only indicated in current pediatric trauma practice if the fracture callus does not have sufficient remodelling capacity. The indications will mainly depend on the child's age and the fracture site. Exceptions to this rule are polytrauma [12], associated severe head injury, pathological fractures or certain underlying diseases such as neurological impairment or congenital bone fragility.

The following rules of remodelling underpin the indications for bone fixation:

- a malunion will be properly remodelled if:
  - the child is young (usual limit is about 8 years of age),
  - the malunion is near the metaphysis,
  - this metaphysis is highly active, with a high potential for growth (near the knee, away from the elbow, etc.),
  - the callus displacement plane corresponds to a potential movement of the neighbouring joint (high tolerance at wrist; no tolerance for valgus-varus displacement at ankle).

Any offset, or rotated callus, cannot correct itself. Be careful with supracondylar fractures at the elbow, mid-shaft fixation of the humerus and femur, and metacarpal or phalangeal fractures!

These factors help to explain the many indications for conservative treatment of wrist or proximal humerus fractures, and a large number of indications for fracture fixation at the elbow or ankle.