Bone healing and fractures

Principles and concepts

Philipp M. Lenzlinger
Learning objectives

• Know about the biology and biomechanics of bone healing, as well as their failure
• Know the properties of angular stable implants
• Know the AO Fracture classification
Topics covered

• Biology and biomechanics of bone healing
  - primary / secondary
  - absolute / relative stability

• Angular stable implants

• Delayed union

• Fracture classification
Topics covered

• Biology and biomechanics of bone healing
  - primary / secondary
The unstabilized fracture
The unstabilized fracture

- Nature tries to stabilize by muscle-contraction, and hydrostatic pressure of hematoma and edema
The unstabilized fracture

- Nature tries to stabilize by muscle-contraction, and hydrostatic pressure of hematoma and edema
- Shortening and malalignment -> impairment of function
The unstabilized fracture
The unstabilized fracture

- Initial mobility is well compatible with solid bone healing
Goal of Fx Treatment

• Basis for good function:

Fracture reduction and immobilisation to restore anatomical relationships and allow fracture healing
Immobilisation

• Of the limb:
Immobilisation

- Of the patient:
Immobilisation

- Creates problems:
  - stiff joints, loss of function
Immobilisation

- Creates problems:
  - stiff joints, loss of function
  - general complications (pneumonia, decubitus etc.)
Life is movement - movement is life!
Goal of Fx Treatment

• Early and safe mobilization of the injured limb and the patient as a whole
Goal of Fx Treatment

- Fracture reduction and fixation to restore anatomical relationships, allowing functional after care
Goal of Fx Treatment

• Adequate stability by interfragmentary compression or splintage according to the „personality“ of the fracture and soft tissue injury
Goal of Fx Treatment

- Preservation of the blood supply to soft tissue and bone by careful handling and gentle reduction techniques
Topics covered

• Biology and biomechanics of bone healing
  - primary / secondary
2 distinct ways of bone healing

- Stable conditions → direct fracture healing
  no callus formation
Fracture healing

Direct or primary bone healing
2 distinct ways of bone healing

- Stable conditions: direct fracture healing, no callus formation
- Unstable conditions: indirect fracture healing by callus formation
Fracture healing

Indirect or secondary bone healing
Direct fracture healing

Histology

Contact healing

gap < 0.01 mm, strain < 2%
Direct fracture healing

Contact healing

Invasion of osteone

Haversian remodeling
Direct fracture healing

Gap healing
gap 0.8 to 1 mm

Contact healing

Histology
Direct fracture healing

Gap healing

Invasion of capillaries
building of lamellar bone

Osteone invasion
Indirect fracture healing

Inflammation

Immediately to 7d

Hematoma formation

Inflammatory exudate
(growth factors, cytokines)
Indirect fracture healing

Soft callus

1-3 weeks

Hematoma organization

Fibroblasts, capillaries

Stability adequate to prevent shortening
Indirect fracture healing

Hard callus

1- 4 months

Building of fibrous bone (enchondral ossification)

At the end fragments are firmly united
Indirect fracture healing

Remodelling

*Months to years*

Building of lamellar bone from fibrous bone
Indirect fracture healing

Bone healing and pain medication

?
Indirect fracture healing

Bone healing and NSAR

• Lack of cox-2 gene leads to impaired bone healing

• Experimental data is conflicting

• RCTs needed

• Treat NSAR as a risk factor for impaired bone healing
Indirect fracture healing

Stability

- Interfragmentary movement stimulates callus formation
Indirect fracture healing

Stability

Interfragmentary movement in human tibia
Indirect fracture healing

Stability

Radiographies - mid plate

- A: anatomical
- B: biological
- C: biological + PCP

Graph showing time in weeks vs. new/old bone ratio.
Fracture healing

Indirect vs. direct

- Direct healing: higher initial stability, slower bone formation
- Indirect healing: faster bone formation, longer remodelling
Topics

• Biology and biomechanics of bone healing
  - primary / secondary
  - absolute / relative stability
Biomechanical principles

Absolute stability
Biomechanical principles

Relative stability
Biomechanical principles

Absolute vs. relative stability of fracture fixation

- Distinct differences in technique, implant use, and biology of fracture healing
Absolute stability

Advantages

• Open reduction internal fixation (ORIF)
Absolute stability

Advantages

• Open reduction internal fixation (ORIF)

• Exact anatomical reduction is inherent
Absolute stability

Advantages

• Open reduction internal fixation (ORIF)
• Exact anatomical reduction is inherent
• Strain of loading is shared by the implant and the bone, reducing stress on the implant
Absolute stability

Advantages

• Open reduction internal fixation (ORIF)

• Exact anatomical reduction is inherent

• Strain of loading is shared by the implant and the bone, reducing stress on the implant

• Pain due to motion is reduced -> early functional after-treatment
Absolute stability

Disadvantages

• Biological shortcomings:
  - Trauma and surgery result in damage to bone blood supply
Absolute stability

Disadvantages

- Biological shortcomings:
  - Trauma and surgery result in damage to bone blood supply
  - Increased risk of biological complications
Absolute stability

Damage to blood supply

• Stripping of soft tissue from fragments: risk of devitalization

• Mechanics: absolute stability requires interfragmentary compression
Absolute stability

Compression
Absolute stability

Compression
Absolute stability

Conventional internal fixation

- Regular plates require and produce compression
Absolute stability

Friction between plate and bone
Absolute stability

Compression
Absolute stability

Compression and blood supply
Absolute stability

Avoiding necrosis

DCP, LISS (no undercuts)

LC-DCP, LCP (partial undercuts)

PC-Fix (points of contact)

PC-Fix, LISS, LCP (elevated application possible)
Absolute stability

Blood supply

• Once obtained, absolute stability may support repair of damaged blood vessels
Absolute stability

Summary

• High initial stability
• Load sharing btw. bone and implant
• Anatomic reconstruction
• Impaired blood supply, soft tissue problems
Relative stability

Definition

• No exact definition of acceptable flexibility

• Any fixation technique, which does not rely on interfragmentary compression, will allow some interfragmentary movement
Relative stability

Principle

• Fracture fragments displace in relation to each other when load is applied across the fracture site.

• Elastic deformation: after unloading fragments return to original position.
Relative stability

Principle

• Fracture fragments displace in relation to each other when load is applied across the fracture site

• Elastic deformation: after unloading fragments return to original position

• Plastic deformation: irreversible, fragments remain in permanent displacement
Relative stability

Principle

- Requires many fragments and large gaps
Relative stability

Techniques

• Intramedullary nailing
Relative stability

Techniques

• External fixation
Relative stability

Techniques

- Internal fixation
- Bridge plating
Relative stability

Mechanics

- Geometrical Configuration of construct

increasing stability
Relative stability

Mechanics

• Rigidity of the construct depends on
  x  Distance of Schanz screws from fracture
  y  Distance and number of Schanz screws per fragment
  z  Distance between rod and bone axis
Relative stability

Mechanics

- Internal fixator more stable than external fixator
An excess of relatively stable implants does not lead to absolute stability!!!
Relative stability

Advantages

• Less surgical trauma
  - fracture site remains largely untouched
  - blood supply is less compromised
Relative stability

Disadvantages

• Initially the implant bears most of the load
  risk of implant failure
Relative stability

Disadvantages

• Reamed IM nailing will also result in decreased blood supply
Relative stability

Disadvantages

- Correct reduction of axes and rotation is more demanding
- risk of malalignment
Conclusion

Absolute vs. relative stability

• Absolute stability  higher initial stability
  anatomic reduction
  more biological complications

• Relative stability  respects „biology“
  more mechanical complications
  (malalignment, implant failure, instability)
Topics covered

• Biology and biomechanics of bone healing
  - primary / secondary
  - absolute / relative stability

• Angular stable implants
Angular stability

- Why and how does it work
The lockinghead screw (LHS)

- Angular stability through locking of screw in the plate
Advantages of angular stability

- No compression of plate to the bone
Advantages of angular stability

- Blood supply remains intact (internal fixator)
Advantages of angular stability

- Resistance to axial loading
Advantages of angular stability

Conventional screw

• Resistance to pull out
Advantages of angular stability

Locking head screw

• Resistance to pull out
Advantages of angular stability

Angulated LHS

- Resistance to pull out: angulated screws
Advantages of angular stability

Angulated LHS

• Resistance to pull out
Advantages of angular stability

Summary

• No contact between bone and plate
• Blood supply intact
• Resistance to axial loading
• Resistance to pull out
Advantages of angular stability

Clinical advantages

- Poor bone quality $\rightarrow$ Osteoporosis
Advantages of angular stability

Clinical advantages

- Small fragments
- Metaphyseal fractures
Advantages of angular stability

Clinical advantages

• Only approximate contouring of plate

  Minimaly invasive plate osteosynthesis (MIPO)
Advantages of angular stability

MIPO
Advantages of angular stability

MIPO
Topics covered

• Biology and biomechanics of bone healing
  - primary / secondary
  - absolute / relative stability

• Angular stable implants

• Delayed union
Fracture healing?

Delayed union

Fracture healing is not taking place at the expected rate and time (usually 3 months)
Fracture healing?

Delayed union
Fracture healing?

Delayed union

Irritation callus
Loosening of screw
Fracture healing?

Non-union

Fracture will not heal without intervention (not before 6, most likely after 9 months)
Fracture healing?

Non-union

19 years after IM nailing

Fibula prevents union

Hypertrophic callus

Resorption around nail
Fracture healing?

2 Types of non-union

• Well vascularized vital non-union due to impaired stability

Problem of Stability
Fracture healing?

2 Types of non-union

- Well vascularized vital non-union due to impaired stability
  Problem of Stability

- Avascular avital non-union due to devitalized fragments
  Problem of Biology
Fracture healing?

2 Types of non-union

- Well vascularized vital non-union due to impaired stability

hypertrophic atrophic

decreasing stability
Fracture healing?

2 Types of non-union

- Well vascularized vital non-union due to impaired stability

  hypertrophic  atrophic

  Stabilization  plate  plate
  reamed IM nail

  Bone graft  not necessary  yes!
Fracture healing?

2 Types of non-union

- Avascular avital non-union due to devitalized fragments
Fracture healing?

2 Types of non-union

- Avascular avital non-union due to devitalized fragments

  - Resection: shortening of bone
  - Augmentation: bone graft, callus distraction, “bypass” fibulo-pro-tibia
Topics covered

• Biology and biomechanics of bone healing
  - primary / secondary
  - absolute / relative stability

• Angular stable implants

• Delayed union

• Fracture classification
Fracture classification

Why classify?
“A classification is useful only if it considers the severity of the bone lesion and serves as a basis for treatment and for evaluation of the results“
# AO Fx Classification

## Adults

**Diagnosis = “essence” of the fracture**

### Localization

- **Bone**: 1 2 3 4
  - 4 long bones

- **Segment**: 1 2 3 (4)
  - 3 or 4 segments

### Morphology

- **Type**: A B C
  - 3 types

- **Group**: 1 2 3
  - 3 groups

- **Subgroup**: .1 .2 .3
  - 3 subgroups
AO Fx Classification

**Adults**

Diagnosis = “essence” of the fracture

**Localization**
- **Bone**: 1 2 3 4
- 4 long bones
  - 5 or 4 segments

**Morphology**
- **Type**: A B C
- 3 types
- **Group**: 1 2 3
- 3 groups
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1 2 3 4
AO Fx Classification

Diagnosis = “essence” of the fracture

Localization

Bone 1 2 3 4
4 long bones

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3 or 4 segments

Morphology

Type A B C
3 types

Group 1 2 3
3 groups

Subgroup .1 .2 .3
3 subgroups

11-
12-
13-
21-
22-
23-
31-
32-
33-
41-
42-
43-
44-
## AO Fx Classification

### adults

**Diagnosis = “essence” of the fracture**

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# AO Fx Classification

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<tr>
<th>Segment</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Proximal</td>
<td>A Extraarticular</td>
<td>No involvement of displaced fractures extending into the articular surface</td>
</tr>
<tr>
<td></td>
<td>B Partial articular</td>
<td>Part of the articular component is involved, leaving the other part attached to the meta-/diaphysis</td>
</tr>
<tr>
<td></td>
<td>C Complete articular</td>
<td>Articular surface involved, metaphyseal fracture completely separates articular component from the diaphysis</td>
</tr>
<tr>
<td>2 Diaphyseal</td>
<td>Simple</td>
<td>One fracture line, cortical contact between fragments exceeds 90% after reduction</td>
</tr>
<tr>
<td></td>
<td>Wedge</td>
<td>Three or more fragments, main fragments have contact after reduction</td>
</tr>
<tr>
<td></td>
<td>Complex</td>
<td>Three or more fragments, main fragments have no contact after reduction</td>
</tr>
<tr>
<td>3 Distal</td>
<td>A Extraarticular</td>
<td>No involvement of displaced fractures extending into the articular surface</td>
</tr>
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## AO Fx Classification

### Exceptions

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<th>Type</th>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>11- Humerus, proximal</strong></td>
<td>Extraarticular, unifocal</td>
<td>Extraarticular, bifocal</td>
<td>Articular</td>
</tr>
<tr>
<td></td>
<td>Tuberosity or nonimpacted/metaphyseal</td>
<td>With or without metaphyseal impaction, or with glenohumeral dislocation</td>
<td>Displaced, impacted or dislocated</td>
</tr>
<tr>
<td><strong>31- Femur, proximal</strong></td>
<td>Extraarticular, trochanteric</td>
<td>Extraarticular, neck</td>
<td>Articular, head</td>
</tr>
<tr>
<td></td>
<td>Peritrochanteric simple or multifragmentary, or intertrochanteric</td>
<td>Subcapital with displacement or transversal</td>
<td>Split, depression or neck</td>
</tr>
<tr>
<td><strong>52- Femur, shaft, subtrochanteric</strong></td>
<td>See chapter 6.6.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>44- Malleoli</strong></td>
<td>Infra syndesmotic</td>
<td>Trans syndesmotic, fibular</td>
<td>Supra syndesmotic</td>
</tr>
<tr>
<td></td>
<td>With or without medial lesion</td>
<td>With or without medial or posterior lesion</td>
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AO Fx Classification

**Adults**

**Diagnosis** = “essence” of the fracture

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<tr>
<td>A Simple</td>
<td>Spiral</td>
<td>Oblique</td>
<td>Transverse</td>
</tr>
<tr>
<td>B Wedge</td>
<td>Spiral</td>
<td>Bending</td>
<td>Multifragmentary</td>
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<tr>
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<td>Spiral</td>
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<td>Irregular</td>
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</tr>
<tr>
<td>Split</td>
<td>Depression</td>
<td>Split-depression</td>
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<tr>
<td>C Articular</td>
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<tr>
<td>Simple articular, simple metaphyseal</td>
<td>Simple articular, complex metaphyseal</td>
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AO Fx Classification
## Adults

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4 long bones

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**Diagnosis** = “essence” of the fracture

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AO ?
## Adults

**Diagnosis** = “essence” of the fracture

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AO 2

2

AO 2
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4 long bones

Diagnosis = “essence” of the fracture

AO 2?
Diagnosis = “essence” of the fracture

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4 long bones
3 or 4 segments

AO 23 -

21-
22-
23-
### Adults

**Diagnosis** = “essence” of the fracture

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- **Type**
  - A
  - B
  - C

- **AO 23-?**
  - 21-
  - 22-
  - 23-
**Adults**

Diagnosis = “essence” of the fracture

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4 long bones
3 or 4 segments

AO 23-?
Diagnosis = “essence” of the fracture

### Localization

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3 or 4 segments

### Morphology

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3 types

AO 23-C

21-

22-

23-
### Diagnosis = “essence” of the fracture

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#### AO 23-C?

- **Bone**
  - 1: Extra-articular
  - 2: Partial articular
  - 3: Articular

- **Segment**
  - A: Simple
  - B: Wedge
  - C: Complex

- **Type**
  - 1: Split
  - 2: Depression
  - 3: Split-depression

- **Group**
  - A: Simple articular, simple metaphyseal
  - B: Simple articular, complex metaphyseal
  - C: Complex articular, complex metaphyseal
### Adults

**Diagnosis** = "essence" of the fracture

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![AO 23-C2 Diagram]

AO 23-C2
Fragen ?
Thank you!