To break – or not to break?

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Disclosures

• Speakers honoria
  – Synthes GMBH
  – CalMedical (Acute Innovations)
History

• NON-UNION OF THREE RIBS

• Darrell G. Leavitt

NON-UNION OF THREE RIBS

BY DARRELL G. LEAVITT, M.D., SEATTLE, WASHINGTON

Non-union or pseudarthrosis of the ribs following fracture is comparatively infrequent and has received little or no attention in the textbooks. Although the author has seen previous instances, he has not observed any case in which there was non-union of more than one rib; and it has been his impression that non-union of the so-called floating ribs is more common.

In the following case, a dense adhesive process on the posterior portion of the diaphragm, demonstrated in an oblique roentgenogram, no doubt produced abnormal excursion of the proximal fragments of the fractures, thus producing an unusual mechanical basis for instability, and preventing union.

CASE REPORT

A man, fifty-three years of age, was seen on July 29, 1938, complaining of discomfort in the left side of the chest and occasional expectoration of blood.

On September 29, 1937, he had injured the left thorax in a severe fall. Adhesive strapping was applied to the chest, and the patient was kept in bed for three weeks. Removal of the strapping was followed by considerable pain in the left side of the thorax, and the patient coughed up blood. There was marked swelling of the left thorax, extending to the base of the neck, which persisted for several weeks.

Examination of the thorax by the author revealed marked impairment of percussion resonance over the posterior lower third, extending to the lateral aspect. There was absence of breath sounds over the area of percussion dullness. A small amount of sugar was found in the urine. Subsequent fasting blood-sugar studies revealed persistent slight elevation only. Consultation with Dr. Byron Francis disclosed an adhesive process between the posterior quadrant of the left diaphragm and the thoracic wall with a mild bronchiectasis.

Roentgenographic examination (Fig. 1) revealed non-union of the eighth, ninth, and tenth ribs with questionable non-union of the seventh rib. Other roentgenograms demonstrated fractures of a number of adjacent ribs, but these were thought to be healed and united in good alignment.

On October 10, 1938, about one year after the injury, an operation on the left thorax was performed. A long, straight incision was made over the posterolateral thorax, splitting the fibers of the latissimus dorsi in their longitudinal direction. The sites of non-union were then exposed by transverse incision over each rib in its longitudinal direction. This necessitated separating the digitations of the serratus posterior inferior and the periosteum at the ends of the ribs near the sites of non-union. With each expiration and inspiration, marked excursion (from one-half to three-quarters of an inch) was found to exist between the ends of the ununited ribs. There was non-union of the eighth, ninth, and tenth ribs, but the seventh rib was found to be solidly united.

Several methods of producing solid union were considered, but, because of the width of the gap revealed in the roentgenograms, it was decided that a bony bridge should be created. Therefore, three cortical grafts were removed from the right tibia,—each three inches in length and about one-half an inch in width. These were made in the shape of a shuttle. The ribs, having been left mainly covered by periosteum, especially...
away from the fragment ends, were freshened; and an osteotome was driven into each end, splitting it into an external and an internal half. (In one area the intercostal artery was severed and had to be tied.) Each graft was driven into one split fragment; the ends of each fragment were then sprung apart and permitted to settle over the protruding end of the graft. Small bone chips were placed about the grafts, and the deep tissues were closed with chromic-coutgut sutures. (See Figure 2.) Adhesive support only was used after this operation.

The postoperative course was satisfactory. However, about the fifteenth day some ooze from the wound developed, which seemed to consist of fluid and fat. This cleared up shortly without evidence of wound infection. Marked improvement in the degree of pain was evident at first. There was some complaint of intercostal radiation to the front of the chest. Various roentgenograms showed the tibial bone in position, but it was difficult to determine the presence or absence of union until November 8, 1939, when roentgenograms suggested that non-union existed in the site of the lower graft (Fig. 3).

![Image 3](image3.png)

One year after operation. Tibial transplants are still dense. There is apparent non-union of the proximal fragment of the tenth rib to its graft.

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About this time a prominence appeared in the chest over one end of this graft, which was painful on pressure. There was also increased complaint of local discomfort in the chest at this time.

On November 23, 1939, a second operation was performed, in which the three fractured ribs were exposed as before. The eighth rib had become solidly united. In the case of the ninth rib the graft had united solidly to one of the fracture fragments, but a very narrow stable pseudarthrosis existed between the graft and the other fragment; the graft was still in excellent position, but was sliding slightly in the smooth reciprocating surface of the rib. The graft in the tenth rib was solidly united to the distal fragment and appeared to be viable; but the other end protruded into the soft tissues, having eroded its way out of the proximal fragment. The pseudarthrosis in the ninth rib was freshened. The bone, however, was left in its bed. Cancellous bone from the shaft of the rib away from the fracture site was taken off with an osteotome and placed about the freshened site of non-union. A wire loop was placed about the protruding graft in the tenth rib to hold it closely approximated to the proximal fragment. Here, again, cancellous bone was removed from the rib at a greater distance and packed around this pseudarthrosis.

![Image 4](image4.png)

January 24, 1941. Solid union of all three ribs. Stainless-steel suture in situ.
Several methods of producing solid union were considered, but, because of the width of the gap revealed in the roentgenograms, it was decided that a bony bridge should be created.

Therefore, three cortical grafts were removed from the right tibia, each three inches in length and about one-half an inch in width. These were made in the shape of a shuttle.
An osteotome was driven into each end, splitting it into an external and an internal half. (In one area the intercostal artery was severed and had to be tied.)

Each graft was driven into one split fragment; the ends of each fragment were then sprung apart and permitted to settle over the protruding end of the graft.

Small bone chips were placed about the grafts.
The trunk was encased in plaster with very little padding, the plaster remaining in place for twelve weeks.

Roentgenographic examination (Fig. 4) on January 24, 1941, showed solid union of all three ribs, with the stainless-steel wire still in situ.

This patient was an Industrial Accident case, and the degree of persisting discomfort was difficult to determine. However, he admitted that there had been a great deal of improvement in the pain in the left chest.

SUMMARY AND CONCLUSIONS

Non-union in rib fractures is not common. The case presented suggests that it requires an unusual circumstance, such as the occurrence of dense adhesions between one portion of the chest wall and the adjacent fragments, to produce sufficient excursion of the fragments to result in non-union. In this case tibial bone grafts assisted in securing union, although two operations were required to obtain union of all three fractures. A plaster cast about the trunk is probably advisable after this type of surgery to assist in securing some restriction of trunk, if not thoracic, motion.
Surgical stabilization of severe rib fractures: Several caveats.
Mayberry J.
J Trauma Acute Care Surg. 2015 Sep;79(3):515. doi:

Prospective clinical trial of surgical intervention for painful rib fracture nonunion.
Fabricant L, Ham B, Mullins R, Mayberry J.

The contribution of rib fractures to chronic pain and disability.
Gordy S, Fabricant L, Ham B, Mullins R, Mayberry J.

Prolonged pain and disability are common after rib fractures.
Fabricant L, Ham B, Mullins R, Mayberry J.

Rib fracture fixation for flail chest: what is the benefit?
Bhatnagar A, Mayberry J, Nirula R.

Early stabilization of flail chest with locked plate fixation.
Mayberry J.

Lidocaine patches reduce pain in trauma patients with rib fractures.
Zink KA, Mayberry JC, Peck EG, Schreiber MA.

Rib fracture fixation: controversies and technical challenges.
Nirula R, Mayberry JC.

Long-term morbidity, pain, and disability after repair of severe chest wall injuries.
Mayberry JC, Kroeker AD, Ham LB, Mullins RJ, Trunkey DD.

Surveyed opinion of American trauma, orthopedic, and thoracic surgeons on rib and sternal fracture repair.
Mayberry JC, Ham LB, Schipper PH, Ellis TJ, Mullins RJ.

Nirula R, Diaz JJ Jr, Trunkey DD, Mayberry JC.

Biomechanical testing of a novel, minimally invasive rib fracture plating system.
Sales JR, Ellis TJ, Gillard J, Liu Q, Chen JC, Ham B, Mayberry JC.
J Trauma. 2008 May;64(5):1270-4. doi: 10.1097/TA.0b013e31804a7fd5.

Absorbable plates for rib fracture repair: preliminary experience.
Mayberry JC, Terhes JT, Ellis TJ, Wanek S, Mullins RJ.

Rib fracture pain and disability: can we do better?
Kerr-Valentic MA, Arthur M, Mullins RJ, Pearson TE, Mayberry JC.
J Trauma. 2003 Jun;54(6):1058-63;

Operative stabilization of a flail chest six years after injury.
Slater MS, Mayberry JC, Trunkey DD.

Imaging in thoracic trauma: the trauma surgeon’s perspective.
Mayberry JC.

The fractured rib in chest wall trauma.
Mayberry JC, Trunkey DD.


Why I know that I am going to win this debate...
This article presents a unified clinical theory that links established facts about the physiology of bone and homeostasis, with those involved in the healing of fractures and the development of nonunion. The key to this theory is the concept that the tissue that forms in and around a fracture should be considered a specific functional entity. This ‘bone-healing unit’ produces a physiological response to its biological and mechanical environment, which leads to the normal healing of bone. This tissue responds to mechanical forces and functions according to Wolff’s law, Perren’s strain theory, and Frost’s concept of the “mechanostat”. In response to the local mechanical environment, the bone-healing unit normally changes with time, producing different tissues that can tolerate various levels of strain. The normal result is the formation of bone that bridges the fracture – healing by callus. Nonunion occurs when the bone-healing unit fails either due to mechanical or biological problems or a combination of both. In clinical practice, the majority of nonunions are due to mechanical problems with instability, resulting in too much strain at the fracture site. In most nonunions, there is an intact bone-healing unit. We suggest that this maintains its biological potential to heal, but fails to function due to the mechanical conditions. The theory predicts the healing pattern of multifragmentary fractures and the observed morphological characteristics of different nonunions. It suggests that the majority of nonunions will heal if the correct mechanical environment is produced by surgery, without the need for biological adjuncts such as autologous bone graft.

Cite this article: Bone Joint J 2016;98-B:884–91.

If the reader believes that medicine can only advance with level 1 evidence and prospective randomised controlled trials, it may be best to stop reading now. This article presents a unified clinical theory that links established facts about the physiology of bone and homeostasis, with those involved in the healing of fractures and the development of nonunion. The key to this theory is the concept that the tissue that forms in and around a fracture should be considered a specific functional entity. This ‘bone-healing unit’ produces a physiological response to its biological and mechanical environment, which leads to the normal healing of bone. This tissue responds to mechanical forces and functions according to Wolff’s law, Perren’s strain theory, and Frost’s concept of the “mechanostat”. In response to the local mechanical environment, the bone-healing unit normally changes with time, producing different tissues that can tolerate various levels of strain. The normal result is the formation of bone that bridges the fracture – healing by callus. Nonunion occurs when the bone-healing unit fails either due to mechanical or biological problems or a combination of both. In clinical practice, the majority of nonunions are due to mechanical problems with instability, resulting in too much strain at the fracture site. In most nonunions, there is an intact bone-healing unit. We suggest that this maintains its biological potential to heal, but fails to function due to the mechanical conditions. The theory predicts the healing pattern of multifragmentary fractures and the observed morphological characteristics of different nonunions. It suggests that the majority of nonunions will heal if the correct mechanical environment is produced by surgery, without the need for biological adjuncts such as autologous bone graft.
Wolf’s Law (1898)

Perrin’s Theory (1978)

Frost’s “Mechanostat” Proposal (1987)

Bone Healing and Non-Union Theory

STRAIN
The response of the Bone Healing Unit to strain

- **Strain**: change in length according to load

- **Strain tolerance**: maximum strain at which a tissue will continue to exhibit normal physiological function
  
  (Lamellar bone 2%)

  - Initial granulation tissue 100%
  - Then cartilage 10%
  - Subsequent bone 2-5%
The response of the BHU to strain

• “the tissue that forms after a fracture progressively stiffens the site, until the strain is low enough for bone to form”
A: e.g. microgravity (prolonged bed rest/lack of physiological activity)
B: Homeostasis (see next slide)
A: e.g. microgravity (prolonged bed rest/lack of physiological activity)
B: Homeostasis
C: Point beyond which there is excessive strain for fracture healing: 10%

i.e. MOVEMENT - EXCESSIVE STRAIN - PREVENTS HEALING !!!
Different scenarios of excessive movement result in different types of non-union, depending on the strain of the BHU and the strain tolerance of the tissue within the BHU.

- Healing by callus
  - intramedullary nail / splint
- Primary bone healing
  - anatomical reduction / fixation
- Non-union
  - failure of the BHU

Bone Joint J 2016;98-B:884–91
Different scenarios of excessive movement result in different types of non-union, depending on the strain of the BHU and the strain tolerance of the tissue within the BHU.

Types of non-union (Weber and Czech, 1976)

- Hypertrophic
- Atrophic
- (infective)
Models of Non-Union

• Vascular or Avascular
  – But there has been the failure experimentally to demonstrate devascularisation in atrophic non-union

• Mechanical or Biological
The Mechanical Model of Non-Union

• In most non-unions there is an intact bone-healing unit

• Failure of the BHU due to mechanical conditions:
  – Fixation fails to reduce strain to a level where healing can occur
  – Fixation construct so stiff that strain always to the left of Point B
Persistent high strain and BHU failure

• “Where very high strain persists, the movement at the fracture site breaks down the bone-healing unit. A ‘synovial’ cavity develops and the bone ends heal, which creates a pseudoarthrosis.”

• “Freshening of the fracture ends and compression osteosynthesis is required to restore the mechanics, recreate the bone healing unit and facilitate union.”

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Metalwork fatigue and failure

• “Following plate fixation of a simple fracture where anatomical reduction is not achieved, leaving a gap with persistently high strain...the fracture will fail to heal, and the plate will fail due to fatigue”

• How often has this occurred after fixation of a non-united rib fracture?
Biological influences

- Severity
- Peripheral vascular disease
- Prior radiotherapy
- Diabetes
- Endocrine diseases
- Smoking
- NSAIDs
X: delay formation  
Y: narrow the strain range of bone formation  
Z: prevent bone formation

Theoretical impact of biological factors that reduce fracture healing (X, delayed formation of bone over the normal physiological range of strain).
Management of non-union

• Treatment will be successful if the strain at the non-union is changed to one within the bone formation range (points B and C)

• Reducing strain can be achieved by reducing forces applied or direct stabilisation

• “There is no requirement to excise tissue from the fracture site. It will heal if the mechanical environment is corrected”
Management of non-union

• “There is evidence that, if a low strain environment can be achieved, a non union will will without the use of Bone Morphogenic Proteins (BMPs)”

• “The authors primarily use mechanical techniques in the surgery of a non-union and reserve the use of biological adjuncts, including bone graft, to cases where there is significant bone loss.”
Bone Healing and Non-Union Theory is consistent with:

- Non-union of multi-fragmentary fractures (fragments heal to each other, leaving a single fracture line with a higher strain)
- Ilizarov technique (compression causes low strain at fracture site)
- Distraction of a non-union/osteotomy (greater rates of distraction exceed strain tolerance – to the right of point C – resulting in failure)
Application of BHN Theory to non-united rib fractures

• It is the mechanical environment that is key
• External cortical plating should be successful:
  – With minimal fracture debridement
  – Or without any fracture debridement
• Bone Morphogenic Proteins are not required
• Bone grafting is only required if there is a significant gap
Different techniques from the Literature

- Inlay bone grafts +/- prior excision of pseudarthrosis +/- plates
- Excision of pseudarthrosis +/- plates +/- bone graft
- Excision of fibrous tissue within pseudarthrosis +/- plates +/- bone graft
- Decortication/bone graft/reaming/plates
<table>
<thead>
<tr>
<th>Non-union</th>
<th>Bone graft</th>
<th>Bone graft source</th>
<th>Plates</th>
<th>Plate Fixation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nothing</td>
<td>None</td>
<td>Hypertrophic non-union</td>
<td>None</td>
<td>Screws</td>
</tr>
<tr>
<td>Debride</td>
<td>Intramedullary shuttle</td>
<td>Iliac crest</td>
<td>Titanium</td>
<td>Wire circlage</td>
</tr>
<tr>
<td>Debride &amp; Ream</td>
<td>Inlay bone graft</td>
<td>Neighboring ribs</td>
<td>Absorbable</td>
<td></td>
</tr>
<tr>
<td>Excise</td>
<td>Chips</td>
<td>Tibia</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Author</td>
<td>Year</td>
<td>Patient Number</td>
<td>Technique</td>
<td>Outcomes</td>
</tr>
<tr>
<td>---------------</td>
<td>------</td>
<td>----------------</td>
<td>----------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Leavitt</td>
<td>1942</td>
<td>1</td>
<td>intramedullary tibial cortical shuttle grafts</td>
<td></td>
</tr>
<tr>
<td>Reber</td>
<td>1993</td>
<td>1</td>
<td>AO – 3.5mm plates and cancellous screws</td>
<td></td>
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<tr>
<td>Morgan-Jones</td>
<td>1996</td>
<td>1</td>
<td>longitudinal gutter, inlay bone graft block</td>
<td></td>
</tr>
<tr>
<td>Cacchione</td>
<td>2000</td>
<td>1</td>
<td>excision of pseudarthroses, plating</td>
<td></td>
</tr>
<tr>
<td>Ng</td>
<td>2001</td>
<td>1</td>
<td>Excision of fibrous tissue within pseudarthroses, recon plates</td>
<td></td>
</tr>
<tr>
<td>Slater</td>
<td>2001</td>
<td>1</td>
<td>resection, AO platesx2 and wire circlage</td>
<td></td>
</tr>
<tr>
<td>Sing</td>
<td>2002</td>
<td>1</td>
<td>VATS resection</td>
<td></td>
</tr>
<tr>
<td>Richardson</td>
<td>2007</td>
<td>1</td>
<td>plate fixation</td>
<td></td>
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<tr>
<td>Gardenbroek</td>
<td>2009</td>
<td>3</td>
<td>debridement (1 case) , locking compression plates VAS</td>
<td></td>
</tr>
<tr>
<td>Cho</td>
<td>2009</td>
<td>1</td>
<td>Excision of pseudarthrosis, inlay block bone graft + plate</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>local decortication/bone graft, intramedullary canal re-established, plates with compression across fracture</td>
<td></td>
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<tr>
<td>Anavian</td>
<td>2009</td>
<td>1</td>
<td>Iliac bone graft, plates</td>
<td></td>
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<tr>
<td>Dean</td>
<td>2014</td>
<td>1</td>
<td>Iliac bone graft, plates</td>
<td></td>
</tr>
<tr>
<td>Fabricant</td>
<td>2014</td>
<td>24</td>
<td>Resect, Plate if &lt;1cm (Titanium if PL, absorbable if AL). &gt;2cm not fixed, no bone grafts or BMPs. Avoid &gt;2 neighbouring NU's. Resection only 9</td>
<td>McGill Pain Questionnaire, SF-36, activity level, work status</td>
</tr>
<tr>
<td>Gouger</td>
<td>2015</td>
<td>10</td>
<td>Predominantly iliac crest bone graft + locking precontoured plates</td>
<td>SF-36</td>
</tr>
<tr>
<td>Edwards</td>
<td>2017</td>
<td>24</td>
<td></td>
<td>retrospective SF-36, Brief Pain Inventory, modified Glasgow Outcome Scale - Extended</td>
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Prospective Clinical Trial of Surgical Intervention for Painful Rib Fracture Nonunion

LOIC FABRICANT, M.D., BRUCE HAM, M.D., RICHARD MULLINS, M.D., JOHN MAYBERRY, M.D.

From the Division of Trauma, Critical Care, & Acute Care Surgery, Oregon Health & Science University, Portland, Oregon

We performed a prospective clinical trial of resection with or without plate fixation for symptomatic rib fracture nonunion three or more months postinjury with 6-month postoperative followup. The McGill Pain Questionnaire (MPQ) and RAND 36 Health Survey were administered and activity level (sedentary, ambulatory, moderately active, vigorous), functional status (disabled, nonphysical labor, physical labor), and work status (employed, unemployed, retired, student) were queried pre- and postoperatively. Twenty-four patients 4 to 197 months (median, 16 months) postinjury underwent surgical intervention for one to four rib fracture nonunions (median, two nonunions). Evidence of intercostal nerve entrapment was present in nine patients (38%). MPQ Present Pain Intensity and Pain Rating Index and RAND 36 Physical Functioning, Role Physical, Social Functioning, Role Social, Bodily Pain, Vitality, Mental Health, and General Health were significantly improved at six months compared with study entry ($P < 0.05$). Activity levels significantly improved ($P < 0.0001$) but functional and work status did not change. Twenty-four-hour morphine equivalent dosage of opioids at study entry was 20.3 ± 30.8 (mean ± standard deviation) and at study completion was 9.4 ± 17.5 ($P = 0.054$). Complications included one wound infection, two partial screw backouts, and one chest wall hernia at one year after resection of adjacent nonunions with significant gaps repaired with absorbable plates. Surgical intervention for rib fracture nonunion may improve chronic pain and disability but without change in functional or work status. Resection of adjacent nonunions with significant gaps may lead to chest wall hernia.
• Resect non-union
• Gap <1cm then plate:
  – Titanium plate/screws if posterolateral
  – Absorbable plate/circlage if anterolateral
• Gap 1 – 2cm
  – Surgeon choice
• Gap >2cm
  – Generally not fixed,
  – Occ. Absorbable plate/circlage

• No bone grafts or Bone Morphogenic Proteins
• Avoid resection of >2 neighbouring NU’s

TABLE 1.  Techniques and Mean Rib Gaps Postresection

<table>
<thead>
<tr>
<th>Technique</th>
<th>No. of Subjects</th>
<th>No. of Nonunions</th>
<th>Mean Gap (range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resection</td>
<td>13</td>
<td>24</td>
<td>1.7 cm (0.5–4)</td>
</tr>
<tr>
<td>Resection only</td>
<td>9</td>
<td>18</td>
<td>1.6 cm (0.5–4)</td>
</tr>
<tr>
<td>Titanium fixation</td>
<td>5</td>
<td>7</td>
<td>1.2 cm (0.6–2)</td>
</tr>
<tr>
<td>Absorbable fixation</td>
<td>12</td>
<td>20</td>
<td>2.1 cm (0.3–4)</td>
</tr>
</tbody>
</table>
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Table 3. McGill Pain Questionnaire (MPQ) and RAND 36 Health Survey Results

<table>
<thead>
<tr>
<th>Measure</th>
<th>Study Entry</th>
<th>60 Days</th>
<th>120 Days</th>
<th>180 Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPQ-PPI</td>
<td>4.1 ± 0.8</td>
<td>2.9 ± 0.9*</td>
<td>3.0 ± 1.0*</td>
<td>2.7 ± 0.9*</td>
</tr>
<tr>
<td>MPQ-PRI</td>
<td>34.5 ± 14.5</td>
<td>23.3 ± 17.1*</td>
<td>20.0 ± 14.1*</td>
<td>18.0 ± 11.8*</td>
</tr>
<tr>
<td>Physical Functioning</td>
<td>49.1 ± 27.5</td>
<td>58.8 ± 24.7</td>
<td>67.5 ± 25.9*</td>
<td>72.5 ± 26.4*</td>
</tr>
<tr>
<td>Role Physical</td>
<td>20.7 ± 31.7</td>
<td>18.8 ± 29.7</td>
<td>39.8 ± 41.3</td>
<td>54.2 ± 38.8*</td>
</tr>
<tr>
<td>Bodily Pain</td>
<td>37.7 ± 21.7</td>
<td>47.5 ± 22.5</td>
<td>55.6 ± 19.4</td>
<td>56.3 ± 21.4*</td>
</tr>
<tr>
<td>Vitality</td>
<td>36.7 ± 18.8</td>
<td>45.8 ± 24.5*</td>
<td>47.7 ± 23.0*</td>
<td>53.8 ± 23.9*</td>
</tr>
<tr>
<td>General Health</td>
<td>34.4 ± 24.2</td>
<td>53.8 ± 27.3*</td>
<td>67.1 ± 26.0*</td>
<td>76.0 ± 28.1*</td>
</tr>
<tr>
<td>Social Functioning</td>
<td>47.9 ± 30.3</td>
<td>58.3 ± 25.5</td>
<td>68.8 ± 24.9</td>
<td>74.0 ± 31.3*</td>
</tr>
<tr>
<td>Role Emotional</td>
<td>44.4 ± 38.9</td>
<td>69.4 ± 36.7*</td>
<td>71.2 ± 38.9</td>
<td>73.6 ± 42.8*</td>
</tr>
<tr>
<td>Mental Health</td>
<td>58.0 ± 20.6</td>
<td>71.7 ± 17.2*</td>
<td>70.0 ± 18.2*</td>
<td>71.7 ± 25.2*</td>
</tr>
</tbody>
</table>

* P < 0.05.
PPI, Present Pain Intensity; PRI, Pain Rating Index.

Table 4. Percentage of Patients Using Various Categories of Medications for Pain at Each Interval

<table>
<thead>
<tr>
<th>Category</th>
<th>Study Entry</th>
<th>60 Days</th>
<th>120 Days</th>
<th>180 Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opioids</td>
<td>41.7%</td>
<td>70.8%</td>
<td>45.5%</td>
<td>41.7%</td>
</tr>
<tr>
<td>NSAID</td>
<td>12.5%</td>
<td>20.8%</td>
<td>18.2%</td>
<td>41.7%</td>
</tr>
<tr>
<td>Acetaminophen</td>
<td>29.2%</td>
<td>54.2%</td>
<td>36.4%</td>
<td>37.5%</td>
</tr>
<tr>
<td>Muscle relaxant</td>
<td>12.5%</td>
<td>4.2%</td>
<td>9.1%</td>
<td>0%</td>
</tr>
<tr>
<td>Neuropathic pain agent</td>
<td>16.7%</td>
<td>33.3%</td>
<td>31.8%</td>
<td>16.7%</td>
</tr>
<tr>
<td>Lidocaine patch</td>
<td>4.2%</td>
<td>8.3%</td>
<td>4.5%</td>
<td>4.2%</td>
</tr>
</tbody>
</table>

* Twenty-two patients; the rest of the values includes all 24 patients.
NSAID, nonsteroidal anti-inflammatory drug.
• Summary:
  – subjective improvements in chronic pain and activity tolerance
  – Functional status and work status did not change.
  – The percentage of patients taking opioids for chronic pain did not change (improvement in MED but not significant)
“Conventional surgical treatment for fracture nonunions assumes that the fracture will heal if the osteoinductive process were reinvigorated by resecting the fibrous callous and if excessive motion were controlled with plate fixation.”

“The patient’s fracture healing potential is also maximized by cessation of smoking and by optimal treatment of any medical conditions, e.g., diabetes. Bone grafting is used to fill in bony gaps. In general, a gap 2 cm or greater is considered a “critical-sized defect” that is not likely to heal without a bone graft.”
Application of BHN Theory to non-united rib fractures

WHAT I DO:

• External cortical plating should be successful:
  – With minimal fracture debridement
  – Or without any fracture debridement

• Bone Morphogenic Proteins are not required

• Bone grafting is only required if there is a significant gap
• 24 cases with 63 non-united fractures

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Number of Fractures</th>
<th>Number of Patients</th>
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</thead>
<tbody>
<tr>
<td>Debridement</td>
<td>42</td>
<td>15</td>
</tr>
<tr>
<td>excision</td>
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<td>2</td>
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<tr>
<td>None</td>
<td>19</td>
<td>8</td>
</tr>
<tr>
<td>Bone chips</td>
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<td>5</td>
</tr>
<tr>
<td>none</td>
<td>45</td>
<td>19</td>
</tr>
<tr>
<td>Graft from non-union debridement</td>
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<td>4</td>
</tr>
<tr>
<td>Iliac crest graft</td>
<td>3</td>
<td>1</td>
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<tr>
<td>Reconstruction ribbon</td>
<td>21</td>
<td>6</td>
</tr>
<tr>
<td>Precontoured plates</td>
<td>42</td>
<td>18</td>
</tr>
<tr>
<td>Non-union</td>
<td>Bone graft</td>
<td>Bone graft source</td>
</tr>
<tr>
<td>-----------------</td>
<td>---------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>Nothing</td>
<td>None</td>
<td>Hypertrophic non-union</td>
</tr>
<tr>
<td>8</td>
<td>19</td>
<td>4</td>
</tr>
<tr>
<td>Debride</td>
<td>Intramedullary shuttle</td>
<td>Iliac crest</td>
</tr>
<tr>
<td>15</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Debride &amp; Ream</td>
<td>Inlay bone graft</td>
<td>Neighboring ribs</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excise</td>
<td>Chips</td>
<td>Tibia</td>
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<td>2</td>
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<tr>
<td>Non-union</td>
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<td>2</td>
<td>18</td>
<td></td>
</tr>
</tbody>
</table>
• 24 cases with 63 non-united fractures

• Outcomes.... to follow

• 1 plate failure (bridged across excised NU)
• No infections
• 1 further operation ( + 1 planned)
Summary

- Application of Bone Healing and Non-Union Theory to non-united rib fractures suggests that *mechanical stability* is the key to gaining union.

- Surgical stabilisation is the key.

- Excision / Debridement / Reaming / BMPs are not required.