Iatrogenic Thoracic Outlet Syndrome Secondary to VEPTR Vertical Expansion Thoracoplasty: Pathogenesis and Strategies for Prevention/Treatment

Nassr A[1], Crane B[1], Hammerberg K[1,2], Sturm, P[2], Mardjetko S[1,2]

1-Rush University Medica Center, Chicago, IL

2-Shriners Hospital for Children, Chicago, IL

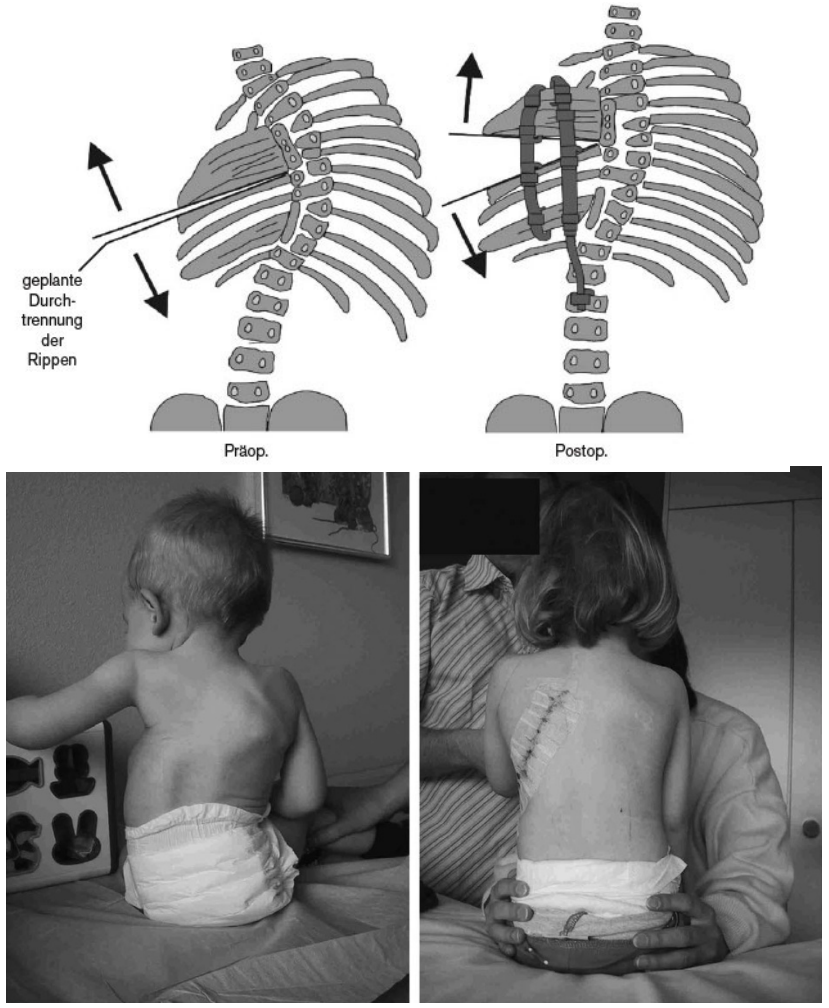
Thoracic Insufficiency Syndrome

- A condition where the thorax is unable to support normal respiration and pulmonary development.
- Diagnosed by respiratory insufficiency, loss of thoracic excursion, radiologic studies, abnormal pulmonary function tests (VC), repeated resp. infections, failure to thrive.
- Ideal treatment would increase thoracic volume while maintaining the ability of the chest and spine to grow and correcting underlying deformities.

Cambell et al, JBJS 2003

VEPTR Expansion Thoracoplasty

- A non-fusion procedure developed by Dr. Campbell allowing for expansion of the thoracic cavity and secondary control of spinal deformity.



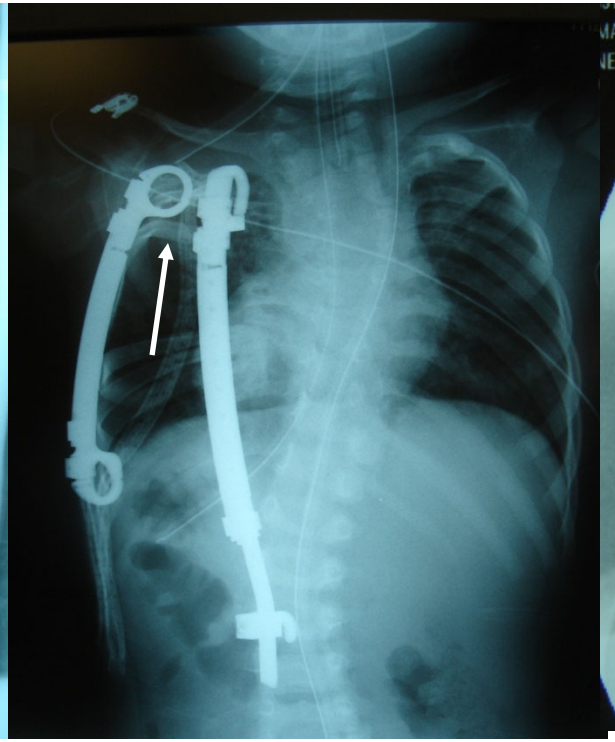
Hell et al, Journal of Pediatric Orthopedics B, 2005

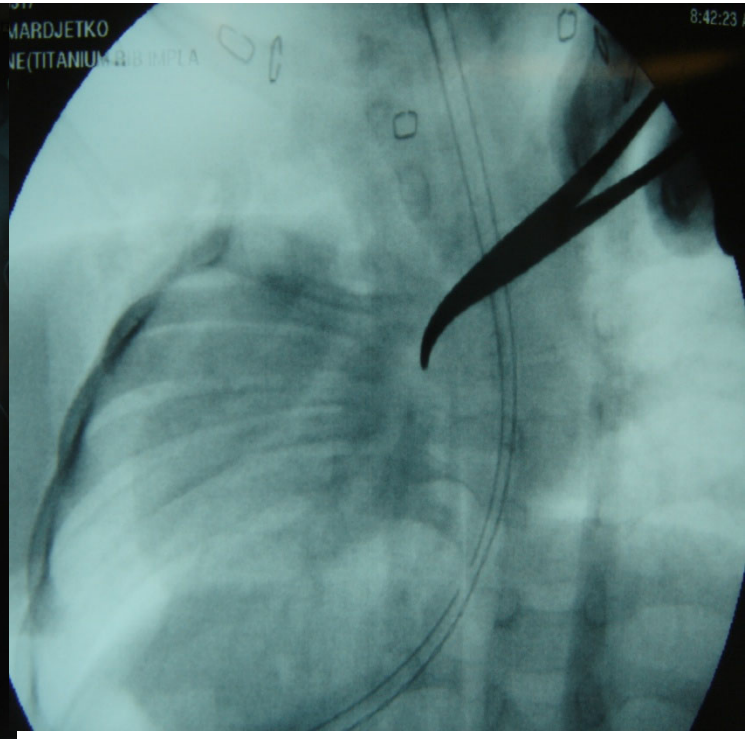
Complications of VEPTR Expansion Thoracoplasty

Reported complications include:

- Device migration
- Rib fracture
- Skin complications
- Infection
- Upper extremity dysfunction
- Thoracic Outlet Syndrome (TOS)

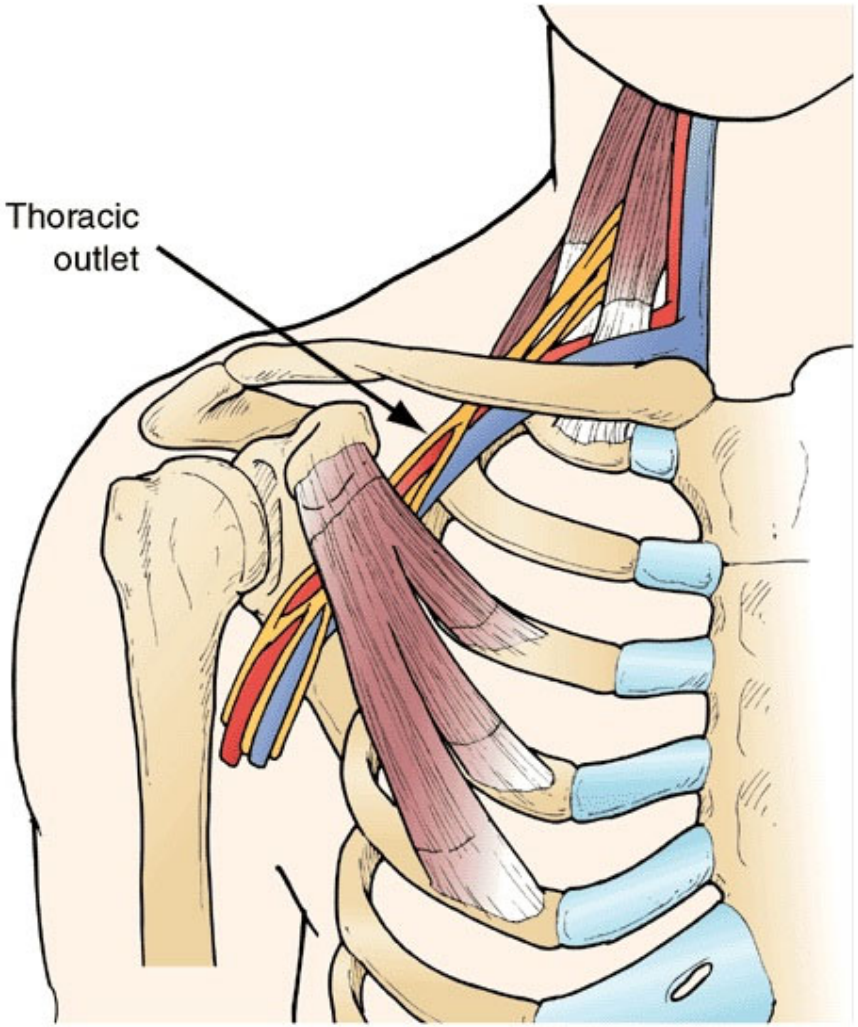
First Case at Shriner's Hospital Chicago 2004
3 yo M with congenital rib fusions Left T1-7
rib mass osteotomy T4-5
5cm expansion thoracoplasty with great correction
Proximal Cradles capture #2 and #3 ribs
SSEP/EMG/MEP UE/LE and NVS normal throughout surgery
Remained intubated and sedated for 24 hours
Profound Brachial Plexopathy encountered upon awakening
Treatment: Supportive Sling, Occ. Tx
Complete recovery took 8 weeks
No Problem with subsequent lengthenings





Thoracic Outlet Anatomy

- Three regions of the thoracic outlet identified as potential areas of compression include
  - Interscalene triangle
    - (supra-clavicular)
  - Costoclavicular space
    - (mid-clavicular)
  - Subcoracoid space
    - (infra-clavicular)

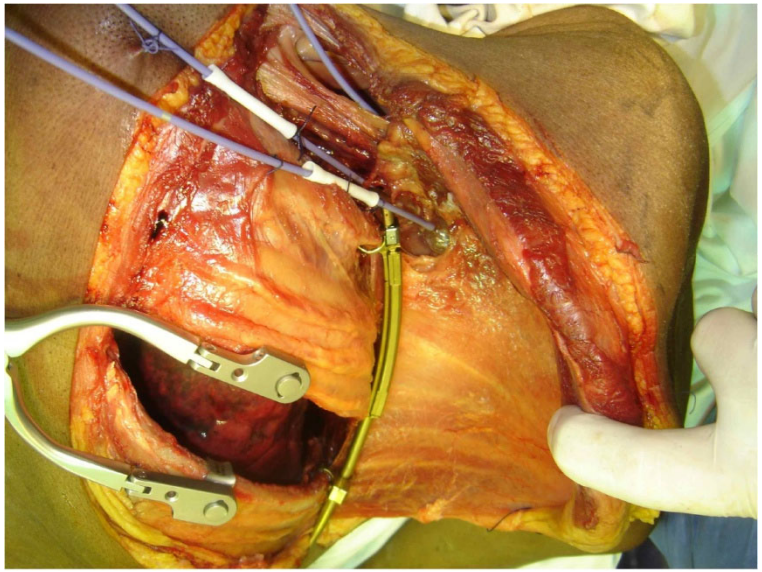


Hypothesis

- We hypothesize that brachial plexus dysfunction and TOS are caused by cephlad displacement of the proximal rib cage, during the procedure, with resultant compression of the neurovascular structures within the costo-clavicular region of the thoracic outlet.
- Intra-operative Scapular positioning may contribute to this compression
- Mid-clavicular osteotomy maybe a useful means of relieving compression in this region of the thoracic outlet thereby decreasing the likelihood of these complications in appropriately selected patients.

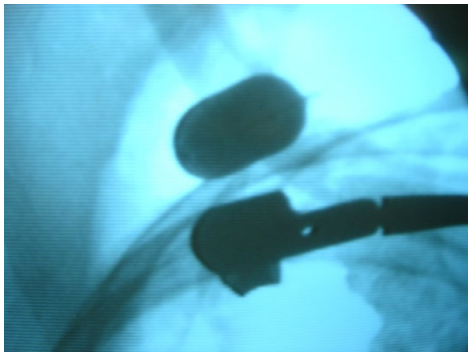
Materials and Methods

- The first part of the study involved manometric evaluation of the three zones of the thoracic outlet using Balloon Pressure Transducers (Kyphon Inc, Sunnyvalle, CA), under fluoroscopic guidance, before and after performing an expansion thoracoplasty in five fresh cadaveric specimens.
- Pressure measurements were obtained with the Scapula in three positions: Cepalad/Anatomic/Distally Displaced
- One additional specimen was prepared for a descriptive anatomic study of the thoracic outlet after expansion thoracoplasty using a barium impregnated putty to delineate areas of compression with the aid of fluoroscopy. A mid-clavicular osteotomy was then performed in order to observe the effect of decompressing this region.

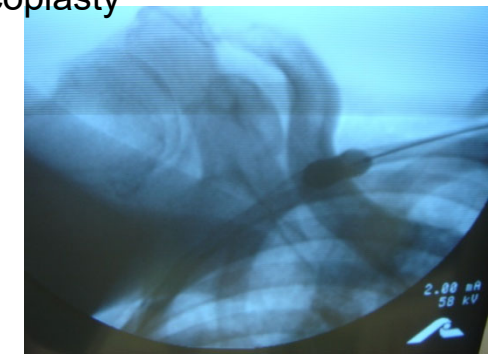


20mm Kyphon Balloons with 10cc Barium

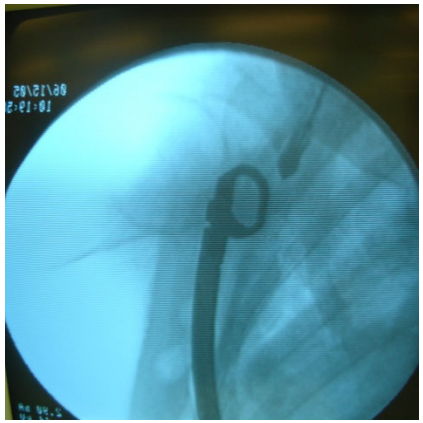
15 mm diameter no Compression Scapula elevated



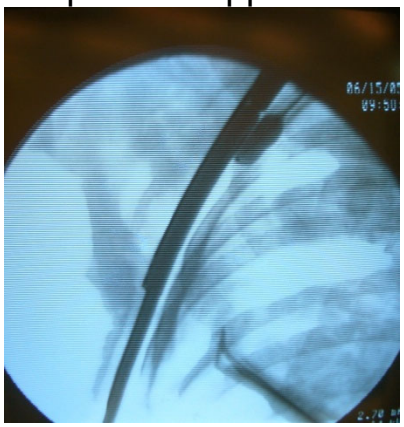
Balloon Compression noted in mid-clavicular zone with distal scapular position without thoracoplasty



VEPTR/Thoracoplasty with distal scapular displacement compresses balloon



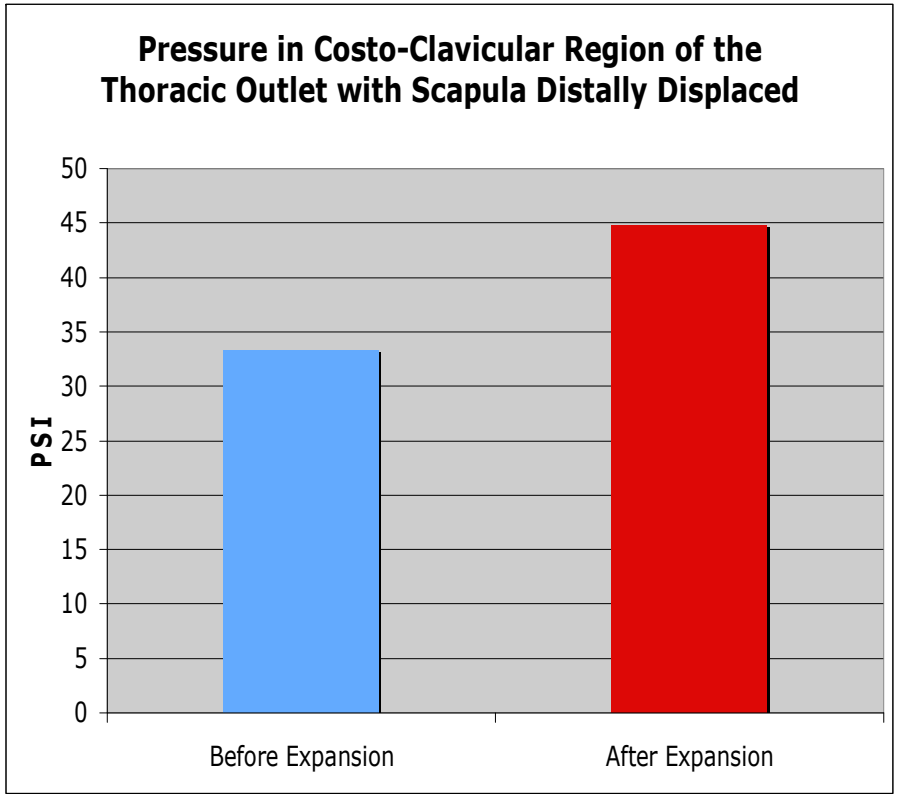
Infra-Clavicular compression of Balloon after clavicular osteotomy and anatomic scapular re-approximation



Results

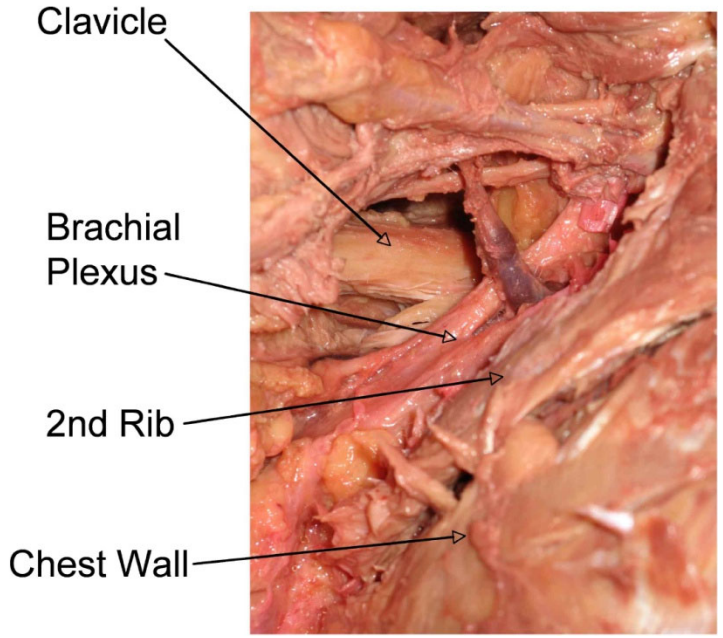
Pressure measurements were obtained with the scapula in 3 positions: Proximal/Anatomic/Distally Displaced. The highest pressures were recorded with the scapula in the distally displaced position.

A 26% mean increase in pressure in the costo-clavicular region of the thoracic outlet was noted after expansion thoracoplasty. This increase was only seen when the scapula was distally displaced. The other regions of the thoracic outlet did not demonstrate significant changes in pressure after expansion thoracoplasty and scapular repositioning.

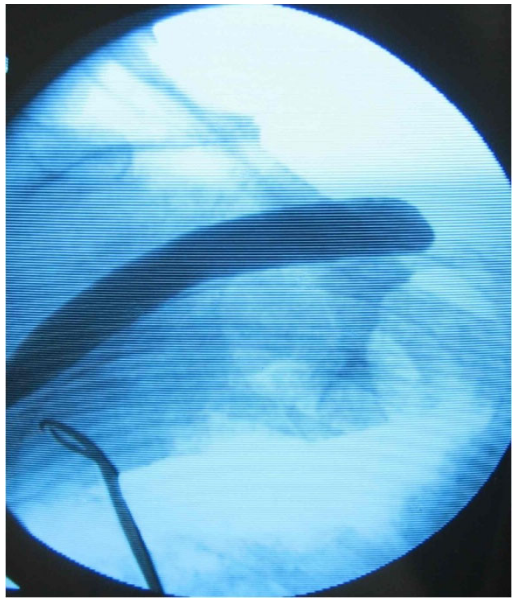


Results

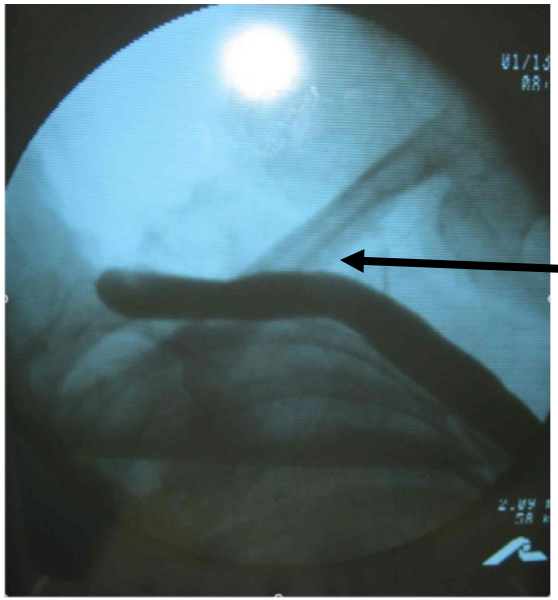
- Anatomic dissection revealed the source of compression to be between the clavicle and the proximal rib cage which had been displaced cephalad and lateral after the expansion thoracoplasty. This was demonstrated by indentation of our barium impregnated putty seen on fluoroscopy.

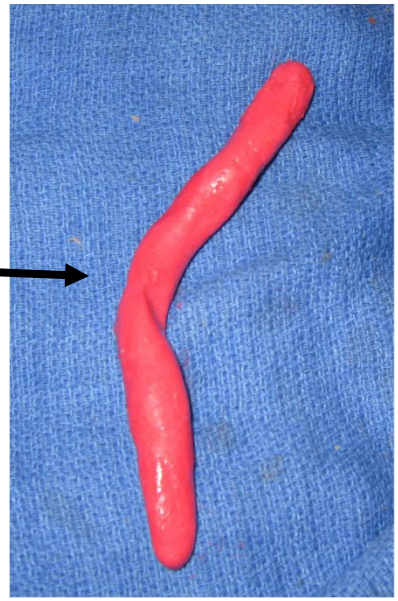


Scapula proximal



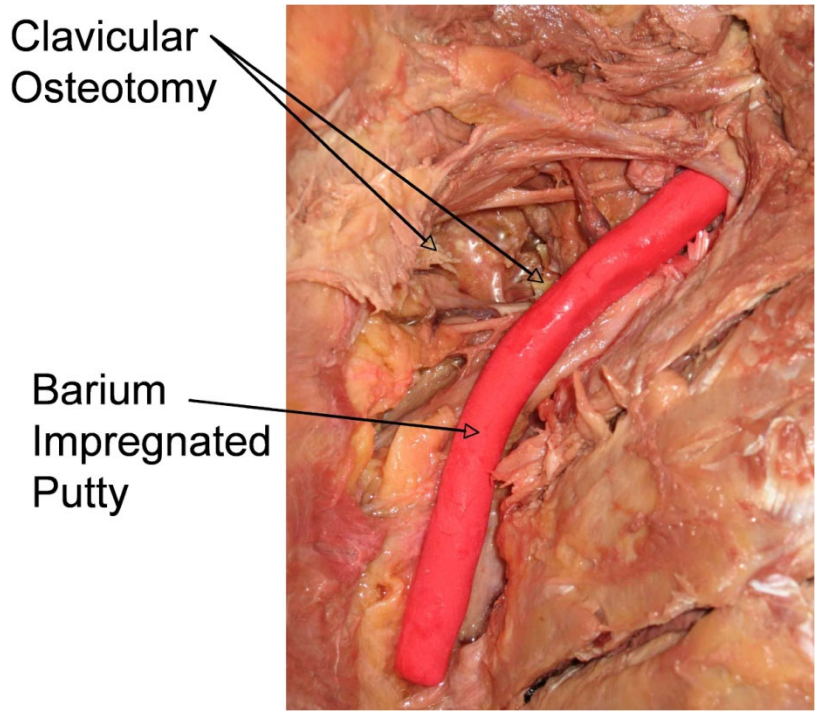
Scapula distal

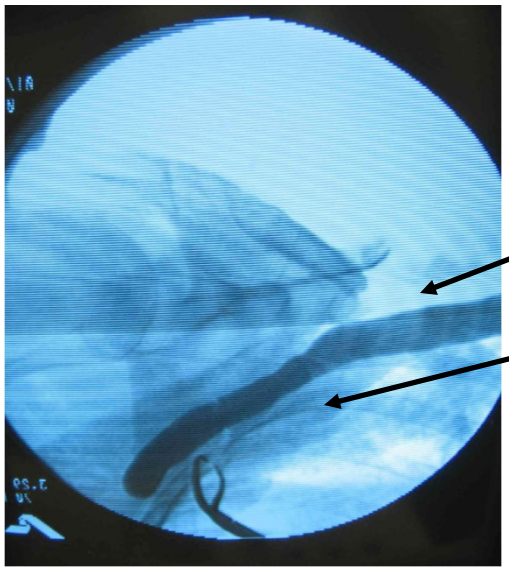


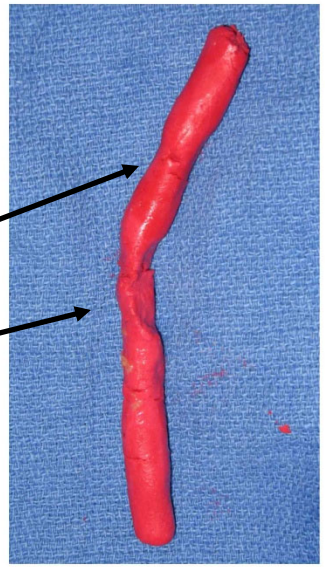


Results

- Relief of this area of compression was seen after mid-clavicular osteotomy however a second area of compression of the putty was noted distal to the midclavicular region between the scapula and lateral proximal chest wall with scapular re-approximation.







Discussion

- The costo-clavicular region of the thoracic outlet was identified as the most likely area of compression resulting in Brachial Plexus related neurovascular deficits after expansion thoracoplasty based on manometric data and anatomic evidence.

Discussion

- Distal Scapular Repositioning following expansion thoracoplasty may be a risk factor for TOS
- Mid-clavicular osteotomy was identified as one potential method of decompression of the midclavicular region of the thoracic outlet. But may have the undesired effect of shifting TO compression to a more distal position

Study Weakness

- Small sample size
- Use of adult cadaveric material without significant deformity.
- Discrete pressure sensors rather than a long continuous catheter.
- Inability to correlate compression sites identified to clinical Brachial Plexus dysfunction.
- Future Anatomic evaluation using CT generated 3-D models from VEPTR treated patients

Strategies for Prevention/Dx/Tx

- Determine “at risk” cases, ie. multiple proximal rib fusions
- Intra-operative neurophysiologic monitoring with Wake-up test if possible
- Anatomic re-approximation of the scapula and surrounding soft tissues. Avoid Distal Scapular displacement.
- Smaller initial thoracic expansion distance
- Post-operative positioning with UE elevation
- Careful Neural assessment/Occupational Therapy
- Post-operative imaging if TOS is suspected: Chest CT with 3-D and Brachial Plexus MRI
- Dynamic UE EMGs/NCVs
- Mid-clavicular Osteotomy
- 1st/2nd rib Osteotomies ??

References

1. Atasoy, E., *Thoracic outlet syndrome: anatomy.* Hand Clin, 2004. **20**(1): p. 7-14, v.
2. Motoyama, E.K., et al., *Effects on lung function of multiple expansion thoracoplasty in children with thoracic insufficiency syndrome: a longitudinal study.* Spine, 2006. **31**(3): p. 284-90.
3. Hell, A.K., R.M. Capbell, and F. Hefti, *The vertical expandable prosthetic titanium rib implant for the treatment of thoracic insufficiency syndrome associated with congenital and neuromuscular scoliosis in young children.* J Pediatr Orthop B, 2005. **14**(4): p. 287-93.
4. Emans, J.B., et al., *The treatment of spine and chest wall deformities with fused ribs by expansion thoracostomy and insertion of vertical expandable prosthetic titanium rib: growth of thoracic spine and improvement of lung volumes.* Spine, 2005. **30**(17 Suppl): p. S58-68.
5. Cunningham, M.E., et al., *Fusionless scoliosis surgery.* Curr Opin Pediatr, 2005. **17**(1): p. 48-53.
6. Kose, N. and R.M. Campbell, *Congenital scoliosis.* Med Sci Monit, 2004. **10**(5): p. RA104-10.
7. Gollogly, S., et al., *The volume of lung parenchyma as a function of age: a review of 1050 normal CT scans of the chest with three-dimensional volumetric reconstruction of the pulmonary system.* Spine, 2004. **29**(18): p. 2061-6.
8. Gollogly, S., J.T. Smith, and R.M. Campbell, *Determining lung volume with three-dimensional reconstructions of CT scan data: A pilot study to evaluate the effects of expansion thoracoplasty on children with severe spinal deformities.* J Pediatr Orthop, 2004. **24**(3): p. 323-8.
9. Campbell, R.M., Jr., et al., *The effect of opening wedge thoracostomy on thoracic insufficiency syndrome associated with fused ribs and congenital scoliosis.* J Bone Joint Surg Am, 2004. **86-A**(8): p. 1659-74.
10. Campbell, R.M., Jr., M.D. Smith, and A.K. Hell-Vocke, *Expansion thoracoplasty: the surgical technique of opening-wedge thoracostomy. Surgical technique.* J Bone Joint Surg Am, 2004. **86-A Suppl 1**: p. 51-64.
11. Campbell, R.M., Jr., et al., *The characteristics of thoracic insufficiency syndrome associated with fused ribs and congenital scoliosis.* J Bone Joint Surg Am, 2003. **85-A**(3): p. 399-408.
12. Campbell, R.M., Jr. and A.K. Hell-Vocke, *Growth of the thoracic spine in congenital scoliosis after expansion thoracoplasty.* J Bone Joint Surg Am, 2003. **85-A**(3): p. 409-20.
13. Vercellio, G., et al., *Thoracic outlet syndrome in paediatrics: clinical presentation, surgical treatment, and outcome in a series of eight children.* J Pediatr Surg, 2003. **38**(1): p. 58-61.
14. Mackinnon, S.E. and C.B. Novak, *Thoracic outlet syndrome.* Curr Probl Surg, 2002. **39**(11): p. 1070-145.
15. Landry, G.J., et al., *Long-term functional outcome of neurogenic thoracic outlet syndrome in surgically and conservatively treated patients.* J Vasc Surg, 2001. **33**(2): p. 312-7; discussion 317-9.
16. Huang, J.H. and E.L. Zager, *Thoracic outlet syndrome.* Neurosurgery, 2004. **55**(4): p. 897-902; discussion 902-3.
17. DiFiore, J.W., J.R. Reid, and J. Drummond-Webb, *Thoracic outlet syndrome in a child--transaxillary resection of anomalous first rib.* J Pediatr Surg, 2002. **37**(8): p. 1220-2.
18. Demondion, X., et al., *Thoracic outlet: anatomic correlation with MR imaging.* AJR Am J Roentgenol, 2000. **175**(2): p. 417-22.
19. Degeorges, R., C. Reynaud, and J.P. Becquemin, *Thoracic outlet syndrome surgery: long-term functional results.* Ann Vasc Surg, 2004. **18**(5): p. 558-65