Recent developments in scoliosis surgery

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Summary
Traditional surgical correction of spinal deformity has involved relatively long instrumentation and fusion techniques, producing a straighter but stiffer spine. In the infant this approach leads to a shorter trunk. Current surgical techniques may also have an adverse effect on pulmonary function. In order to minimize the latter, strategies have been devised to limit exposure related morbidity. These have largely focused on minimally invasive and thoracoscopic techniques, and endoscopic techniques of spinal instrumentation and scoliosis correction are now well established.

Non-fusion techniques in the growing spine, to maximize or modulate future growth potential, are being explored. Their potential advantages are obviation of the need for early fusion and countering of the resultant relative axial shortening from spinal arthrodesis.

The development of expandable devices to treat deformity of both spine and thorax have seen their application in the management of thoracic insufficiency whether due to congenital scoliosis with rib fusions, thoracic hypovolaemia syndromes and various early onset scoliosis conditions.

Advances in metallurgy have produced more ‘intelligent’ implants, capable of delivering sustained corrective forces to the spine in the post-operative period. The shape memory effect of Nitinol alloys may also facilitate spinal instrumentation.

This article details the following subjects:

- Thoracoscopic scoliosis surgery
- Fusionless scoliosis surgery
- Growing rod techniques
- Vertical Expandable Prosthetic Titanium Rib (VEPTR)
- Anterior tether implants for deformity correction
- Vertebral osteotomy
- Memory metal technology & spinal implants

Thoracoscopic scoliosis surgery

Jacobeus is credited with performing the first thoracoscopy in 1910. Thoracoscopic surgical procedures were widely practiced throughout Europe in the 1920s, but the advent of tuberculosis antibiotic therapy reduced the need for thoracoscopy procedures in the 1950s.

Though popular in Europe, thoracoscopy was not widely practiced in the USA until fibreoptics and flexible operating endoscopes were developed in the 1970s.
The introduction of the endoscopic video camera further enhanced the functionality of thoracoscopy, permitting multi-portal procedures. The term ‘video assisted thoracoscopic surgery’ (VATS) was applied to these new techniques. Mack reported his early experience using VATS for anterior scoliosis release, thoracic discectomy, vertebral biopsy, spinal abscess drainage and interbody fusion.1

Thereafter, other authors described their experiences performing similar procedures, but also with instrumentations in scoliosis cases 2–5 (Figs. 1 and 2). The anterior approach to the spine offers several advantages over posterior surgery for thoracic adolescent idiopathic scoliosis. These include fusion of fewer motion segments, less blood loss, and better restoration of sagittal contour in hypokyphosis.6 However, the anterior approach results in deterioration (albeit temporary) of pulmonary function and in shoulder girdle strength.7–10 Pulmonary function is reduced after open anterior approaches to the thoracic spine and remains so up to 2 years after the index procedure.

Thoracoscopic surgery theoretically minimizes thoracotomy-associated morbidity, with less pain, speedier recovery, improved cosmesis, pulmonary function and shoulder function and quicker return to normal life.11,12 Picetti et al. reported on VATS assisted deformity correction in 50 patients with thoracic scoliosis. Endoscopic instrumentation was successfully employed in all cases. The average curve correction was 50%, and postoperative pain was reduced in the VATS group compared with a matched cohort of ‘conventional’ openly performed cases.13 Thoracoscopic procedures induced less physiological stress and less overall pulmonary dysfunction, with a quicker recovery to normal.

There is minimal data from the published clinical series on patients’ perceptions of self-image or functional outcome compared to open techniques, but 2-year patient satisfaction scores were high on standardised quality of life and scoliosis questionnaire assessment.

These encouraging findings must, however, be tempered by reports of late complications. Thoracoscopic surgery may have a higher pseudarthrosis rate compared with open techniques, with a maximum reported incidence of 20%. It is also clear that there is a significant rate of implant failure, with rod breakage rates as high as 30%.

**Fusionless scoliosis surgery**

The work of Dimeglio demonstrates that spinal growth is at its peak during the first five years of life, with normal spinal longitudinal growth averaging 2 cm per year (from T1 to S1) during this time. The occurrence and progression of spinal deformity is significant in this phase.
Surgical intervention is indicated for progressive deformity that is not controlled satisfactorily by other means.

Growing rod techniques

Non-fusion based surgical solutions have been sought for the treatment of progressive deformities of early onset (infantile). The aims are to delay the time of definitive surgery, allowing axial growth of the spine and thorax, and maximum preservation of spinal mobility.

Moe was the first to describe the technique of subcutaneous Harrington instrumentation in 1984. Variations on this procedure include other subcutaneous growing rod types of constructs, such as the ‘Isola’ system. With the exception of subperiosteal dissection and/or local fusion at the anchor points of the construct, the spine is not exposed, thus permitting theoretical longitudinal growth.

Better results, in terms of lengthening, initial correction and late deformity control are achieved with dual rod configurations. Periodic distraction achieves further spinal longitudinal growth. It does, however, by definition involve a lengthy treatment course with repeat operations for lengthening. There are significant instrument-related morbidities, such as implant migration and breakage.

A multi-centre international study reviewed the ability of dual growing rods to correct deformity and allow longitudinal growth. The authors found good capacity for deformity correction and maintenance. Complications, however, occurred in 48%, and included hardware failure and infection.

Webb et al. have described an alternative surgical philosophy, with some long-term reported results at skeletal maturity. They have described a combined apical convex hemi-epiphysiodesis and passive self-lengthening, with ‘trombone-like’ posterior instrumentation, as pioneered by Luque. The benefit of this ‘Luque trolley’ technique seems to be a reduced need for repeat surgery, with 35% of cases at maturity requiring no further surgery or definitive fusion. There is still significant axial spinal shortening and moderate or severe pulmonary dysfunction in about 60% of cases. It should be noted that functional outcome scoring (using validated health questionnaires) of these cases at latest follow-up, indicate relatively good function and overall patient satisfaction ratings (Fig. 3).

Vertical expandable prosthetic titanium Rib (VEPTR)

Another form of fusion-less surgery is increasing in its clinical application. The VEPTR dual rod technique employs an extra spinal dual (or bilateral) costo-pelvic instrumentation to indirectly apply corrective coronal plane forces on the spinal column. VEPTR is also frequently applied in rib-to-rib and spine-to-rib (hybrid) configurations. This procedure has demonstrable capacity for gradual, incremental alteration of thoracic cage dimensions as well as correcting spinal deformity.

Campbell et al. developed the VEPTR device (and the related technique of ‘expansion thoracostomy’) to treat both spine and chest wall deformity during growth. They promoted a more comprehensive view of combined chest and spine deformities seen in early-onset spinal disorders of various aetiologies. The term coined by Campbell and his group, of “thoracic insufficiency syndrome” (TIS), has been widely accepted and is defined as the “inability of the thorax to support normal respiration and lung growth”. It applies to the combined chest wall and spinal deformity seen with infantile spinal deformity of many types, as well as the thoracic hypoplasia and ribcage deformity classically associated with congenital scoliosis.

Normal growth in volume of the lung and the thorax continues throughout childhood and adolescence. Increases in the number of alveoli, however, do not continue beyond early childhood. Expansion thoracostomy aims to increase thoracic volume and indirectly improve spinal contour (Fig. 4). The concept requires serial lengthening procedures to maintain thoracic volume relative to growth and allow continued axial lengthening.

Growth has been documented even in congenital anomalies, including failed segmentation and scoliosis. Campbell et al. in 2003 reported a series of 21 cases and noted an average growth of up to 1.2 cm/year. The VEPTR is, however, not without potential complications and risks. Insertion of the device involves significant soft tissue dissection and mobilisation and the device can be rather prominent under the subcutaneous tissues. There is a significant rate of deep infection and wound breakdown, affecting 1 of 15 cases. The device is relatively loosely fixed to its skeletal anchor points and implant migration and loosening can occur. These may, on occasion, be associated with rib fracture.

Anterior tether implants for deformity correction

Blount originally pioneered staples in 1949, and transphyseal stapling techniques have long been established as a method of modulating long bone growth and correcting limb deformity in young children. The potential for such techniques in the growing spine was recognised, and early animal experimental work by Naclas and Borden in 1951 demonstrated possible efficacy.

Concerns about spinal arthrodesis in the immature skeleton and difficulties with other treatment approaches, as outlined above, have led to recent resurgence of interest in vertebral body stapling for influencing spinal growth. This procedure is recommended for scoliosis curves measuring between 20° and 45°, which have demonstrated progression.

A variety of staples, tension band devices and even bone-ligament tethers have been explored experimentally in cadaver and large animal models.

Over the last decade, Betz and Braun have revisited the concept of stapling. They have used Nitinol memory metal prongs, which are straight when cooled but which clamp into the bone by reconfiguring into a claw or ‘C’ shape as they warm to body temperature. [Illustration-clinical picture Betz]. The technique lends itself to endoscopically assisted insertion.

Betz and Braun published a review of their clinical experience in 2005. Twenty-one patients had 25 curves stapled. Three of the 25 (13%) curves progressed more than 10°. None of the 8 preoperative curves less than 30° in magnitude had progressed by latest follow up.
Vertebral osteotomy

Wedge shaped vertebral osteotomy was initially employed in animal models to create scoliosis deformity. The potential for this technique to 'correct' misshapen vertebrae that had undergone morphological change through spinal growth (thus contributing to deformity and its progression) was recognised. A ‘one-stop’ solution, consisting of correction of vertebral deformity and axial skeletal realignment combined with late biomechanically induced remodelling, is a theoretically attractive concept.

The principle advantage of this philosophy over conventional fusion is in situations where maintenance of truncal mobility is functionally important. Thus, it has been used to correct paralytic scoliosis, and myelodysplasia in children and adolescents. Fourteen such cases are described in one series. All successfully underwent surgery to insert a wedge-rod system, with an average initial correction of 86% of the initial deformity. Spinal mobility was retained in all patients.

The greatest long-term data comes from a report by Maruyama et al., describing the outcome of multiple vertebral osteotomies in a selected cohort largely composed of late onset idiopathic scoliosis cases. The average pre-operative Cobb angle of 64° was corrected to 48° at 9 years after surgery. There were 2 patients (10%) where the procedure was converted to posterior instrumentation because of deterioration of the deformity.
Summary and conclusion

The above studies illustrate the potential for fusion-less corrective surgery using a combination of hemiepiphysiodesis, implant-controlled and ‘soft tissue’ tethering techniques. These all aim for spinal growth modulation as solutions for the future. It remains to be seen, however, how much spinal mobility is ultimately preserved by their usage.

Memory metal technology & spinal implants

In current surgical practice, instantaneous correction of scoliosis is achieved by manoeuvres performed by the surgeon with the aid of spinal instrumentation. Typically, this is done by shaping the rod construct to a suitable profile and then bringing the spine or instrumented vertebral segments to the rod, forcing it toward adoption of that profile.

The development of the alloy ‘Nitinol’, derived from Nickel and Titanium (Naval Ordnance Laboratory), with different shapes depending on its thermal environment, exploits the differing capacities of certain alloys for expansion/contraction and ductility at different temperature profiles. This has excited interest in the potential for creating ‘intelligent metal’ implants. This is via the so-called “shape-memory effect” of the alloy. Their use in scoliosis surgery would be to correct deformity by the inherent predisposition to return, under normal ambient body temperatures, to a shape or profile ‘predetermined’ at that temperature. In the initial phase the rod is kept well below the transition temperature, at a lower temperature form (martensite phase). In this phase, the rod has very low yield strength, and can be deformed quite easily into the shape of the spine deformity. Thus, in this malleable state, the rod can be fixed to the spine more easily than with current implants. When the rod is subsequently heated to its higher temperature form (austenite phase), it will regain its original rigidity and will attempt to regain its original shape. If this shape recovery is prevented, the rod generates considerable recovery stresses. Using an adequate anchoring system, these stresses can be turned into forces that correct the scoliosis.

Preliminary tests on human cadavers have shown that these devices can be implanted easily, and that they are capable of inducing a scoliosis with a Cobb angle of about 45°. In experimental studies, the shape-memory metal rod induced a significant scoliosis deformation in all test animals (pigs). Some preliminary clinical trial insertions of Nitinol based scoliosis implants (in an ‘inert’ non-memory mode), have begun, although there is as yet no published data.

Editorial comment

Memory metal technology does sound a splendid way of dealing with spinal deformities in growing children but one of the biggest problems is an inability in spinal surgeons to understand this complex deformity in three dimensions. Having just returned from a splendid instructional course in spinal deformity in Miami hosted by Harry Shufflebarger and Juergen Harms, one heard the devisor of a recent classification of scoliosis still using the term “kypho-scoliosis”! If one does not know how the deformity develops from a primary lordosis through secondary buckling into a scoliosis in tortion, how on earth will memory metalwork be able to reverse this process.