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The role of the intervertebral disc in correction of scoliotic curves. A theoretical model of Idiopathic Scoliosis pathogenesis

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Abstract. Wedging of the scoliotic inter-vertebral disc (IVD) was previously reported as a contributory factor for progression of idiopathic scoliosis (IS) curves. The present study introduces a theoretical model of IVD’s role in IS pathogenesis and examines if, by reversing IVD wedging with conservative treatment (full- and night-time braces and exercises) or fusionless IS surgery with staples, we can correct the deformity of the immature spine. The proposed model implies the role of the diurnal variation and the asymmetric water distribution in the scoliotic IVD and the subsequent alteration of the mechanical environment of the adjacent vertebral growth plates. Modulation of the IVD by applying corrective forces on the scoliotic curve restores a close-to-normal force application on the vertebral growth plates through the Huerer-Volkmann principle and consequently prevents curve progression. The forces are now transmitted evenly to the growth plate and increase the rate of proliferation of chondrocytes at the corrected pressure side, the concave. Application of appropriately directed forces, ideally opposite to the apex of the deformity, likely leads to optimal correction. The wedging of the elastic IVD in the immature scoliotic spine could be reversed by application of corrective forces on it. Reversal of IVD wedging is thus amended into a “corrective”, rather than “progressive”, factor of the deformity. Through the proposed model, treatment of progressive IS with braces, exercises and fusionless surgery by anterior stapling could be effective.

Keywords. Idiopathic scoliosis, intervertebral disc, asymmetrical growth, pathogenesis of idiopathic scoliosis, conservative treatment of Idiopathic scoliosis, fusionless surgery of Idiopathic scoliosis, stapling of the spine.

1. Introduction

The rationale for management of idiopathic scoliosis (IS) during skeletal growth assumes a biomechanical mode of deformity progression, based on the Huerer-Volkmann principle [1], whereby extra axial compression decelerates growth and reduced axial compression accelerates it [2]. In treating IS conservatively, application of corrective forces does nothing more than exploiting this principle, by applying appropriately directed forces through the skin, soft tissues and ribs to the vertebral growth plates. The role of the IVD as a contributory factor to the development of the scoliotic curve has been emphasized in a previous study [3]. The response of IVD to abnormal stresses imposed on them in scoliosis is essential to the long-term prognosis of untreated lumbar and thoracolumbar curves [4] and it is very likely that the changes in cartilagenous endplate (vertebral body growth plate) and IVD are key factors in the progression of scoliosis and the manner in which the curve will respond to different therapeutic regimens [5].
The present study illustrates the effect of IVD modulation and its subsequent benefits in IS treatment. The proposed model is examined on conservative treatment (full- and night-time braces and exercises) and fusionless IS surgery with staples.

2. Material and Methods

A theoretical model of IVD’s role in progressive IS pathogenesis is introduced. The IVD contains the aggrecans of glycosaminoglycans (GAGs) which imbibe water through the so-called Gibbs-Donnan mechanism. The highest concentration of GAGs is in the nucleus pulposus (NP) where they are entrapped in a type II collagen network [6] and are exposing a convex-wise asymmetrical distribution. There is an increased collagen content in the NP of the apical IVD but also in the adjacent discs in IS, which is maximal at the apex of the curvature. Furthermore, in the scoliotic spine the NP in the IVD is displaced towards the convex side of the wedged interspaces [4]. Differences also exist in the collagen distribution between the concave and convex sides of the scoliotic annulus fibrosus in IS, with fewer collagen fibres in the concave compared to the convex side [7].

A diurnal variation in the water content of lumbar IVD has also been documented [8, 9], resulting in diurnal variations in loading of the vertebral growth plates, because of IVD’s periodical “swelling” (during night time) and “shrinkage” (for the period of day time under the application of the body load during the upright posture) during the 24 hour period. This asymmetrical pattern of water distribution in the scoliotic IVD, combined with the diurnal variation in the water content of IVDs resulting to a sequence of “swellings” and “shrinkages”, imposes asymmetrical, convex-wise, concentrated cyclical loads to the IVD and the adjacent immature vertebrae growth plates of the child during the 24 hours period [3]. The convex side of the wedged IVD sustains greater amount of cyclic (swelling) expansion than the concave side, leading to the sequelae of asymmetrical growth of adjacent vertebrae (Hueter-Volkmann’s law).

Consequently, the response of bone growth to asymmetrical loading follows an asymmetrical pattern and gradually can enhance the correction of the deformity if optimal corrective forces are applied, with full time and night time braces, exercises and fusionless surgery.

3. Results

The IVD may be modulated by applying corrective forces on the curve thereby eliminating any asymmetrical accumulation of water in the apical and adjacent IVDs. This, in turn, restores a close-to-normal force application on the vertebral growth plates through the Hueter-Volkmann principle and consequently may prevent curve progression. The forces are now transmitted evenly to the growth plate increasing the rate of proliferation of chondrocytes at the corrected pressure side, the concave. All the stated treatment methods aim at alteration of the mechanical environment and modulation of the endochondral growth of the immature vertebrae. Application of appropriately directed forces, ideally opposite to the apex of the deformity, likely leads to optimal correction.

Exercises for IS are using techniques to correct and maintain the correction which has been achieved, during every day activities. By activating the appropriate muscle groups, corrective forces are transmitted on the wedged IVD and are reversing to a degree the wedging, altering the mechanical environment of the adjacent vertebral growth plates.
Full time braces, through the 3D correction and the combination of derotation together with the three point pressure principle, are exerting constant corrective forces on the wedged IVD and are restoring a close to normal force application on the vertebral growth plates. The mechanical stimulus to the concave side of the growth plate is weaker, allowing new cells to be produced in the proliferative zone and extracellular matrix to be produced in the hypertrophic zone of the growth plate, according to Hueter-Volkman principle. As a consequence, longitudinal growth is faster at the concave side of the curve, when a skeletally immature scoliotic child is treated with a full time brace and eventually this could stop its progression or even correct the curve, depending on child’s growth potential.

The night time braces are rather overcorrecting the mild or moderate scoliotic curves, simulating gravity, acting also on the apical and adjacent wedged IVDs [10]. Their action is by reducing the previously described asymmetrically imbibed water (greater amount in the convex rather that in the concave side), but additionally they are taking advantage of the diurnal variation in the water content of IVD, which is increased during the night. Hypercorrection of the IVD with the nighttime brace results in vertebral growth under more normal conditions. Under the action of the nighttime brace, the convex side sustains no greater amount of expansion than the concave side, (ceasing the asymmetrical application of Hueter-Volkman law), reversing the deleterious hypothesis of progression of IS curves; consequently, the growth of the apical and adjacent immature vertebrae turns more normal, within a close to normal biomechanical environment.

Fusionless surgery with staples, theoretically allows preservation of growth, motion, and spinal function, and perhaps has a reduced risk of adjacent segment degeneration and other spinal de-compensation problems [11]. This method has been shown to retard growth on the convex side while allowing the concave side to continue growing, enabling the abnormal curve to “self-correct” [12]. Additionally, stapling between two adjacent vertebrae at the side of curve convexity inhibits IVD expansion due to its asymmetrical water distribution and therefore, one significant factor for curve progression is eliminated. Theoretically, by stapling the growth plates, the accelerated growth on the convexity of a curve is ceased, both by inhibiting the longitudinal growth (acting directly on the convexwise vertebral end-plate cells) and by eliminating the effect of IVD asymmetrical force application on the growth plates. Perhaps growth is stimulated on the concavity of a curve, and therefore correction of the deformity can occur (Hueter-Volkman principle). The goal of stapling is to harness the scoliosis patient’s inherent abnormal spinal growth and alter it to achieve correction, rather than progression.

4. Discussion

The proposed theoretical model requires three conditions in order to be successful. First, there must be enough growth potential left; otherwise the final correction will be suboptimal. Second, the elastic properties of the IVD should allow adequate modulation and through that adequate alteration of the mechanical environment of the growth plate and third, the corrective forces should be towards the correct level, ideally perpendicular to the level of maximum deformity.

The wedging of the elastic IVD in the immature scoliotic spine could be reversed by application of corrective forces on it. Reversal of IVD wedging, by altering the mechanical environment of the adjacent growth plates, is thus amended into a
"corrective", rather than "progressive", factor of the deformity. Through the proposed mechanism, treatment of progressive IS with full time and night time braces, exercises and fusionless surgery by anterior stapling could be effective.

References