Adult degenerative deformity: principles of sagittal balance, classification and surgical management

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Abstract

Deformity has always been part of the gradual spinal degenerative process occurring in older ages causing pain and disability. The shift of the adult population towards older ages has rendered this entity a much more frequent problem requiring treatment. Restoration of global balance is important to achieve pain relief and improve health related quality of life. Advances in the understanding of the spinal balance provided insight into the goals of surgical treatment. Moreover, progress of instrumentation expanded the spectrum of possible operations. However, the altered bone biology and presence of medical co-morbidities define the surgical limitations and restrict the number of patients who are fit to undergo such major surgery. This article reviews the fundamental principles of spinal balance and clinical aspects of adult deformity. There is no doubt that surgical correction plays an important role in the management of this condition but this is not indicated for all patients. Indications for deformity correction and treatment options are discussed. Finally the complications are presented as this is an important parameter for a sound patient selection process.

Keywords adult scoliosis; adult spinal deformity; sagittal balance; spinal osteotomies; surgical treatment

Introduction

Adult spinal deformity has become a frequent clinical entity as people tend to live longer into old age and maintain their level of activity. Pain and functional restriction cannot be tolerated leading patients to look for surgical solutions. Pain and disability are the main complaints in adult degenerative deformity in comparison to cosmesis, which is the main concern in patients with adolescent idiopathic scoliosis.[1] The deformity can produce global imbalance affecting significantly quality of life.[2] The incidence of adult deformity is 60% in the general population with 6% being symptomatic. There is no gender predominance and the average age of patients seeking medical care is in their 60s but ranges from early 50s onwards.

Surgical correction in paediatric deformity focuses on coronal plane alignment, curve type and vertebral rotation, whereas the main targets in adult deformity are the restoration of segmental subluxation, lumbar lordosis and global sagittal balance.[1] Often neurological decompression is needed. Anterior column support is mandatory. The medical co-morbidities, extent of surgical insult and poor bone biology dictate a thorough preoperative optimization and detailed surgical planning. These extensive operations have still an inherent high rate of surgical complications,[3] which limits the number of patients fit to receive surgical treatment. Patient selection, knowledge of the principles of sagittal spinopelvic balance and surgical experience are keys to successful treatment.

Sagittal balance

In the erect position of healthy individuals, the gravity line (GL) crosses the femoral heads and falls between the two feet (Figure 1). This is a low-energy posture, which allows the spine to achieve normal gait and balance in all movements. The C7 plumb line (C7PL) is parallel to the GL and it may differ in asymptomatic individuals according to the type of their spine (Figure 1).[4,5] The GL moves anterior to the femoral heads (FHs) in older people (>60 years) along with increasing thoracic kyphosis (TK) or reduced lumbar lordosis (LL); this causes trunk imbalance. A balanced position requires the C7PL line to be close to the sacrum and posteriorly to the FHs.

Pelvis types and pelvic parameters (Figure 1)

The centre of FHs and the orientation of the sacral plateau, as main load transmission points, represent the main anatomical landmarks for the assessment of spinopelvic balance.[4] In a two-dimensional lateral radiograph, the line connecting the centre of the sacral plateau and the centre of the FHs represents the 'size' of the pelvis. The orientation of the sacral plateau is independent of the 'size' of the pelvis and is characterized by a perpendicular line starting from its centre. Pelvic incidence (PI) is the angle formed between these two lines. It is a unique anatomical parameter to each individual and remains constant following skeletal maturity.[4] The angle between the 'size'-line and the vertical axis is called pelvic tilt (PT). It is a measure of pelvic rotation around the FH axis. Sacral slope (SS) is the angle formed between the sacral plateau and the horizontal line. This is an anatomical parameter of the sacrum. Similarly to PT, SS angle changes along with the rotation of the pelvis.[4] There is direct positional relationship between SS and PT. The sum of PT and SS is constant and equals PI ($SS + PT = PI$).[4]

Description of pelvis type and its orientation requires measurement of all angles. PT is directly related to PI in normal population. Average PT is 15° in 70% of the population with PI 53° (low PT cohort: 15% of population with average PT = 7° and

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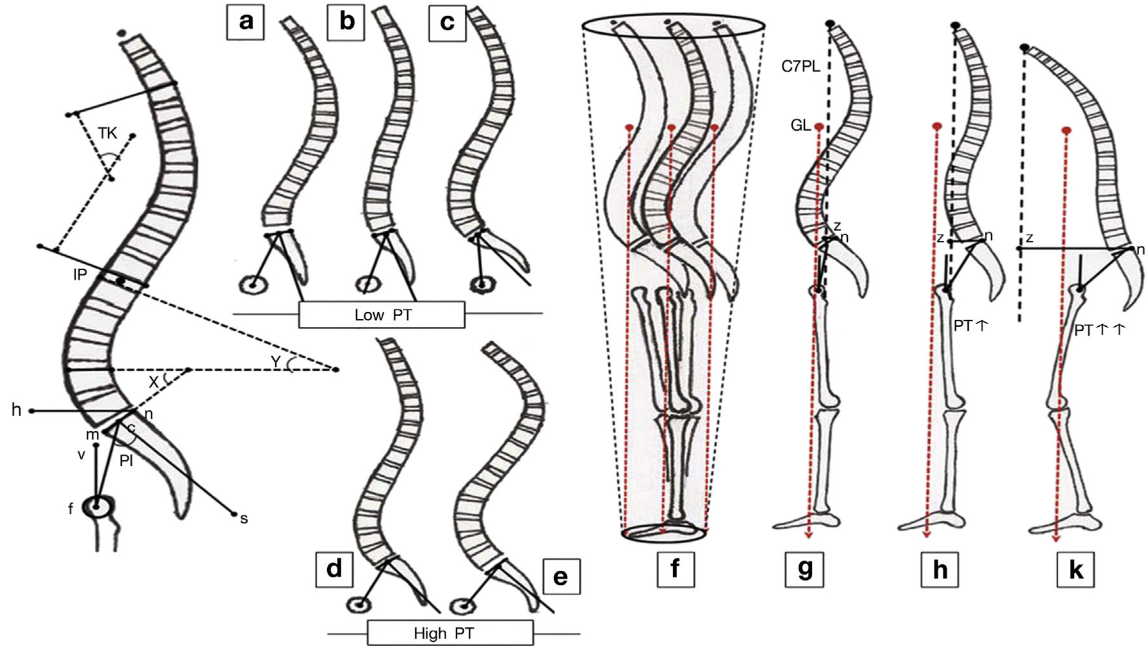

Figure 1 Sagittal spinopelvic parameters on standing lateral radiograph. (mn): S1 endplate, (c) centre of the sacral plateau, (cs) ⊥ (mn), (hn): horizontal line, (vf): vertical line, fcs angle: pelvic incidence (PI), mfc angle: pelvic tilt (PT), fcs angle: pelvic incidence (PI), mfc angle: pelvic tilt (PT), hnm: sacral slope (SS),PI = SS + PT. X: inferior lumbar arch, Y: superior lumbar arch, + X + Y = lumbar lordosis, TK: thoracic kyphosis, sagittal vertical axis (SVA): the distance of the posterior edge of the sacral plateau to the C7PL. Types of sagittal balance. (**a**) Type 1 (12% of population, SS < 35°, PI = 39 ± 5°, LL = short hyperlordosis), (**b**) Type 2 (22% of population, SS < 35°, PI = 41 ± 6°, LL: less pronounced lumbar curve), (**c**) Type 3 anteverted (16% of population, SS > 35, PI = 48°, LL including five vertebrae), (**d**) Type 3 (30% of population, 35° < SS < 45°, PI = 53 ± 7°, LL: 4.5 ± 1 vertebrae), (**e**) Type 4 (20% of population, SS > 45°, PI = 62 ± 8°, LL: hyperlordosis). (**f**) The cone of economy: A conically shaped 'stable' area surrounding the individual. Deviation from the centre within this area results in greater muscle effort and energy expenditure to maintain upright posture. Deviation of the body outside the cone results in falling or requiring support. (**g**) Relationship between gravity line and C7PL (GL: gravity line, C7PL: C7 plumb line, GL ∥ C7PL). (**h** and **k**) showing the second and third stage of compensatory mechanism respectively with increased PT and further balancing by hip and knee flexion beyond maximum achievable PT.

PI = 35°. High PT cohort: 15% of population with average PT = 22° and PI = 81°).

Spinal shape and parameters (Figure 1)

The apex of LL in the standing position fluctuates between the inferior aspect of L3 and superior aspect of L5. The inflexion point, which is the point where LL is transitioning to TK is more constant and stable in terms of movement.[4] LL incorporates two arcs. The inferior lumbar arc (angle X) is defined by the extension of the sacral plateau line and the horizontal line crossing the lumbar apex. The superior lumbar arc (angle Y) is defined by the extension of the superior endplate of the inflexion point vertebra to the horizontal line. The angle Y has a small spectrum of values ranging from 18° to 21° in healthy individuals meaning that LL is mainly represented by the X angle (lordosis between L4-S1). Therefore, 70% of LL is located at the L4-S1 segments (40% at L5/S1 and 30% at L4/5).[6] This indicates that most lumbar movement is taking place at the lower lumbar segments and it needs to be considered in the preoperative planning of lumbar fusions.

Spinopelvic correlation – the compensatory mechanisms

Given the associations described, LL is directly related to PI (LL = PI ± 9°). According to the distribution of pelvic parameters in healthy individuals there are five main spinopelvic types (Figure 1A–E). Also, new findings suggest, that LL is associated more with SS rather than PI.[4]

With ageing the shape of the spine can change adopting a kyphotic posture.[7] This starts with degeneration of the mobile lumbar spine resulting into loss of LL and a flatback deformity. In order for the body to maintain horizontal gaze and a balanced erect position in the best economical way it compensates by altering spinopelvic relationships (Figure 1F). The compensatory mechanisms aim to maintain the GL between the feet (through the FH is possible) and restore the position of the C7PL through the superior endplate of S1 (Figure 1G).[5] The first compensatory mechanism is decrease of TK and increase of LL by active muscle contraction.[6] The latter may cause retrolisthesis in the lumbar spine. If the required compensation exceeds the hyperextension ability of the lumbar spine (or in case of muscle fatigue, pain or other pathology, such as spondylolisthesis/spinal stenosis) the second compensatory mechanism comes into action; increase in PT (Figure 1H).[6] The greater the PI the bigger the ability to compensate. Failure of both spinopelvic compensatory mechanisms, leads to bending of the hips and knees (the third compensatory mechanism) and a crouched posture in order to achieve erect position (Figure 1K).[6]

Adult deformity types – definition and classifications

Adult spinal deformity is divided into two major components: coronal and sagittal. Scoliosis affects the coronal plane with curves greater than 10°. Increased TK or loss of LL involves the sagittal plane leading to forward leaning and positive (anterior)

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