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Review

Fundamental biomechanics of the spine—What we have learned in the past 25 years and future directions

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ABSTRACT

Since the publication of the 2nd edition of White and Panjabi's textbook, Clinical Biomechanics of the Spine in 1990, there has been considerable research on the biomechanics of the spine. The focus of this manuscript will be to review what we have learned in regards to the fundamentals of spine biomechanics. Topics addressed include the whole spine, the functional spinal unit, and the individual components of the spine (e.g. vertebra, intervertebral disc, spinal ligaments). In these broad categories, our understanding in 1990 is reviewed and the important knowledge or understanding gained through the subsequent 25 years of research is highlighted. Areas where our knowledge is lacking helps to identify promising topics for future research. In this manuscript, as in the White and Panjabi textbook, the emphasis is on experimental research using human material, either in vivo or in vitro. The insights gained from mathematical models and animal experimentation are included where other data are not available. This review is intended to celebrate the substantial gains that have been made in the field over these past 25 years and also to identify future research directions.

Contents

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1. Introduction

Clinical problems of the human spine continue to be prevalent in our society. Examples include low-back pain, sciatica, spinal deformity in both adults and children, spinal tumors, and spinal injury, including trauma to the spinal cord. Given that these clinical problems remain largely unsolved and that the spine plays an important mechanical role in human function, it is thus not a surprise that biomechanical research on the spine has expanded at a rapid pace. A PubMed search in June 2015 with the search terms 'spine' and 'biomechanics' showed that the number of articles in this field has increased exponentially over the past 25 years.

The classic textbook, Clinical Biomechanics of the Spine by White and Panjabi, was last published in 1990 and the next edition of this book is in the final stages of preparation. In the preparation of this third edition, we have had the opportunity to conduct a detailed literature review on the salient biomechanics literature related to the human spine over the past 25 years.

The purpose of this manuscript is to review what we have learned over the past 25 years in regards to the fundamentals of spine biomechanics. The material is organized in three main areas —the Whole Spine, the Functional Spinal Unit, and the Spinal Components (e.g. vertebra, intervertebral disc, spinal ligaments). My approach will be to briefly review what we knew in 1990, to outline what we have learned since that time, and to suggest areas for future research. Detailed reviews of papers are not provided, but classic references on a topic along with key new manuscripts are included for the reader to review. Due to space limitations, the spinal components of rib cage, muscle, spinal cord, and nerve root are not addressed in detail, nor is a review of in vivo spine kinematics or mechanobiology included. Further, topics such as the clinical biomechanical aspects of spinal trauma, spinal deformity, and surgical devices, techniques and instrumentation used in spine surgery are not included.

2. Whole Spine

The Whole Spine consists of the vertebrae of the cervical, thoracic, lumbar, sacral and coccygeal regions along with the intervertebral discs, ligaments, rib cage, and spinal musculature. In addressing the Whole Spine, a global view is taken towards spinal function rather than the local view when we address specific features of a Component such as the annulus fibrosus of the intervertebral disc. A summary of the topics addressed for the Whole Spine is shown in Table 1.

2.1. Quantitative anatomy

In 1990, we had a basic appreciation for the three-dimensional anatomy of the entire spine, with the obvious lordotic curves in the cervical and lumbar regions and the thoracic kyphosis. However, quantification of the global spine anatomy was not described in detail (Table 1).

Over the past 25 years, a detailed anatomic description of the entire spine was introduced that includes descriptions of the spine with respect to the pelvis and the hip joints. A new parameter, termed 'sagittal balance', has arisen. With respect to the pelvis, the notion of pelvic incidence and sacral slope (Fig. 1) provided a succinct way to quantitatively describe the position of the pelvis as it relates to the hip joints and to the sacrum (Duval-Beaupère et al., 1992; Legaye et al., 1998; Jackson et al., 1998; Roussouly et al., 2011). This pelvic geometry is also important in positioning the whole spine since the pelvis serves as the foundation upon which

Table 1
Whole Spine summary. This table presents an overview of our past (up to 1990) and current (1990–2015) knowledge on the key topics related to the Whole Spine. Possible future research directions are noted in the right-hand column.

	Up to 1990	1990–2015	Looking towards the future
Whole Spine — anatomy	i. Basic anatomy of the whole spine (i.e. cervical and lumbar lordosis and thoracic kyphosis) ii. Little quantitative anatomical data	i. Anatomical relationship between the spine, pelvis, and hip joints and the 'Sagittal Balance' concept ii. Considerable quantitative anatomical data	i. Explore spino-pelvic relationships in terms of the fundamental biomechanical principles (motion, stability and mechanical loads) ii. Develop normative anatomic databases for the spino-pelvic anatomy, including diurnal variations iii. Consider other possible anatomic principles that explain spinal function
Whole Spine — system	i. The three basic goals of the whole spine (load bearing, motion, neural protection)	i. Spine Stabilizing System hypothesis	i. Spine Stabilizing System hypothesis needs to be addressed clinically ii. Alternative principles upon which the spine functions should be considered
Whole Spine— loading	i. Compressive forces in the lumbar spine ii. Cervical intradiscal pressures	i. Predictions of in vivo lumbar compressive and shear forces and bending moments from math models ii. Thoracic intradiscal pressures; no new cervical load data	i. Further description of lumbar shear, bending, and torsion loads ii. Additional data on thoracic and cervical loads iii. Loads at the junctional regions of the spine (e.g. cervico-thoracic, thoraco-lumbar)
Mechanical stability	i. Low mechanical stability of the spine	i. Key role of spinal musculature in maintaining spine stability	i. What clinical problems can be addressed with advanced math. models?