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Biomechanical simulations of scoliotic spine correction due to prone position and anaesthesia prior to surgical instrumentation

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Abstract

Background. The positioning of patients during scoliosis surgery has been shown to affect the scoliosis curve, yet positioning has not been exploited to help improve surgical outcome from a biomechanics point of view. Biomechanical models have been used to study other aspects of scoliosis. The goal of this study is to simulate the specific influence of the prone operative position and anaesthesia using a finite element model with patient personalized material properties.

Methods. A finite element model of the spine, ribcage and pelvis was created from the 3D standing geometry of two patients. To this model various positions were simulated. Initially the left and right supine pre-operative bending were simulated. Using a Box–Benkin experimental design the material properties of the intervertebral disks were personalized so that the bending simulations best matched the bending X-rays. The prone position was then simulated by applying the appropriate boundary conditions and gravity loads and the 3D geometry was compared to the X-rays taken intra-operatively. Finally an anaesthesia factor was added to the model to relax all the soft tissues.

Findings. The behaviour of the model improved for all three positions once the material properties were personalized. By incorporating an anaesthesia factor the results of the prone intra-operative simulation better matched the prone intra-operative X-ray. However, the anaesthesia factor was different for both patients. For the prone position simulation with anaesthesia patient 1 corrected from 62° to 47° and 43° to 31°. Patient 2 corrected from 70° to 55° and 40° to 32° for the thoracic and lumbar curves respectively.

Interpretation. Positioning of the patient, as well as anaesthesia, provide significant correction of the spinal deformity even before surgical instrumentation is fixed to the vertebra. The biomechanical effect of positioning should be taken into consideration by surgeons and possibly modify the support cushions accordingly to maximise 3D curve correction. The positioning is an important step that should not be overlooked by when simulating surgical correction and biomechanical models could be used to help determine optimal cushion placement.

Keywords: Scoliosis; Finite element modeling; Prone position; Surgery; Biomechanics

1. Introduction

Scoliosis is a three-dimensional (3D) deformity of the spine and trunk affecting between 1.5% and 3% of the population (Longstein, 1994). Scoliosis often occurs secondary to neuromuscular diseases but the most

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common type is adolescent idiopathic scoliosis and the cause is unknown. Although scoliosis is recognized as a 3D deformity, the gold standard for quantifying the curve is the Cobb angle of the spine measured on a two-dimensional radiograph (Cobb, 1948). For severe cases of scoliosis, where the Cobb angle is greater than 45°, surgical correction is often required to promote vertebral fusion and straighten and stabilise the curve. During a typical surgical procedure, the patient is anesthetized, placed prone on the operating table, an incision is made down the centre of their back, and instrumentation is fixed to the vertebrae straightening the curve. An average total correction in the Cobb angle of about 57% is obtained after surgery but over half of that total correction (37%) is due to the positioning and anaesthesia and the remaining correction is due to the instrumentation (Delorme et al., 2000).

The positioning of patients with scoliosis is a critical step in the surgical procedure. The fathers of the modern prone spinal frame are Relton and Hall (1967), whom emphases that the abdomen must remain free and pendulous during the surgery to minimize blood loss. Callahan and Brown (1981) described various positioning techniques for spinal surgery. They identified the three most important factors attributing to optimal position as stability of the spine, exposure required and physiological limitations. They recommended the Relton–Hall frame. Tables similar to the Relton–Hall frame are sometimes referred to as four post, chest roll, and the Jackson table (OSI, Union City, CA, USA).

The positioning of patients undergoing posterior spine surgery has been shown to have an effect on the sagittal alignment of the spine (Marsicano et al., 1998; Stephens et al., 1996; Tribus et al., 1999). It is important that normal standing lumbar lordosis is maintained after surgery. In general, a lordosis, similar to that found in standing, is maintained when the hips are flexed less then 30° (Peterson et al., 1995).

A few studies have shown that the spinal deformity can decrease prior to the insertion of posterior spinal instrumentation (Behairy et al., 2000; Delorme et al., 2000; Labelle et al., 1995). This improvement can be attributed to the prone positioning of the patients under anesthesia and surgical exposure. Other studies have shown that the trunk deformity of patients with adolescent idiopathic scoliosis can be altered while the patients are lying on the surgical table (Duke et al., 2002; Mac-Thiong et al., 2000). While the positioning of the patient is recognized as an important step in the surgery, it has not been exploited to help improve surgical correction from a biomechanics point of view.

Biomechanical models have been used to aid in the study of scoliosis biomechanics. In particular, models have been used to simulate the surgical instrumentation (Aubin et al., 2003; Gardner-Morse and Stokes, 1994; Ghista et al., 1988). Supine bending test X-rays aid in the assessment of patient flexibility, the selection of fusion levels, and are also useful in the prediction of surgical outcome. Recent studies have looked at personalizing the material properties based on the results of the bending test X-rays (Lafage et al., 2004; Petit et al., 2004). In all of these models, the effect of gravity on the positioning of the patient during surgery was not considered as an independent step. Stokes et al. (1999) noted that before biomechanical simulations can become a reliable tool to assist with pre-operative planning, the intra-op changes due to positioning and anaesthesia are some of the issues that must be addressed. A preliminary study showed that simulating the absence of gravity as a traction type load in the cranial direction is a first step in simulating scoliotic patients positioned on the operating table (Duke et al., 2004). This model was limited in that it did not simulate the anaesthesia.

The purpose of this study is to develop a biomechanical model that can simulate and analyse the specific influence of the prone operative position and anaesthesia on the correction observed prior to posterior scoliosis surgical instrumentation.

2. Methods

2.1. Patient description

Two adolescent idiopathic scoliosis (AIS) patients with different curve types were selected: one had a double, right thoracic, left lumbar, King II curve and the other had a single right thoracic curve, King III (King

Table 1
Clinical data for both patients

	Clinical information		Cobb angles (°)	Standing	Left bending	Right bending	Prone intra-op
Patient 1	Age	18	Proximal thoracic	45	22	42	*
	King curve type	II	Main thoracic	62	59	35	46
	Weight (kg)	58.6	Lumbar	43	11	42	27
Patient 2	Age	11	Proximal thoracic	39	11	33	25
	King curve type	III	Main thoracic	70	73	53	46
	Weight (kg)	36.8	Lumbar	40	16	33	21

* Data not available.