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Morphological parameters for implantation of the screwless spring loop dynamic posterior spinous process stabilizing system

Geun Soo Song[a], Yeon Soo Lee[b,*]

[a] Department of Biomedical Engineering, Graduate School, Catholic University of Daegu, Gyungbuk, South Korea
[b] Department of Biomedical Engineering, College of Medical Science, Catholic University of Daegu, Gyungbuk, South Korea

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ABSTRACT

Purpose: This study aimed to quantify morphological characteristics of the posterior lumbar spinous process, which may affect stable implantation of screwless wire spring loops.
Methods: Virtual implantations of a screwless wire spring loop onto pairs of lumbar spinous processes were performed for computed tomography (CT)-derived three-dimensional vertebral models of 40 Korean subjects. Morphological parameters of lumbar vertebrae 1 through 5 (L1–L5) were measured with regard to bone-implant interference.
Results: In males, the transspinous process fixation lengths decreased from 57.8 ± 3.0 mm to 48.8 ± 3.2 mm as the lumbar joints descend from L1–L2 to L4–L5, with those in females about 4.1 ± 0.4 mm shorter ($p < 0.05$) than in males through all lumbar joints. The fixation angle on the sagittal plane varied from 105.0° to 101.3° relative to the transverse plane as the vertebrae descend. The clenched thickness in females was the least (6.7 ± 1.2 mm) for the L2 lower spinous process and the greatest (8.1 ± 2.2 mm) for the L4 upper spinous process; this was 1.0 ± 10.3 mm less than that for males at corresponding levels ($p > 0.05$). The ratio of the spinous process clenched thickness to the transspinous fixation length increased from 0.133 ± 0.016 to 0.196 ± 0.076 for the upper spinous processes as the lumbar joints descend.
Conclusions: The ratio of the spinous process clenched thickness to the transspinous fixation length varies, depending on gender and whether the clenched level is the upper or lower spinous process. These parameters related to the clenching fixation stability should be considered in development and implantations of the screwless wire spring loop.

1. Introduction

Use of intervertebral stabilization systems for lumbar degenerative disk disease has rapidly increased (Barr et al., 1997; Chen et al., 2004; Erbulut et al., 2013; Kim et al., 2006; Picetti et al., 2001). In contrast to intervertebral immobility with rigid stabilization systems, dynamic systems permit both intervertebral flexibility and stabilization of the spinal column (Kim et al., 2006).

Pedicle screw-based systems are composed of pedicle screws and a structurally flexible component (Kim et al., 2006). Pedicle screw-based spring-type dynamic stabilization systems comprise pedicle screws and wire springs (Hellstrom et al., 2003; Zhang et al., 2009). Despite flexibility from the spring, implantation of pedicle screws into vertebrae still bears a risk of bone fracture due to improper placement of the implant. Using too large screws, malpositioning, or invasion of neighboring joints contribute to improper placement. A loop spring spinal fixation system comprising shape memory alloy was recently developed for use as a new dynamic posterior stabilization system. This addresses both psychological discomfort and intervertebral immobility (Kumar et al., 2001; Lee, 1988; Lehmann et al., 1987).

Proper implantation of the shape memory loop system into a lumbar joint requires that the size of the implant must enable sufficient gripping stability of the joined segments. At surgery, the shape memory spring implant is kept at 0 °C, just before implanatation. It can then be deformed easily using a clamp applied to the spinous process. Once the implant has reached body temperature, it reverts to its memory shape and tightens the linked spinous processes. Kim et al. (2012) reported 6-month short-term follow-up results for two types of nitinol memory loop systems in posterior cervical dynamic fixation (Kim et al., 2012). They used a length of memory loop

* Corresponding author at: Department of Biomedical Engineering, College of Medical Science, Catholic University of Daegu, 5 Geumrak St, Hayang-eup, Gyeongsan-SI, Gyeongbuk 712-702, South Korea. Tel.: +82 53 850 2514; fax: +82 53 850 3292; mobile: +82 10 6460 4021.
E-mail address: biomechanics.yslee@gmail.com (Y.S. Lee).

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Table 1
Nomenclature.

Object	Morphological or geometrical parameter	Acronym
Intervertebral disk	Anterior height of the intervertebral disk (in the sagittal view)	aIVDH
	Posterior height of the intervertebral disk (in the **s**agittal view)	pIVDH
	Intervertebral disk angle (in the sagittal view) (θ)	IVDA
Vertebral body	Superior vertebral endplate coordinate system	sECS
	Superior vertebral endplate length (in the sagittal view)	sEPL
	Inferior vertebral endplate length (in the sagittal view)	iEPL
Spinous process	Trans-spinous process length (in the sagittal view)	TSPL
	Trans-spinous process fixation length of an implant (in the sagittal view)	TSPFL
	Trans-spinous process fixation angle (in the sagittal view) (Φ)	TSPFA
	Clenched thickness of the upper posterior spinous process among a pair (in the coronal view)	uSPCT
	Clenched thickness of the lower posterior spinous process among a pair (in the coronal view)	lSPCT

shorter than the measured distance between the C1 ring and the C2 ring lamina, enabling the grafted material and posterior C1–C2 ring to remain tightly bound when the loop reverted to its original shape. However, the loop length required to provide sufficient surgical stability is unknown. The C1–C2 joint has no intervertebral disk and is more stable than lumbar joints. A dynamic screwless loop system for lumbar joints should be designed to ensure good initial stability as well as near-natural flexibility. To the best of the authors' knowledge, there has been no clinical follow-up report on the screwless dynamic loop system, the development of which is still in its infancy.

When paired posterior spinous processes are clenched with a wire loop, stability depends both on morphological parameters of the lumbar and fixation mechanism of the spring wire loop. There is insufficient anatomical data for Korean and Asian populations on posterior lumbar morphological parameters. In the Korean market, various stabilizing systems for degenerated lumbar disk have been developed. Anatomical information on the lumbar joint is necessary for development of a spring-type dynamic spinous process stabilizer for use in other Asians.

The objective of the present study was to measure lumbar anatomical parameters that could affect the implantation stabilization of a screwless shape memory wire spring loop.

2. Materials and methods

Abbreviations for complex terms are listed in Table 1.

2.1. 3D model reconstruction

Three-dimensional (3D) models of the lumbar vertebrae (L1-L5) were reconstructed from computed tomography (CT) images of 40 Korean subjects (20 males and 20 females) with a mean age of 38.7 ± 15.8 year (range, male 17–66, female 18–68). The source was a CT database at the author's affiliated university hospital. Even though CT images were from patients with spine-related diseases, morphological data were only obtained from healthy lumbar joint components which do not show any morphological abnormality with stenosis or fracture. CT data were loaded onto Mimics 15.01 software (Materialize, Leuven, Belgium); i.e. a medical imaging system, with patient names removed. Only gender and age were used for the study. The institutional board of research at the author's hospital approved the data acquisition process as ethically acceptable. The original CT images had a slice thickness of 1.00, 1.25, or 1.50 mm. 3D models were reconstructed using Mimics 15.01 software.

2.2. Superior vertebral endplate coordinate system (sECS)

3D lumbar morphological parameters were measured using Rapidform 2006 (INUS Technology, Seoul, Republic of Korea). To ensure reproducibility, the sECS was fixated on the superior intervertebral endplate (Fig. 1). A coordinate system comprises an origin and two mutually perpendicular axes passing through the origin, with the third axis determined mathematically. The origin of sECS specified as the center of a circle constructed by Rapidform's reference geometry creation function, which statistically and mathematically builds a circle based on digitized points *Pi*. The circle represents the XY plane of the sECS. The X axis is defined as the vector extending from the origin to the superior bulge of the posterior process; the Y axis is the vector extending from the origin and perpendicular to the X axis on the plane of the circle.

2.3. Anatomic intrinsic parameters

Dimensions based on vertebral anatomy, rather than implantation choice, are anatomic intrinsic morphological parameters. Intervertebral disk parameters were indirectly measured using endplate 3D bone models; i.e. not measuring intervertebral disk cartilage. Indirect measurement is reasonable since vertebral bodies and intervertebral discs are in perfect contact.

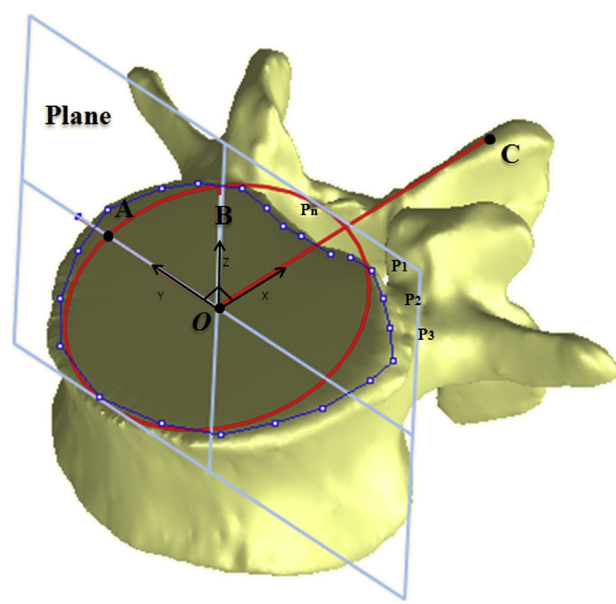

Fig. 1. Superior vertebral endplate coordinate system. The Origin (*O*) of the coordinate system was indicated as the center of a circle which was mathematically determined by $P_1, P_2, P_3 \ldots, P_n$ on the upper end-plate. The X-coordinate was specified on the vector staring from *O* to the point C which is the superior-most point of the spinous process. The Y-coordinate was specified as the vector directing to the point A from *O*. The point *A* is determined as the intersection between the circle on the upper endplate and the perpendicular plane to the X-coordinate. The Z-coordinate was numerically defined by the vector cross-product of the X-coordinate and Y-coordinate.