A Voxel-Based 2D/3D Registration Method for In Vivo 3D Cervical Spine Kinematics Using Bi-planar Fluoroscopy

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摘要

頸椎骨在屈曲-後仰時之運動學在過去透過二維Ｘ光技術被廣泛研究，並且已被使用在臨床診斷上。然而在缺乏三維動態運動學資訊的情況之下，在臨床上分辨正常人與病人之間運動學差異時的資訊將會受到限制。因此本研究的目的為運用以立體像素骨模型為基底的二維/三維影像契合技術來量測活體三維頸關節運動學。此為首篇描述活體頸椎骨在屈曲-後仰時各關節貢獻度的變化與螺旋軸分析並將之量化的報告，各關節極限角度的結果也與過去二維分析的文獻相符合。本研究運用此創新方法量測活體三維頸椎骨在屈曲-後仰時之運動學，將有助於提升臨床上診斷與術後評估之相關運用。

INTRODUCTION

The intervertebral motion of cervical spine on sagittal plane during flexion-extension had been investigated mainly using lateral radiography[1, 2]. The patterns of flexion-extension coupled anterior-posterior translation could be revealed efficiently and accurately. The significant contribution of these measurements was improving the clinical diagnosis through quantifying the kinematic differences between normal and abnormal cervical spines[3]. However, the absence of the information about the ranges of rotations and translations in another two planes would restrict the recognition for unstable cervical spine, and the screw axes of spine motion also cannot be evaluated from two-dimensional (2D) analysis. Therefore, for the purpose of realizing three-dimensional (3D) dynamic kinematics of cervical spine, we have developed a new voxel-based 2D/3D registration method for skeletal system[4]. The aim of this study was to further apply this new method to reveal the human 3D subaxial cervical spine kinematics during flexion-extension.

MATERIALS AND METHODS

*S*ix volunteer healthy subjects with no any neuro-muskulo-skeletal system disease of neck and shoulder were recruited in this study. Each subject received a computed tomography (CT, Imatron Model C-150L, USA) scan from clavicle to C1 vertebra. The bony part of CT data comprised C3-C7 were then divided from spinal column into individual vertebra respectively as an individual volumetric model. These subject-specific models comprise the external surface model for operating an initial pose in the GUI environment as shown in Figure1, and internal voxel information for rendering digital reconstructed radiography (DRR)[5]. Each subject also sat on the chair at upright position and performed active flexion-extension in the intersect region of bi-planar fluoroscopy (Angiography, AXION Artis, Floor Stand dFC, Siemens, Germany) to get the 2D dynamic motion of cervical spinal column.

3D voxel-based models then precisely registered to the 2D fluoroscopic images using a self developed voxel-based 2D/3D registration method. Through this method, the 3D poses of each C3 to C7 vertebrae at each fluoroscopic image frame were obtained by searching the 6DOFs poses of each vertebra model by an optimization procedure. The algorithm is based on the digital reconstructed radiography (DRR) of bone models best matched the fluoroscopic image according to a similarity measurement.

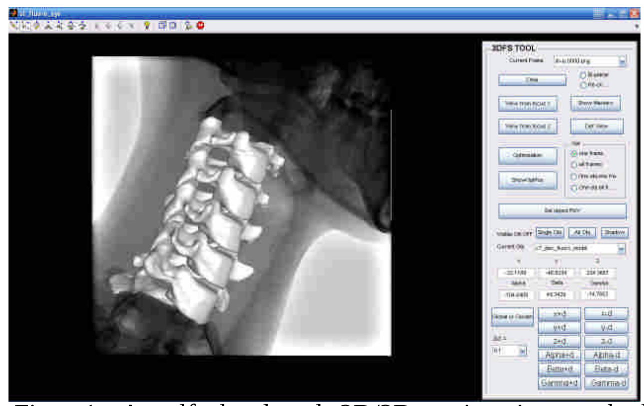


Figure1. A self developed 2D/3D registration method using computer graphics user interface (GUI) program to assist the visualization of the registration and reconstruction of the 3D bone kinematics.

The poses of each vertebra through optimization procedure were used to calculate the 3D joint kinematics. Joint angles of cervical spine were described as the relative rotation between the local coordinate system of adjacent levels such as C3-C4, C4-C5 etc. In order to correspond with clinical definition, the joint angles of each level at the neutral position were defined as zero degree. The Euler angles were obtained using the sequence Z-Y-X. Means and standard deviations for the range of motion and dynamic intervertebral motion of each level during flexion-extension were computed.

Screw axes analysis is another approach to describe the rigid body motion. Since the movement of the rigid body between two subsequent positions could be regard as a screw motion, the motion can be described through a spatial axis that the rotation occurred around this axis and translation generated along it. The finite screw axis in this study was calculated between two rotations that the increment is equal to 2° in flexion-extension, and the next screw axis was calculated at the increment angle equal to 1° relative to the last instant. The non-adjacent sequential pairs of vertebra position could display the continuous finite screw axis during flexion-extension.

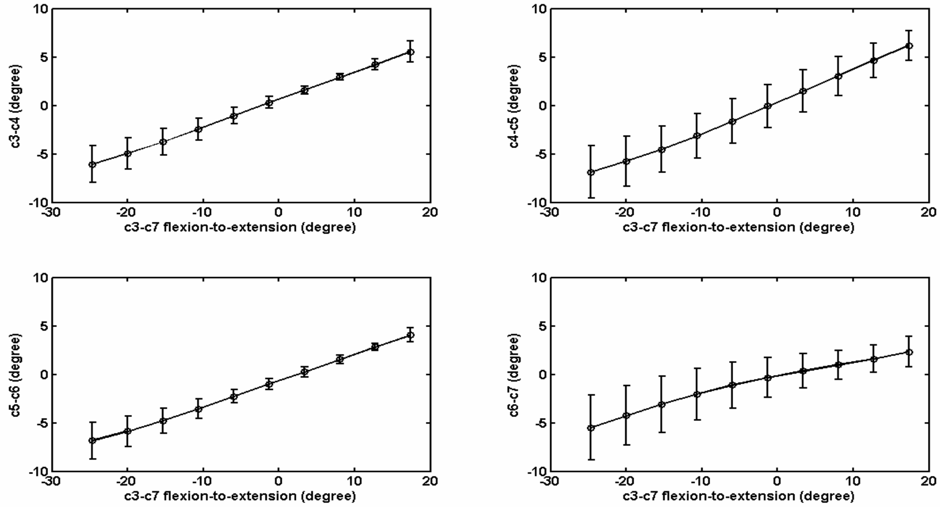
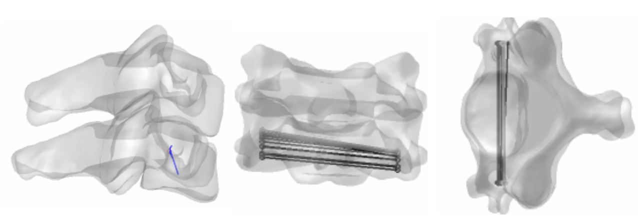


Figure2. The angle contribution of each cervical spine segment during flexion-extension

RESULTS

The *in vivo* three-dimensional intervertebral motions of cervical spine during flexion-extension were evaluated. The means and standard deviations of ROM of cervical spine during flexion-extension were 12.6(±2.3)˚ at C3-C4, 16.3(±3.8)˚ at C4-C5, 14.5(±5.0) ˚ at C5-C6, and 12(±5.0) ˚ at C6-C7. The continuous angle contribution of each segment during flexion to extension was also shown in Figure 2.

Finite screw axes were computed during flexion-extension. Figure 3 shows the result of one normal subject at C4-C5 level in three anatomy planes. Figure 3.(a) shows the projected center of rotation in mid-plan of cervical vertebra. Figure3. (b) and (c) show the screw axes in frontal view and transverse view, respectively.



(a) (b) (c)

Figure3. Center of rotation in (a) sagittal plane and finite screw axes in (b) frontal plane (c) transverse plane

DISCUSSION

The current study provides a dynamic and 3D approach to measure the intervertebral motion of cervical spine. The result of ROM was agreed with previous 2D analysis studies, the contributions of C4-C5 and C5-C6 were larger than the C3-C4 and C6-C7 levels. The results of continuous intervertebral motion revealed the role of each level at different flexion and extension poses, Figure 2. The finite screw axis is another approach to describe the cervical spine motion directly and visually. From the result of Figure 3, each screw axis was nearly parallel each other and perpendicular to the sagittal plane. It meant that the couple rotation of the other two planes is unremarkable for normal cervical spine during flexion-extension. The distribution of center of rotation was mainly located on the vertebral body, which agrees with previous 2D studies. However, the locations of center of rotation were not fixed during motion; it meant that the ratio of rotation around transverse axis and anterior-posterior translation was not a constant during flexion to extension.

Other than the rotation in sagittal plane, anterior-posterior translation and 2D analysis for center of rotation, screw axes can be used in describing the 3D motion directly to distinguish the normal and abnormal pattern of intervertebral motion. It may be able to provide a new approach to improve the clinical application such as diagnosis and treatment for cervical spine pathology.

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