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Morphology-based realization of a rapid scoliosis correction simulation system

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ABSTRACT

Objective: Scoliosis is a complex spinal deformity in 3D space that commonly occurs in teenagers, especially teenage girls, and judging the actual deformed spine situation using only CT images is difficult. However, using 3D finite element models to help doctors analyse the deformed spine is also time-consuming and laborious. Therefore, software that can quickly and easily perform scoliosis correction analysis is needed. To achieve rapid preoperative simulation of scoliosis correction in 3D space and help doctors construct surgical programmes faster, a morphology-based system was developed for simulating scoliosis correction performance.

Methods: The simulation system first takes advantage of the centre point of each vertebra on the entire spine model to fit a space curve. Then the system obtains information from the models and the space curve, and finally, uses the information to simulate scoliosis correction. The deformed spine model in the system can be corrected to a better state.

Results: During the simulation process, doctors can easily and clearly see how the vertebral models move, and the deformed spine parameters are also updated and shown. Using this system, doctors can easily simulate scoliosis correction according to their experience and quickly construct a surgical programme.

Conclusions: The experimental results show that this system is capable of simulating scoliosis correction according to a doctor's own experience to speed up the operation and provides a scientific basis for the development of surgical programmes.

1. Introduction

Scoliosis is a common orthopaedic disease that occurs frequently in adolescents [1]. Minor scoliosis affects physical coordination and aesthetics, while serious scoliosis affects the growth and development of infants and young children, resulting in bodily deformation. Serious scoliosis even affects heart and lung functions, resulting in serious consequences [2]. For scoliosis corrections, mild scoliosis (Cobb angle less than 25°) should be observed and corrected using external orthosis, while severe scoliosis (Cobb angle greater than 25°) requires surgical treatment, which usually has high risks. To diminish the risks as much as possible, doctors need to observe and analyse the shape of the patient's spinal cord in advance, obtain essential parameters, such as the Cobb angle, correctly determine the type of spinal deformity, and finally, construct a reasonable operation programme. Because a standard set of rules has not yet been established in the field of surgical scoliosis correction, most doctors must construct an operation plan and produce an orthopaedic bent bar on the basis of spinal parameters and their own experience [3]. However, during the actual operation, doctors typically must temporarily adjust the bent bar shape and the operation plan, undoubtedly wasting operation time and increasing the patient's surgical risk. Currently, with the development of medical imaging technology [4, 5], diagnosing and characterizing these spinal lesions mostly relies on medical imaging, and computed tomography (CT) is a first-line imaging procedure [6]. Doctors mostly observe and execute measurements on 2D CT images [7], which is time-consuming, and single slices of CT images limits the field of view. But scoliosis is actually a spinal deformity in 3D space [8], so 2D images cannot provide a visual impression of the spine, potentially affecting the doctor's accurate judgement of the situation.

Although software capable of reconstructing 3D models of the spine that allows the spine to be visualized in an intuitive way is available [9], these models reconstructed from CT images are mostly of the entire spine, which can be used for only some basic observations and measurements and cannot be adjusted at will. Furthermore, some software

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Nomenclature

OCA	original center point array
UCA	updated center point array
OP	original point
PT	point
ODA	original distance array
UDA	updated distance array
PVA	previous vector array
CVA	current vector array

operation processes are complicated and difficult, which is not suitable for making rapid, personalized analysis. Thus, herein, we developed a simulation system based on spatial curve construction that can rapidly simulate scoliosis correction using a sequence of vertebral models of a patient and assist doctors in effective surgical planning in advance.

This system utilizes a sequence of single vertebral models segmented from the whole spine model which is reconstructed from a patient's CT images to simulate the morphological process of scoliosis correction. The model segmentation is implemented with the bounding box by our partners, and we will not make more explanation in this paper. This system aims to provide quick and intuitive simulations of scoliosis correction surgery in 3D space. It allows doctors to observe the effects of surgery in advance and obtain the corresponding parameter changes (such as the Cobb angle) so that they can make operation plans according to simulation results from this system and construct the spinal orthopaedic bent bar in advance. Simulation results are proven to effectively assist doctors in performing corrective surgery.

2. Methods

2.1. Brief introduction to the system

The human spine is composed of 26 vertebrae, inter-vertebral discs and ligaments that are connected to each other, and there is a narrow spinal canal in the middle that contains the spinal cord [10]. Therefore, this system regards the spine as a smooth curve in 3D space [11], since scoliosis is a disease of the spinal deformity in three-dimensional space which mainly affects the spinal curve on the coronal plane, the curve will be straightened as much as possible in the correction process to achieve a perfect correction effect on the coronal plane.

In the process of scoliosis correction simulation, vertebral models extracted from the whole-spine model beforehand will be scanned into the system and ranked according to the Z axis value of each model's centre. Since the spine in 3D space can approximately be regarded as a curve, the correction should conform to the shape of the curve. After the models are scanned into the system, the centre of the spine model is used

Algorithm 1: Obtain Points From Models

Input: Vertebral Models

Output: Array **OriginalCentre**, Array **UpdatedCentre** & Point **OriginalPoint**

Process:

```
n= NumberOfVertebrae
OriginalPoint= {0,0,0}
for i = 1 to n:
    Get OriginalCentre[i] From ith Model;
    Set UpdatedCentre[i] To the Value of OriginalCentre[i];
    If  OriginalPoint.Z < OriginalCentre[i].Z Then
        OriginalPoint= OriginalCentre[i];
    end if
end for
```

Parameter Values

Number Of Models: Number of vertebral models

OriginalPoint: A point that stands for point ***OP***

OriginalCentre[]: An array that stands for the above array ***OCA***

UpdatedCentre[]: An array that stands for the above array ***UCA***