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Application of finite element analysis in diagnosis and treatment of cervical spondylosis

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Abstract: Different types of cervical spondylosis have different clinical symptoms and treatment methods, finite element analysis can simulate the structure of the cervical spine in different types of cervical spondylosis pathological state, so as to study the pathogenesis of the cervical spine and the cone disc force, finite element analysis provides an ideal platform for us to study the etiology and mechanism of cervical spondylosis as well as the diagnosis and treatment of rehabilitation. In this paper, we have made a systematic discussion on the current application of the finite element analysis in different types of cervical spondylosis with a more objective attitude, hoping to make corresponding contributions to the future research.

1. Introduction

The cervical spine is the most fragile nerve centre "corridor" in the human body, as a pivotal structure connecting the human body's head and trunk, its activity is significantly greater than the thoracic spine, lumbar spine, but it is fragile and vulnerable to injury. In recent years, with the development of the Internet and the application and popularity of electronic products, people overuse electronic products, especially mobile phones and computers, etc., the fragile cervical spine has been further damaged, and cervical spondylosis has also become one of the most prevalent and most disturbing diseases. Due to the complex structure of the cervical spine and its proximity to a variety of important tissues, research on the cervical spine has always been a focus of attention. The finite element method, also known as finite element method (FEM), is a technique used to solve systems of differential or integral equations[1]. In short, it is an analytical method in which complex problems are simplified and then solved. Technological progress has led to the presentation of various types of biomechanical models with the aid of computers, and the finite element model has evolved from the initial two-dimensional model to a more elaborate network construction, and then to the present-day multi-segment cervical spine model[2]. With its introduction into medicine, finite element analysis has an irreplaceable role in the treatment research of cervical spondylosis. By reviewing a large amount of related literature, the authors provide a comprehensive review on the application of common finite element analysis in cervical spondylosis.

2. Current status of cervical spondylosis

Cervical spondylosis (CS), excessive flexion and extension of the cervical spine, the muscles, ligaments and nerves of the neck are compressed and discomfort symptoms such as pain, numbness and limited movement of the neck occur, with the modern lifestyle changes its incidence rate increases year by year while the age of onset gradually decreases[3]. Cervical spondylosis can be divided into cervical, nerve root, spinal cord, sympathetic and vertebral artery types according to the clinical symptoms and the site of lesion involvement, and if two or more types exist at the same time, it is called mixed cervical spondylosis[4]. Currently, the treatments for cervical spondylosis are basically divided into conservative treatment and surgical therapy. Non-surgical means of treatment for cervical spondylosis can effectively relieve patients' pain[5]. Because of the disadvantages of surgical treatment, such as high risk, many complications, traumatic and slower recovery in the later stage, more than 95% of the treatment is still based on conservative non-surgical methods[6]. Conservative treatment includes acupuncture treatment, massage treatment, functional exercise, neck traction treatment, etc. Although the methods are diverse, the results are variable and often prone to recurrence. Because there is no uniform operation norms and standards, there are often cases of exacerbation due to improper operation[7]. Therefore, the establishment of an accurate finite element model of the cervical spine provides us with a visual standard and norms in the process of conservative treatment of cervical spondylosis, so that the effect of conservative treatment of cervical spondylosis has been significantly improved.

3. Development of finite element analysis of the cervical spine

The development of 3D finite element modelling of the cervical spine is relatively recent, with relevant cervical spine models only being available in the early 1990s[8]. The first finite element model of the whole cervical spine was established in 1993 by Kleinberger et al. Although the outline of the model was very simplified and the overall model was very rough, it was a new breakthrough in finite element technology in the field of spine[9]. Since then, finite element models of the cervical spine have been developed as a result of the development of the cervical spine. Zhang Mingcai[10], Huang Zuhe[11]and other successive use of spiral CT to establish a three-dimensional finite element model of the cervical spine, and the anatomical form of the cervical spine has a high degree of similarity, and through a series of validation of the model has a high degree of biological fidelity, the ability to simulate the human cervical vertebrae in reality, the force situation and activity detection. The development of the cervical spine finite element model has evolved from a two-dimensional linear model to a three-dimensional linear model, and from a purely bony cervical spine finite element model to a cervical spine finite element model with ligaments and muscle tissues[12][13]. At present, more and more researchers have become skilled in the application of finite element analysis, and the cervical spine finite element model has been perfected over and over again, and is constantly moving forward in the direction of perfect simulation of the human cervical spine.

4. Application of finite element analysis in the treatment of different types of cervical spondylosis

4.1 Application of finite element analysis in the treatment of neurogenic cervical spondylosis

Cervical spondylotic radiculopathy (CSR) is caused by posterior lateral herniation of intervertebral discs or narrowing of the intervertebral foramina that squeezes the nerve roots, and the inflammatory reaction of the nerve roots can also cause the main symptoms of cervical spondylosis such as radiating pain and numbness in the neck and shoulders and the affected side of the upper limbs. CSR accounts for approximately 60-70% of the total incidence of cervical spondylosis[14]and is the most prevalent type of cervical spondylosis. With the development of computers, finite element analysis plays an irreplaceable role in the treatment of CSR. Sun and Shi Bin established a three-dimensional finite element model of CSR through 64-slice spiral CT scanning, and then used gesture motion capture technology to standardise the precise treatment for different patients, obtaining good therapeutic effects, so that the precise treatment of traditional Chinese medicine (TCM) can achieve an objective transformation from basic research to clinical treatment, and promote the development of TCM orthopaedic technology towards internationalisation[15]. In addition, the C3 ~ C7 finite element model established by Shengnan Cao and Bin Shi not only realistically simulated the geometry and material properties of the cervical spine in CSR, but also accurately reflected the biomechanical properties of the cervical spine in CSR patients, which provided a direct visual observation and basic research on the management of CSR by TuiNa manipulation, and was of great significance for the mechanical analysis of cervical vertebrae and manipulative treatment[16]. For further exploration, Cao Shengnan and Wang Dandan verified the intrinsic mechanism of CSR treatment by establishing a three-dimensional finite element model of a patient with CSR at the C3 to C7 segments, proving that the therapeutic effect of "three-dimensional balanced chiropractic manipulation" is safe, reliable, and effective, which reduces the incidence of medical malpractice[6]. qiang ye et al. found through finite element modelling analysis that the choice or position of cervical motion for diagnosis and treatment has guiding significance for CSR accompanied by posterior-lateral disc herniation, and at the same time the increase in the magnitude of deformation of the posterior-lateral annulus fibrosus on the side of disc herniation may also be the reason for the dynamic impingement on the nerve root of CSR accompanied by the posterior-lateral herniation of the disc, which has made the finite element analysis on the treatment of in the cervical spondylosis to rise to a new level[17].

4.2 Application of finite element analysis in the treatment of vertebral artery cervical spondylosis

Cervical spondylosis of vertebral artery type (CSA) refers to the insufficient blood supply of vertebrobasilar artery due to various factors such as cervical spine degeneration, intervertebral instability, and other factors, which caused by the vertebral artery mechanically or dynamically, resulting in a series of clinical symptoms, such as sudden collapse, vertigo, etc., which adversely affects the daily life of patients[18], and accounts for about 15% to 20% of the total incidence[19]. Yin Hao proved the mechanism of action of traction in treating CSA by establishing a finite element model and proposed a reasonable way of traction, and the finite element analysis provided a theoretical basis for clinical prevention and treatment to a certain extent, although it could not completely replace the clinical experiment[20]. Huang Zuhe and Xu Zhibin established a three-dimensional finite element model of the cervical segment of the spine, which can observe the bony structures such as intervertebral discs, hooked vertebral joints, and intervertebral foramina from multiple perspectives, and clearly observe the distribution of the effect force in the anterior-flexion and posterior-extension states, and clearly show the complex anatomical structure of the vertebral body of CSA, with strong practicability and high precision, providing a strong basis for the development of clinical research[21].

4.3 Application of finite element analysis in the treatment of cervical cervical spondylosis

Cervical spondylosis (cervical spondylosis), mainly due to long-term strain of the cervical spine, various loads, etc., resulting in tension and spasm of the neck muscles, intervertebral structural instability, resulting in stiffness and pain in the back and shoulders, or dizziness, numbness of the limbs, limited neck movement and a series of clinical symptoms[22]. Cervical cervical spondylosis is the most common among all types of cervical spondylosis, and it is the earliest and most basic type of cervical spondylosis, and other types of cervical spondylosis mostly develop on the basis of this type of cervical spondylosis[23]. Cervical cervical spondylosis is usually treated by non-surgical treatments such as acupuncture and massage, neck exercises, and bone setting in traditional Chinese medicine, so there are few finite element analyses of cervical cervical spondylosis. Dongxin Lin et al. established and validated a detailed finite element model of the entire cervical spine, including the spinal nerve roots, and simulated the key steps of two different cervical rotational manipulation techniques to explore the biomechanical mechanism of the surgery, concluding that the oblique wrenching technique may be more suitable for the treatment of radiculopathy, while cervical rotational traction is more suitable for the treatment of cervical cervical spondylosis, and proposing a more precise method of manipulation for the treatment of cervical spondylosis[24].In addition, Li Zhirong etal[25] established a finite element model combined with the functional exercise of the Southern Shaolin Yi Jin Jing Totian Style, and found that patients with cervical spondylosis could obtain a better near-term therapeutic effect, and that the exercise could reduce the pain and enhance the function of the cervical spine, which found a more reasonable approach to the functional exercise of cervical spondylosis. In addition, the researchers applied finite element analysis to a model of cervical cervical spondylosis to validate their ideas. This provides an objective and effective method to explore the etiology of cervical spondylosis and fills a gap in this field.

4.4 Application of finite element analysis in the treatment of spinal cervical spondylosis

Cervical spondylotic myelopathy (CSM), a type of cervical spondylosis caused by cervical spine degeneration, is a disease of the cervical spine that compresses the spinal cord or nerve roots and impedes blood return, accounting for 10-15% of cervical spondylosis[26]. If there is no contraindication to surgery, surgery is usually carried out as early as possible after diagnosis to relieve the compressed nerves and spinal cord, restore segmental stability as well as normal cervical physiological curvature, and avoid further aggravation of spinal cord injury[27]. Tan Bei et al. found that CSM patients may have changes in the mechanical balance of the cervical vertebrae, intervertebral discs and ligaments as well as limited cervical spine range of motion through the establishment of a three-dimensional finite element model, however, these changes may be highly correlated with the mechanical pathogenesis of CSM, which provides scholars with a new direction and ideas for the study of CSM[28]. Meanwhile, Liu Jinyu et al. simulated the normal physiological motion of the human body by establishing a finite element model of the cervical spine and analysed the reliability of minimally invasive surgery for spinal cord-type cervical spondylosis by using the obtained data, which, although there is a certain gap with the actual human body's motion, can still provide a theoretical basis for the improvement of surgical techniques in the future[29].

5. Conclusions

Since the 1980s, finite element analysis has been applied to the study of cervical spine[30] and lumbar spine[31], and after more than 40 years of development, finite element analysis has an irreplaceable role in our study of cervical spine and lumbar spine. Finite element method analysis has an irreplaceable role in diagnosing the etiology and pathogenesis of cervical spondylosis and studying its pathogenesis with current instruments, especially in guiding the treatment and rehabilitation of various types of cervical spondylosis, which can be differentiated according to the individual and achieve precise treatment. Although finite element analysis is still insufficient in facing individual differences and soft tissues of the cervical spine, the flaws do not hide the weaknesses[32]. The finite element model of the cervical spine provides an ideal platform for us to gain an in-depth understanding of the biomechanical mechanisms of the cervical spine and its related diseases, to analyse the biomechanics of cervical spondylosis treated by Chinese medicine manipulation, and to study the application of finite element models in clinical surgery. We should strive to overcome the human body variability of finite element simulation and use it as an analytical tool to assist us in diagnosis and treatment in preoperative simulation, intraoperative observation, and postoperative rehabilitation. With the development of science and technology, finite element data acquisition will be more accurate and the model will be more precise. As an analytical tool, we still need to combine with clinical practice to make better and correct diagnosis and treatment.

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