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Research Progress of Paraspinal Muscle Fat Infiltration in Osteoporotic Vertebral Compression Fractures

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Abstract: *The paraspinal muscle fat infiltration and osteoporotic vertebral compression fractures (OVCFs) are common degenerative diseases of the skeletal muscle system in the elderly population, which seriously affect the quality of life. In recent years, many studies have focused on the relationship between paraspinal muscle fat infiltration and common lumbar diseases. However, the impact of this extrinsic factor on the progression of OVCFs has not yet received sufficient attention in clinical practice. This article summarizes the imaging characteristics and clinical relevance of paraspinal muscle fat infiltration in OVCFs, aiming to provide some ideas for the prevention, treatment, and related research of OVCFs and paraspinal muscle fat infiltration.*

Keywords: *Paraspinal Muscles, Fat Infiltration, Osteoporotic Vertebral Compression Fractures*

1. Introduction

Spinal osteoporotic vertebral compression fractures (OVCFs) are currently the most common type of spinal fractures in clinical practice, and also the most common complication secondary to osteoporosis [1]. With the aging population in China and even the world, the prevention and treatment of osteoporotic fragility fractures are becoming increasingly important [2]. The pain and activity limitations caused by OVCFs often lead to long-term bed rest for a large proportion of patients, resulting in degenerative changes in the paraspinal muscles and seriously affecting the quality of life of middle-aged and elderly people [3]. The main manifestation of paraspinal muscle degeneration is an increase in fat content, which often leads to decreased spinal stability and increased segmental load, thereby increasing the incidence of osteoporotic fractures [4]. Currently, there is a lack of systematic reviews on the correlation between paraspinal muscle fat infiltration and OVCFs. This article reviews the literature on the clinical and basic research progress related to paraspinal muscle fat infiltration and OVCFs. With the aim of providing references for the treatment of OVCFs and exploring the pathological mechanism of fat infiltration for basic research.

2. Characteristics of Paraspinal Muscle Fat Infiltration Based on Imaging

2.1. The Anatomical and Physiological Characteristics of Paraspinal Muscles

The paraspinal muscles are a general term for multiple muscle groups that are symmetrically distributed around the spine. As an important anatomical structure for spine stability, the occurrence and development of fat infiltration are closely related to its morphological function and functional changes. In human anatomy, it is divided into anterior and posterior groups. The anterior group mainly refers to the quadratus lumborum, psoas major, and psoas minor, while the posterior group mainly refers to the erector spinae, rotatores, multifidus, semispinalis, and intertransversarii [5]. Due to differences in fiber structure, direction, and nerve regulation between the anterior and posterior muscle groups, the posterior group of paraspinal muscles plays a major role in the occurrence and development of most lumbar degenerative diseases [6]. Currently, the most studied fat infiltration is in the multifidus and erector spinae [7]. The multifidus is the muscle closest to the midline, originating from the dorsal surface of the sacrum, transverse processes of the thoracic and lumbar vertebrae, and the articular processes of the cervical vertebrae. It inserts into the spinous processes of the cervical vertebrae to the lumbar vertebrae. Its main functions are divided into two parts: the deep layer maintains lumbar stability, while the superficial layer participates in lumbar rotation and maintains the physiological lordosis of the lumbar spine [8]. The erector spinae is composed of the spinocorrector, longissimus, and iliocostalis. The spinocorrector originates from the spinous processes of the third lumbar vertebra to the tenth thoracic vertebrae, while the others originate from the dorsal surface of the sacrum, spinous processes, and thoracolumbar fascia. They insert into the ribs and terminate on the transverse processes of the thoracic vertebrae, spinous processes, and mastoid process of the temporal bone [9]. When one side of the erector spinae contracts, the spine flexes sideways, and when both sides contract, it extends back. The erector spinae cooperates with the multifidus to counteract the flexion effect produced by abdominal muscles during trunk rotation. Studies have shown that [10,11], changes in the structure and function of paraspinal muscles are often caused by fat infiltration and atrophy. The degree of fat infiltration in paraspinal muscles is often higher than that in lower extremity muscles, and the degree of fat infiltration in lumbar segments is often higher than that in cervical and thoracic segments. These structural changes can easily lead to low back pain and dysfunctional back pain [12]. In patients with osteoporosis, fat infiltration in paraspinal muscles can even lead to vertebral fractures.

2.2. Fat infiltration of paraspinal muscles

Muscle fat infiltration mainly refers to the abnormal increase of lipid components within the muscle, with adipose tissue replacing the original muscle tissue [13]. It mainly includes two aspects. On the one hand, it is the accumulation of intracellular lipid of muscle cells, which may be related to insulin insensitivity, inflammation and muscle dysfunction in skeletal muscle. On the other hand, it is the increase and accumulation of adipose cells between muscle groups. It may be related to the differentiation of satellite cells, differentiation of fibroblast progenitor cells, leptin or leptin receptor deficiency, etc [14]. Some studies have found that [15], in the process of gradually increasing the degree of fat infiltration, paraspinal muscle fat infiltration occurs earlier in time than the changes observed by morphology. Reiter studied the relationship between energy metabolism and body composition of skeletal muscle in healthy adults and believed that muscle fat infiltration not only leads to a decrease in muscle strength and endurance, but also causes muscles to lose elasticity and repairability [16]. A large number of studies have shown that [17-19] paraspinal muscle fat infiltration is common in elderly people, especially in elderly patients with spinal degenerative changes. Paraspinal muscle fat infiltration not only leads to damage of paraspinal muscle strength and decreased spinal stability, affecting the normal physiological function of whole body movement, but also increases the failure rate of spine surgery and affects the effect of postoperative rehabilitation and extends the recovery time under severe infiltration of adipose tissue [10,20]. In addition, spinal morphology may also undergo corresponding changes. Some studies have shown that [21,22], when the degree of degenerative changes in bilateral paraspinal muscles is unequal, the bilateral lumbar forces cannot achieve balance, leading to the occurrence of scoliosis.

2.3. Assessment of fat infiltration in paraspinal muscles

Due to the convenience and practical limitations of various technologies in clinical applications, a gold standard for quantitative detection of muscle fat infiltration has not yet been established. The existing quantitative methods for intramuscular fat mainly include quantitative CT, MRI, and ultrasound. Commonly used indicators for the assessment of paraspinal muscle fat infiltration mainly include cross-sectional area, muscle density, and fat content [23].

The reduction in cross-sectional area is a relatively intuitive morphological change in paraspinal muscle atrophy [15]. Cross-sectional area can be divided into total cross-sectional area, functional cross-sectional area, and fat cross-sectional area depending on the measurement object. Total cross-sectional area refers to the total area within the fascia, including both muscle and fat, while functional cross-sectional area and fat cross-sectional area represent pure muscle area and pure fat area, respectively [24]. In many studies, the degree of fat infiltration in paraspinal muscles is represented by the ratio of fat cross-sectional area to total cross-sectional area. However, most studies mainly use manual delineation and automatic segmentation methods to draw the region of interest (ROI) for muscle groups during measurement. This delineation method has a certain degree of subjectivity and may affect the evaluation results. There is research suggesting that the functional cross-sectional area of paraspinal muscles can effectively predict the occurrence of osteoporotic vertebral compression fractures, and early exercise of paraspinal muscles can reduce the incidence of osteoporotic vertebral compression fractures [25].

Some scholars believe [26] that compared to muscle cross-sectional area, using muscle density as a surrogate indicator of muscle quality may have more clinical significance. Muscle density is usually assessed by CT value, with normal muscle tissue having a CT value of approximately 35-50HU. The distinction between various tissues depends on their respective X-ray attenuation coefficient differences, and the higher the degree of fat infiltration, the lower the CT value. However, normal and abnormal values cannot be uniformly compared between different studies because some researchers use the average HU value of the entire muscle as muscle density, while others select a small, uniformly consistent area within the muscle [27,28].

The assessment of fat content mainly includes semi-quantitative grading methods and quantitative technical evaluation methods. Semi-quantitative evaluation is primarily based on visual analysis. In 1989, scholars such as Goutallier established the Goutallier grading system for quantifying fat infiltration based on CT axial images [29]. In recent years, this grading system has been widely used and has developed into a reliable indicator for assessing fat infiltration in paraspinal muscles. Although a study used a new scoring system, Mo-fi-disc, to optimize the Goutallier grading for assessing fat infiltration in paraspinal muscles, the semi-quantitative evaluation itself is highly dependent on the observer's subjectivity [30]. This leads to lower reliability in ratings and makes it only suitable for comparisons between objects with large differences, not for visually similar fat infiltrations [31]. Therefore, quantitative detection techniques for measuring fat content are necessary. Current research often measures through signal intensity histogram thresholds and area percentages, such as magnetic resonance spectroscopy, water-fat separation techniques based on magnetic resonance chemical shift imaging, MRI longitudinal relaxation time (T1) and transverse relaxation time (T2) measurements, as well as methods like Fuzzy C-means T1-weighted sequences and T1-weighted image threshold quantification [32]. Currently, there is no unified protocol for its quantitative detection in clinical practice.

Due to the diverse qualitative detection methods for fat infiltration, each with its own advantages, clinicians should select appropriate detection techniques based on the patient's condition and the imaging department's capabilities at their respective hospitals. This will enable better qualitative measurement of fat infiltration in patients with osteoporotic vertebral compression fractures, providing a new perspective for preventing and treating osteoporotic vertebral compression fractures by assessing the degree of fat infiltration in paraspinal muscle groups.

3. The effect of paraspinal muscle fat infiltration on the clinical prognosis of OVCFs

Although percutaneous vertebroplasty (PVP) has become the main treatment for such diseases, this minimally invasive treatment not only significantly reduces patients' pain, but also achieves satisfactory correction of kyphosis deformity [33]. However, a large proportion of patients still use traditional conservative treatments, such as bed rest, narcotic analgesics, and the use of thoracolumbar braces. Moreover, due to the decrease in bone density and the destruction of bone trabecular structure, the vertebral support is poor, leading to imbalance in the load of paraspinal muscles and degeneration. At this time, the degenerated paraspinal muscles further reduce the stability of the spine and increase segmental load, thereby increasing the risk of OVCFs [34].

3.1. OVCFs trigger fat infiltration of paraspinal muscles

OVCFs can lead to pathological changes such as muscle atrophy and fat infiltration in paraspinal muscles, and the severity increases with the prolongation of OVCFs. Jeon conducted quantitative MRI evaluations of paraspinal muscles in 55 patients with OVCFs at 1, 3, and 6 months after the initial diagnosis, and found that after the occurrence of OVCFs, there was a significant fat infiltration change in paraspinal muscles, and the severity of the disease increased with the prolongation of time [35]. Tokeshi conducted a regression analysis of the skeletal muscle mass in 142 patients and found that patients with OVCFs were more likely to have sarcopenia [36]. In addition, a meta-analysis showed that [37] paraspinal muscle degeneration plays an important role in the occurrence and recurrence of OVCFs, and evaluating the quality of paraspinal muscles can help identify high-risk populations.

3.2. Paraspinal muscle fat infiltration affects the prognosis of OVCFs

Although PVP surgery can significantly improve symptoms such as pain in patients with OVCFs, and restore patient activity function to a certain extent. However, when there is significant fat infiltration in the paraspinal muscles, coupled with the decrease in bone density and the destruction of bone trabecular structure, the vertebral support cannot function well, leading to a high risk of new vertebral fractures. It has been reported that paraspinal muscle fat infiltration is closely related to the decrease in back muscle strength and the occurrence of new vertebral fractures after PVP surgery [38]. Si retrospectively analyzed the muscle pathological changes in 202 patients with single vertebral OVCFs and found that paraspinal muscle atrophy is a potential risk factor for the occurrence of new OVCFs [39]. Hwang studied 178 patients with OVCFs and found that the more severe the fat infiltration in the paraspinal muscles, the more likely they are to have a second OVCFs [2]. A cross-sectional study that analyzed MRI scans of 120 patients found that a high proportion of fat infiltration in paraspinal muscles increases the risk of spine fractures, and maintaining the quality of back muscles is crucial for preventing OVCFs [40].

3.3. The outcome of fat infiltration in paraspinal muscles

Blocking or reversing the fat infiltration of paraspinal muscles can help improve the prognosis of OVCFs. However, the loss of muscle mass and function with aging is a well-known biological phenomenon. Although regular muscle function exercise can partially counteract fat infiltration, whether it can reverse it remains controversial.

Some studies suggest that fat infiltration is irreversible after the occurrence of OVCFs, and may even continue to progress. Katsu found that conservative treatment for OVCFs will further exacerbate paraspinal muscle atrophy and fat infiltration [41]. Although PVP surgery can effectively relieve pain in patients with OVCFs, some patients still experience residual low back pain, which is consistent with the findings of Eski et al. [12]. Paraspinal muscle fat infiltration is closely related to low back pain. Li et al. [42] retrospectively analyzed 268 patients who underwent PVP treatment for OVCFs and found that residual low back pain after surgery was closely related to severe paraspinal degeneration. Li et al. [43] analyzed the correlation between the degree of paraspinal muscle atrophy and spinal-pelvic parameters in 39 patients with OVCFs and suggested that as paraspinal muscle fat infiltration increases, pelvic degeneration also occurs, and even lumbar lordosis is affected.

However, some scholars believe that paraspinal muscle fat infiltration can be reversed. Habibi et al. [4] evaluated MRI scans of paraspinal muscles in 117 patients with OVCFs and found that patients with higher levels of fat infiltration required stronger treatment. Chen et al. [44] conducted a retrospective analysis of 214 elderly patients with OVCFs and believed that regular muscle function exercise can prevent paraspinal muscle atrophy and thereby prevent OVCFs. An early study showed ^44 that after 16 weeks of progressive resistance training intervention in 30 patients with chronic low back pain, MRI scans showed a reduction in paraspinal muscle fat infiltration. Numerous studies [45,46] have shown that paraspinal muscle fat infiltration is a marker of decreased bone density after assessing the bone density and fat infiltration levels of subjects. Turcotte et al. [47] found through a 18-month randomized controlled trial of exercise interventions that a multi-component exercise program can improve spine bone density and the size of paraspinal muscles, suggesting that exercise improves muscle size and muscle-fat tissue by improving spine bone density.

In summary, the author infers that strengthening paraspinal muscle exercise programs can improve the quality and function of paraspinal muscles in patients with osteoporosis or OVCFs, thereby maintaining or improving bone mass, reducing the risk of falls and fractures.

4. Summary and outlook

OVCFs are often associated with paraspinal muscle fat infiltration, which in turn affects the prognosis of OVCFs repair. Existing evidence suggests that specific exercise interventions can improve the quality and function of paraspinal muscles, but the effects of different exercise modalities vary. More evidence is needed in the future to clarify the factors affecting fat infiltration in OVCFs and the outcome of fat infiltration after PVP surgery.

In addition, the underlying mechanism of paraspinal muscle fat infiltration in OVCFs remains unclear. The complex interaction between muscle and bone may be one of the main reasons for the difficulty in explaining its pathogenic mechanism. However, based on the associated phenomena found in numerous studies, it is suggested that the importance of paraspinal muscles should not be ignored in the diagnosis and treatment of OVCFs. Therefore, future longitudinal studies should focus on quantitatively assessing the changes in paraspinal muscles during the course of the disease and the effects of exercise interventions on them, in order to elucidate the specific mechanism of paraspinal muscle degeneration in OVCFs and provide feasible clinical solutions for prevention and treatment.

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