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It mainly reports new viewpoints, new achievements and new technologies in basic and clinical research of bone and joint surgery. The covered topics include, but are not limited to: sports medicine and arthroscopy, prosthetic design, biomechanics, biomaterials, metallurgy, biologic response to arthroplasty materials *in vivo* and *in vitro*.

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Comparison of the Wiltse Approach and Percutaneous Pedicle Screw Fixation for the Treatment of Neurologically Intact Thoracolumbar Fractures

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Abstract: *Purpose:* To compare the curative effect of two minimally invasive techniques for neurologically intact thoracolumbar fractures. *Methods:* 37 patients with type A fractures without neurological deficits were selected and divided into two groups. Among them, 18 patients received percutaneous pedicle screw fixation (PPSF group), and 19 patients were treated using a mini-open Wiltse approach with pedicle screw fixation (WPSF group). The clinical outcomes, surgery-related results, and radiological findings were compared between the two groups. *Results:* The length of incision, intraoperative blood loss, post-operative hospitalization time, satisfaction, visual analog score (VAS), and Cobb's angle between the two groups showed no significant differences ($P > 0.05$). However, the operation time and the number of intraoperative fluoroscopy of the WPSF group were significantly lower than those of the PPSF group ($P < 0.05$). *Conclusion:* Both minimally invasive techniques are effective for neurologically intact thoracolumbar fractures. Nevertheless, the mini-open Wiltse approach has lower radiation exposure and a shorter learning curve compared with PPSF. A larger sample, multi-center randomized controlled study is necessary to prove the clinical effectiveness of the Wiltse approach.

Keywords: Percutaneous pedicle screw; Wiltse approach; Thoracolumbar fractures

Online publication: February 20, 2024

1. Introduction

The percutaneous pedicle screw fixation is currently the main method for treating thoracolumbar fractures. Still, the traditional midline approach has many shortcomings, such as damage to the paravertebral muscles and postoperative complications. The Wiltse approach and percutaneous pedicle screws are two minimally invasive techniques for the treatment of thoracolumbar fractures. In 1968, Wiltse first used the paravertebral muscle space approach (Wiltse approach) to treat lumbar fractures [1]. In 1977, Magerl reported the first case of percutaneous pedicle screw fixation of the thoracolumbar spine [2]. Compared with traditional approaches, these two minimally invasive techniques have the advantages of less damage to lumbar soft tissue, less intraoperative

bleeding, and shorter postoperative recovery time [3]. This paper conducts a randomized controlled study from different perspectives, such as efficacy, surgery-related parameters, and imaging, to explore which techniques are more suitable for the minimally invasive treatment of thoracolumbar fractures.

2. General information and methods

2.1. General information

From February 2021 to February 2023, 37 patients with thoracolumbar vertebral compression fractures (Danis-Weber type A, AO classification type A) were selected and randomly divided into two groups. Two doctors performed the surgical treatment for the two groups. Inclusion criteria were single vertebral body compression fracture at the T10 to L2 stage (Danis-Weber type A, AO classification type A); no symptoms of spinal cord and nerve root injury; aged between 18 and 60 years old; thoracolumbar fracture occurred within 7 days. Exclusion criteria were spontaneous vertebral fractures caused by pathology or osteoporosis; other serious combined injuries, such as limb fractures, etc.; patients with previous surgery on the fractured vertebral body; patients suffering from spinal stenosis, severe osteoarthritis, etc.; basic diseases of normal life. The hospital's Medical Ethics Committee reviewed and approved this study, and all patients gave informed consent.

2.2. Methods

Patients in the WPSF (Wiltse approach with pedicle screw fixation) group underwent open reduction and pedicle screw internal fixation through a minimally invasive posterior Wiltse approach. The patient laid prone on the operating table. The position of the diseased vertebra was determined through fluoroscopy, and then it was sterilized and draped. A midline incision was made, the skin and subcutaneous tissue were incised, and the bilateral longissimus and multifidus muscles were exposed and separated along the muscle space to expose the bilateral facet pedicle screw implantation points [4]. The pedicle screws were implanted, the position of the screws was confirmed by fluoroscopy, and rods were installed to restore the height of the compressed vertebral body. After it was confirmed that the height had been restored satisfactorily using fluoroscopy, the incision was rinsed repeatedly, the bleeding was carefully stopped, and the incision was closed with sutures (**Figure 1**).

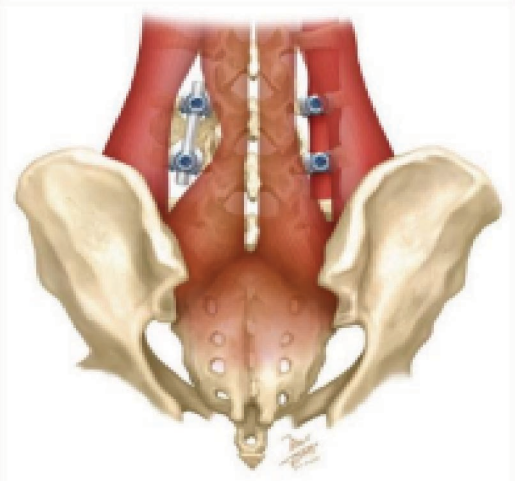

Figure 1. Minimally invasive Wiltse approach

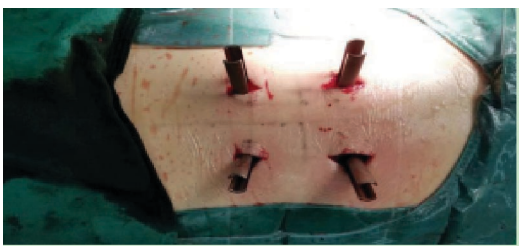

Figure 2. PPSF method

Another group of patients underwent percutaneous pedicle screw internal fixation surgery (PPSF group). G-arm fluoroscopy was used to determine and mark the projection points of the diseased vertebra and the pedicle surface of the upper and lower vertebral bodies. After sterilizing and draping, a longitudinal incision of about 1 cm was made in the marked skin, a puncture needle was inserted under fluoroscopy, making sure the puncture needle was in a good position. Then, six pedicle screws were tapped and screwed in, the rod was installed, and special instruments were used to expand, reduce, and compress the vertebral body. Fluoroscopy showed that the fracture was satisfactorily reduced, and the internal fixation was in a good position. The incision was then flushed and sutured (**Figure 2**).

2.3. Observation indicators

The operation time, incision length, intraoperative blood loss, number of intraoperative fluoroscopies, postoperative hospitalization time, postoperative Cobb angle recovery, visual analog score (VAS index for waist pain level), complications, and patient satisfaction were compared between the two groups.

2.4. Statistical analysis

Sample parameters are expressed as mean ± standard deviation (SD). The location of diseased vertebrae, the ratio of men and women, differences in satisfaction, etc., were analyzed using the χ^2 test. The remaining parameters were analyzed statistically using the *F* test (analysis of variance) and SPSS22.0 statistical software. $P < 0.05$ indicated that there was a statistically significant difference in the data.

3. Results

The ages of the patients ranged from 23 to 60 years old. There were 22 males and 15 females, including 18 cases in the PPSF group (**Figure 3**) and 19 cases in the WPSF group (**Figure 4**). There was no statistically significant difference between the two groups in terms of age, gender, average follow-up time, pre-operative preparation time, compressed vertebral body position, vertebral body compression degree (Cobb angle), etc. ($P > 0.05$, **Table 1**).

Table 1. General information, Cobb angle, and vertebral body position

Group	Number of cases*	Age*	Cobb angle (preoperative)	Cobb angle (postoperative)	Vertebral body position* (t11, t12, l1, l2)
PPSF group	18	36.2 ± 13.8	19.62 ± 2.36	6.71 ± 2.16	2, 6, 7, 3
WPSF group	19	38.4 ± 15.2	20.25 ± 3.16	4.98 ± 2.52	3, 7, 5, 4
P value	-	0.21	0.22	0.26	0.362

*χ^2 test, the rest are Fisher tests (analysis of variance), parameters are expressed as mean ± SD

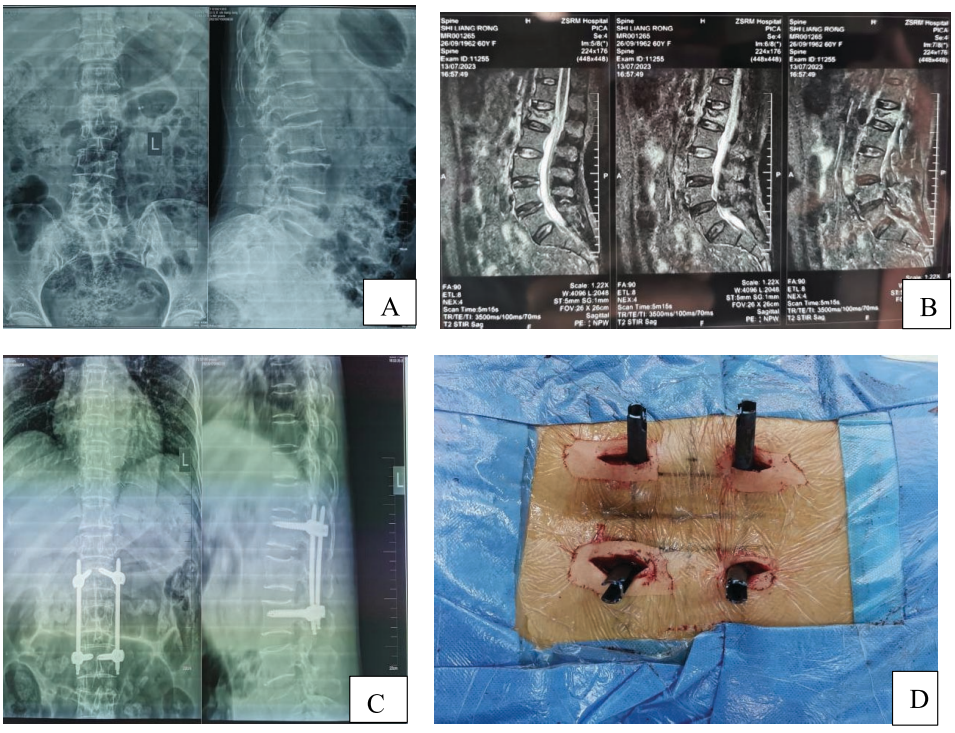

Figure 3. Percutaneous pedicle screw treatment of lumbar fractures. (A) Preoperative X-ray (B) Pre-operative MRI (C) Post-operative X-ray (D) Percutaneous pedicle screw implantation

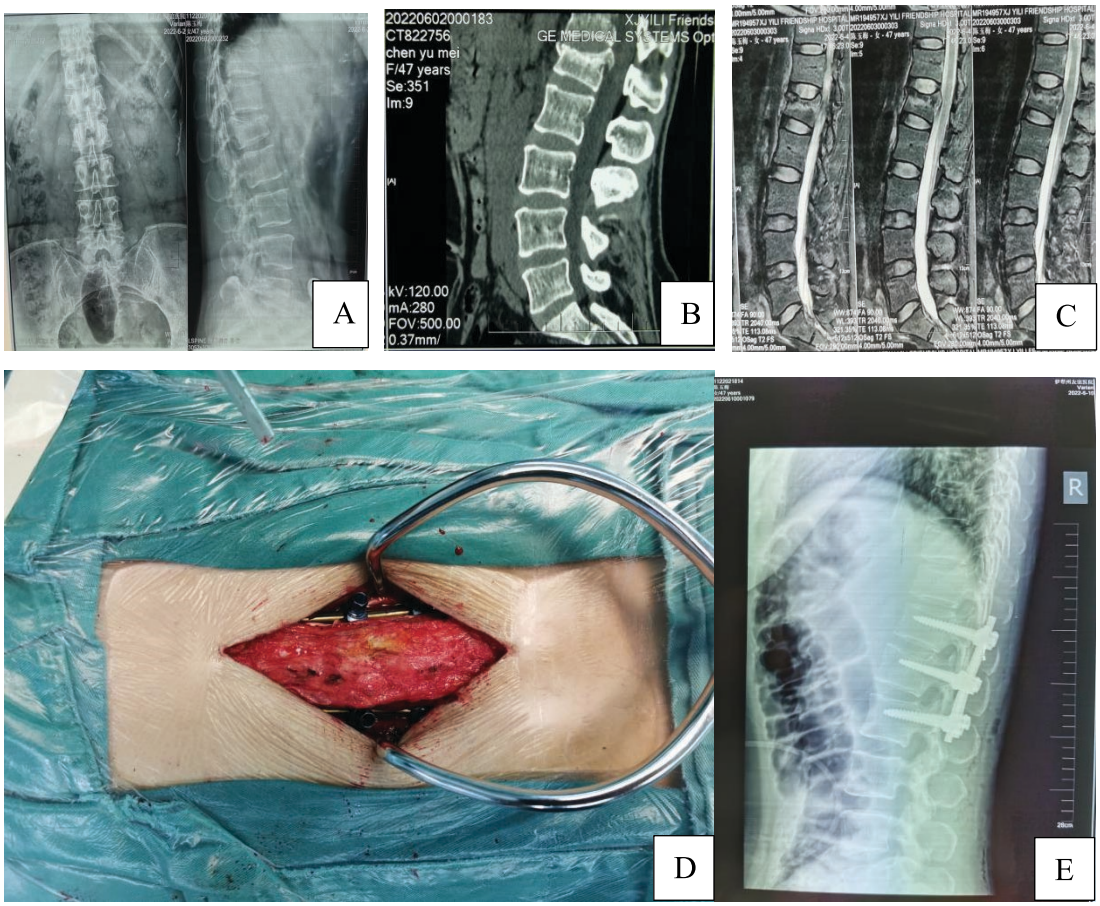

Figure 4. Minimally invasive Wiltse approach to open reduction and pedicle screw internal fixation to treat lumbar spine fractures. (A) Preoperative X-ray (B) Preoperative sagittal CT (C) Preoperative MRI (D) Implantation of pedicle screws through the Wiltse paravertebral muscle space approach (E) Postoperative X-ray

The average operation time of the WPSF group was 72.6 minutes, which was significantly shorter than the 110.4 minutes of the PPSF group ($P < 0.05$), while the number of intraoperative fluoroscopy in the PPSF group was more than that of the WPSF group ($P < 0.01$). The two groups had no significant statistical differences in the incision length, intraoperative blood loss, and postoperative compressed vertebral height recovery ($P > 0.05$, **Table 2**).

Table 2. Intraoperative indicators of the two groups

Parameter	WPSF group	PPSF group	*P* value
Incision length (cm)	6.0 ± 1.5	4.5 ± 0.5	0.44
Operation time (minutes)	72.6 ± 8.4	110.4 ± 10.5	$P < 0.05$
Intraoperative blood loss (ml)	40.3 ± 20.6	30.4 ± 8.2	0.34
Number of fluoroscopy (times)	3.5 ± 0.5	13.8 ± 2.2	$P < 0.01$
Cobb angle (postoperative)	4.98 ± 2.52	6.71 ± 2.16	0.25

Note: Fisher test (analysis of variance), parameters are expressed as mean ± SD

Among them, 2 cases in the WPSF group developed a subcutaneous hematoma at the postoperative incision, and all of them were cured after a puncture, drainage, and pressure bandaging. One case in the PPSF group failed to insert pedicle screws due to anatomical variation, so the screws were inserted through the

Wiltse minimally invasive approach. There was no statistical difference between the two groups regarding postoperative hospitalization time, postoperative waist pain level, and patient satisfaction at discharge ($P > 0.05$, **Table 3**).

Table 3. Postoperative hospitalization, VAS index, and satisfaction

Group	Postoperative hospitalization (days)	VAS index (preoperative)	VAS index (postoperative)	Satisfaction* (high:low)
PPSF group	5.6 ± 1.2	7.2 ± 1.8	1.5 ± 0.5	13:5
WPSF group	7.3 ± 1.9	7.8 ± 1.0	2.8 ± 0.7	14:5
P value	0.32	0.54	0.36	0.94

*χ^2 test, the rest are Fisher tests (analysis of variance), parameters are expressed as mean ± SD

4. Discussion

Traditional posterior surgery for thoracolumbar fractures requires stripping and cutting of the paravertebral muscle attachment points of the longissimus and multifidus muscles, resulting in postoperative lumbar muscle dysfunction and complications such as waist pain [5,6]. In 1977, Magerl first percutaneously inserted pedicle screws to fix the vertebral body temporarily and then removed them [2]. In 2004, Assaker *et al.* [7] first listed thoracolumbar fractures as indications for percutaneous pedicle screw fixation (PPSF). The results of systematic reviews [8,9] and meta-analyses [10] show that the PPSF technique has the advantages of short operation time, little damage to lumbar muscles, less intraoperative blood volume, low infection rate, and short postoperative recovery time. Still, it may lead to spinal fracture rotation, severe osteoporosis, multi-stage fractures, pedicle fractures, severe kyphosis, etc., limiting the scope of use of this technique. In addition, the PPSF technique has shortcomings such as being highly dependent on intraoperative fluoroscopy and having a long technical learning curve. Zhao *et al.* [11] conducted a retrospective study on 781 patients with thoracolumbar fractures treated with PPSF. They found that 48 cases had guidewire breakage, abdominal vascular injury, cauda equina injury, postoperative loosening of internal fixation, screw breakage, reduction failure, and delay complications of varying degrees, such as infection.

In 1968, Wiltse [1] first described the paravertebral muscle space approach, the separation approach between the longissimus muscle and the multifidus muscle, which has the advantages of less bleeding and damage to soft tissue. Since then, this approach has been widely used in posterior internal fixation of thoracolumbar fractures [12-15], scoliosis (neuromuscular) orthopedics [16,17], degenerative spinal disease [18,19], transforaminal lumbar interbody fusion (TLIF) for isthmic spondylolisthesis [20-22], paravertebral giant tumor resection [23], etc., with satisfactory results. Compared with the traditional approach, this approach has the advantages of less damage to the waist muscles, reduced intraoperative blood loss, and postoperative low back pain for a shorter period [24]. Some researchers conducted cross-sectional measurement studies of the multifidus before and after surgery [21], and some scholars also conducted postoperative MRI, histological, and electrophysiological studies on the multifidus and proved that the Wiltse approach causes significantly less damage to the lumbar muscles than the traditional approach [25]. Gagliardi *et al.* [26] found no significant difference in the accuracy of pedicle screw placement between the Wiltse approach and the traditional approach in postoperative CT scans.

The Wiltse approach and percutaneous pedicle screws are two minimally invasive techniques for the treatment of thoracolumbar fractures. There have been retrospective studies in China comparing the efficacy of these two minimally invasive techniques in treating thoracolumbar fractures [27-29]. In this study, we designed

a randomized controlled study to compare the two techniques in many aspects. We found that the operation time of the Wiltse approach was shorter than that of the PPSF group, which may be related to the need for repeated fluoroscopy during the operation to determine the screw entry point and direction in the PPSF group. The number of fluoroscopies in the PPSF group is significantly more than that in the Wiltse approach, and the increased radiation dose is negative for the health of doctors and patients. In this research, we used the G-arm to significantly reduce fluoroscopies. In one patient, it was difficult to insert percutaneous pedicle screws due to anatomical variation, so the screws were inserted through the Wiltse minimally invasive approach. There were no significant statistical differences between the two groups regarding incision length, intraoperative blood loss, Cobb angle correction, postoperative pain, hospitalization time, and satisfaction. We believe that both methods are effective for treating thoracolumbar fractures. Still, the Wiltse approach is slightly better than the PPSF technique regarding application range and safety factors. There are still people in China who cleverly combine these two techniques, that is after determining the projection point of the vertebral pedicle surface through fluoroscopy, an incision of about 1.5 cm is made, the Wiltse approach to the intermuscular space is used to reach the screw insertion point, and a guide wire is inserted to determine the direction. Afterward, pedicle screws are inserted to achieve satisfactory results, which is worthy of promotion [30].

5. Conclusion

The minimally invasive Wiltse approach and percutaneous pedicle screw fixation are two effective and safe techniques for the treatment of thoracolumbar fractures. Still, the Wiltse approach is superior to the PPSF technology in terms of operation time, number of fluoroscopy, and learning curve. Due to the single-center study and small sample size, this topic requires further large-sample, multi-center randomized controlled studies, meta-analysis, or systematic review to prove the clinical effectiveness of the techniques.

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Disclosure statement

The authors declare no conflict of interest.

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Modification of Biodegradable Polymer Nanofibers for Cartilage Tissue Engineering Applications: A Review

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Abstract: Tissue engineering is the use of a combination of cells, engineering and materials methods, and suitable biochemical and physiochemical factors to improve or replace biological functions at the injured site. The designing of a biomaterial that can mimic the three-dimensional tissues *in vivo* is still challenging. Biodegradable polymers are used for the development of tissue engineering constructs in the form of sponges, films, and macroporous scaffolds, which do not influence cell fate processes such as cell differentiation, migration, and proliferation. Biodegradable polymer nanofibers fabricated by electrospinning have gathered great attention in tissue engineering applications. The electrospun materials have a nanofibrous morphology that is closest to the natural extracellular matrix (ECM). The electrospun material is composed of three-dimensional networks of nanosized fibrous materials that mimic an extracellular matrix such as collagen, elastin, and keratin. These polymers fabricated in the form of fibers in nanosize cause a more favorable microenvironment for cells. We prepared the PLGA/PPG (polylactic-co-glycolic acid/polypropylene glycol) nanofibers by electrospinning technique. PLGA (85:15)/PLGA (75:25) nanofibers are hydrophobic, which can be minimized by the addition of PPG to give better hydrophilicity for cell adhesion for tissue engineering constructs. The morphology of the electrospun fibers of the composite of PLGA and PPG was observed using scanning electron microscopy (SEM). The results proved that the small amount of polypropylene glycol polymer to the polylactic-co-glycolic acid (PLGA 85:15) drastically improves the hydrophilicity of the electrospun nanofibers. The addition of a small amount of hydrophilic polymer to the biodegradable hydrophobic polymer increases the hydrophilic property and can be used for nanofiber-based tissue engineering constructs. In addition, the biomimetic approach for tissue engineering scaffolds for cartilage repair has been discussed.

Keywords: Biodegradable polymers; Electrospinning; Polylactic-co-glycolic acid; Cartilage repair and biomimetic approach

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1. Introduction

Electrospinning is an innovative method used for producing ultrafine fibers with diameters ranging from a few

nanometers to several micrometers. It involves the application of an electric field to generate a high voltage between polymer solutions or melts and a grounded collector. This voltage creates a strong electrostatic force that overcomes the surface tension of the polymer solution, causing the formation of a thin jet of polymer solution that is subsequently stretched and solidified into fibers as it travels toward the collector. The electrospinning process offers several advantages over conventional spinning techniques [1]. Firstly, it can produce nanofibers with a large surface area-to-volume ratio, which is desirable for a wide range of applications such as biomedical engineering, filtration systems, and energy storage devices. The small diameter of these fibers can also provide mechanical properties (such as strength and flexibility) superior to those of conventional fibers [2,3]. Furthermore, electrospinning is a relatively simple and cost-effective method compared to other techniques used for producing nanofibers, such as molecular self-assembly or electron beam lithography. It does not require complex equipment or elaborate setup, making it accessible to researchers in various fields. The versatility of electrospinning enables the use of different polymers, blends, composites, or functional materials to create a wide variety of fiber structures. The process parameters, such as the polymer concentration, solvent composition, and applied electric field, can be adjusted to control the morphology, diameter, and alignment of the resulting fibers. In recent years, there has been an increasing interest in the development of novel electrospinning techniques, such as coaxial electrospinning and near-field electrospinning, which further enhance the fiber properties and allow the encapsulation of active substances or the direct writing of fibers onto specific targets. Despite its numerous advantages, electrospinning presents some challenges. The process parameters need to be carefully optimized to achieve the desired fiber morphology and prevent issues such as beading or clogging [4]. The scalability of electrospinning to large-scale production is also a current area of research and development. With continued advancements in materials and process optimization, electrospinning holds great potential for the production of functional nanofibers with tailored properties to meet the demands of modern technology and industry. This method has been widely used in the development of tissue engineering constructs and medical devices [3,5].

Tissue engineering is a rapidly growing field that focuses on regenerating functional tissues and organs to replace damaged or diseased ones [6]. One key aspect of tissue engineering is the development of scaffolds, which provide a three-dimensional (3D) structure for cells to grow and regenerate tissue [7]. **Figure 1** shows the hierarchy of tissues in the human body. The tissue engineering approach can help to repair, regenerate, or restore the injured tissue [8,9]. Electrospinning has emerged as a powerful technique in scaffold development due to its versatility and ability to create structures that closely mimic the properties of natural extracellular matrix. Through electrospinning, these fibers can be collected to form a nanofibrous scaffold with desired structural and mechanical properties. One of the major advantages of electrospinning is the ability to control the fiber diameter. The electrospun fibers can range from a few nanometers to several micrometers, which is similar to the scale of natural extracellular matrix fibers found in tissues. This fine control over fiber diameter allows for the mimicking of native tissue architecture, which is crucial for cell attachment, proliferation, and differentiation [10,11]. Electrospun scaffolds also have a high surface-to-volume ratio, which can promote cell adhesion and nutrient exchange. The interconnected porous structure of electrospun scaffolds allows for the diffusion of oxygen, nutrients, and waste products, enabling cells to thrive and function properly. Furthermore, electrospinning allows for the incorporation of bioactive molecules into the scaffold, such as growth factors, peptides, and drugs [12,13]. These bioactive molecules can be loaded into the polymer solution prior to electrospinning or post-loaded onto the electrospun fibers. This controlled release of bioactive molecules can enhance cell behavior, promote tissue regeneration, and modulate the immune response. Moreover, electrospun scaffolds can be fabricated using a variety of polymers, including natural polymers (e.g., collagen, gelatin) and

synthetic polymers (e.g., polycaprolactone, polylactic-co-glycolic acid). The choice of polymer can be tailored to the specific tissue engineering application, taking into account factors such as biocompatibility, degradation rate, and mechanical properties. It is a versatile and powerful technique in tissue engineering scaffold development. It allows for the fabrication of scaffolds with controlled fiber diameter, high surface-to-volume ratio, and incorporation of bioactive molecules [14]. These scaffolds closely mimic the native tissue architecture, promoting cell attachment, proliferation, and differentiation. Electrospun scaffolds hold great potential for various tissue engineering applications, including wound healing, bone regeneration, cartilage repair, and organ transplantation. The scaffold can act as a reservoir for the cells, drugs, or bioactive molecules for delivery into the damaged site of tissues. The scaffold should have the capacity to induce the cell fate process and produce a microenvironment for better regeneration of the damaged tissues [15]. **Figures 2** and **3** show the concept of tissue engineering scaffold development.

Electrospinning of biodegradable polymers into nanofibrous scaffolds as tissue engineering construct is a versatile technique that has gained significant attention. This process involves the formation of ultrafine fibers from a polymer solution using an electric field. Biodegradable polymers, which can naturally degrade into non-toxic byproducts, are particularly attractive in various biomedical applications due to their ability to minimize long-term foreign body reactions and avoid the need for implant removal. The electrospinning process begins with the preparation of a polymer solution, where a biodegradable polymer is dissolved in a suitable solvent. The choice of polymer and solvent is crucial, as it directly influences the properties of the resulting fibers. Some commonly used biodegradable polymers for electrospinning include polylactic acid (PLA), polyglycolic acid (PGA), polylactic-co-glycolic acid (PLGA), and polycaprolactone (PCL). Once the polymer solution is prepared, it is loaded into a syringe or reservoir connected to a metallic needle or spinneret. A high voltage is applied to the syringe, creating an electrostatic field. As the polymer solution is delivered, a jet of polymer is formed at the needle tip due to the electrostatic repulsion between the charged polymer chain and the applied electric field. The jet is then elongated and thinned by the electrostatic forces, resulting in the formation of ultrafine fibers. The collection of these fibers can be done on a stationary or rotating collector, which is usually a grounded plate or drum. The distance between the needle tip and the collector, as well as the applied voltage, can be adjusted to control the morphology and diameter of the electrospun fibers. Factors such as polymer concentration, solution viscosity, and flow rate also play a crucial role in determining the fiber properties. The unique structural characteristics of electrospun biodegradable polymer fibers, including their high surface area-to-volume ratio and fine fiber diameter attributed to their suitability for various biomedical applications. They can mimic the extracellular matrix (ECM) environment and provide a three-dimensional nanostructured scaffold for cell attachment, proliferation, and differentiation. Additionally, the fiber diameter can be tailored to match the dimensions of natural ECM fibers, enhancing cellular interactions and promoting tissue regeneration. The biodegradability of these electrospun fibers allows for the controlled release of encapsulated drugs or growth factors, making them ideal for drug delivery systems. The degradation rate can be adjusted by selecting an appropriate polymer, molecular weight, or composition, ensuring the sustained release of therapeutic agents over a desired time. Furthermore, the electrospinning technique enables the formation of composite fibers by incorporating various materials such as nanoparticles, proteins, or bioactive molecules into the polymer solution [16]. This provides an avenue for the development of multifunctional scaffolds with enhanced mechanical properties, improved surface bioactivity, and tailored release profiles [17,18].

Tissue engineering is a rapidly advancing field that aims to regenerate damaged or diseased tissues using a combination of cells, biomaterials, and growth factors. One area of focus in tissue engineering is the development of cartilage, a crucial tissue found in joints that provides cushioning and support. The process of cartilage tissue

engineering typically involves three main components: cells, scaffolds, and bioactive molecules [19,20]. Firstly, specialized cells called chondrocytes or mesenchymal stem cells (MSCs) are isolated from a patient's own tissues, such as bone marrow or adipose tissue. These cells have the potential to differentiate into chondrocytes, which are responsible for producing the ECM of cartilage. Next, a scaffold is used to provide structural support for the cells and mimic the natural environment of cartilage. The scaffold can be made from various materials, including natural polymers like collagen or synthetic materials like hydrogels. The scaffold should possess properties such as biocompatibility, biodegradability, and mechanical strength to support cell growth and tissue development. Additionally, bioactive molecules are added to the scaffold to enhance cell growth and tissue regeneration. Growth factors, such as transforming growth factor-beta (TGF-β) and bone morphogenetic proteins (BMPs), can stimulate cell proliferation and ECM synthesis. In addition, other molecules, such as cytokines or small molecules can be incorporated to modulate the cellular behavior and promote tissue maturation. Once the cells, scaffold, and bioactive molecules are combined, the tissue-engineered construct is cultured in a laboratory setting. During this time, the cells proliferate and deposit ECM, gradually forming functional and mature cartilage tissue. Various culture conditions, such as oxygen tension, mechanical stimulation, and nutrient supply, are optimized to promote tissue development. After an adequate period of *in vitro* culture, the tissue-engineered cartilage can be implanted into the patient. Depending on the defect size and location, different implantation techniques can be employed, such as direct injection or surgical implantation. Over time, the implanted construct integrates with the surrounding tissue and promotes tissue remodeling and regeneration. Tissue engineering of cartilage offers several advantages over traditional treatments for cartilage defects, such as arthritis or trauma. It provides a personalized approach by using the patient's cells, reducing the risk of immune rejection. It also has the potential to regenerate cartilage with native structure and function, as opposed to using artificial implants. However, there are still challenges to overcome, such as ensuring long-term durability and functionality of the engineered tissue. Tissue engineering of cartilage holds great promise for the treatment of cartilage defects. By combining cells, scaffold materials, and bioactive molecules, researchers are working towards creating functional and regenerative cartilage tissues that can improve the quality of life for patients with joint disorders. Further research and technological advancements will continue to propel the field forward, ultimately leading to more effective treatments for the regeneration of damaged tissue, either hard or soft tissue [21].

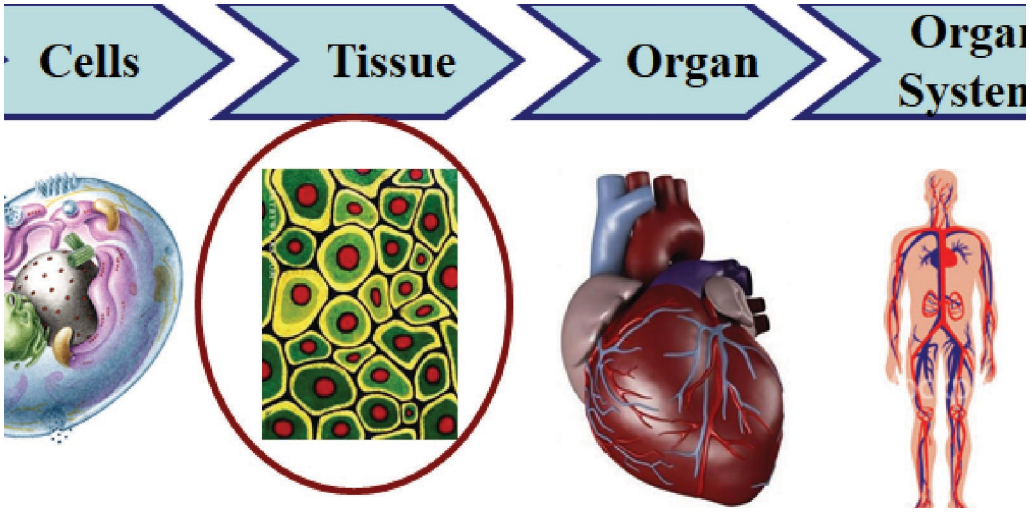

Figure 1. Hierarchical organization of human systems

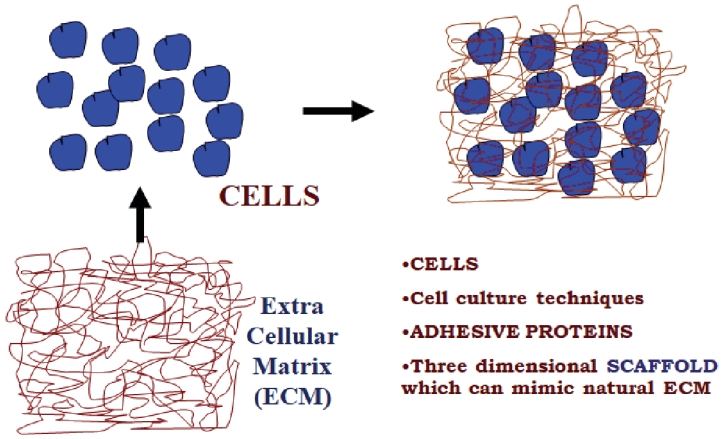

Figure 2. Concept of tissue engineering

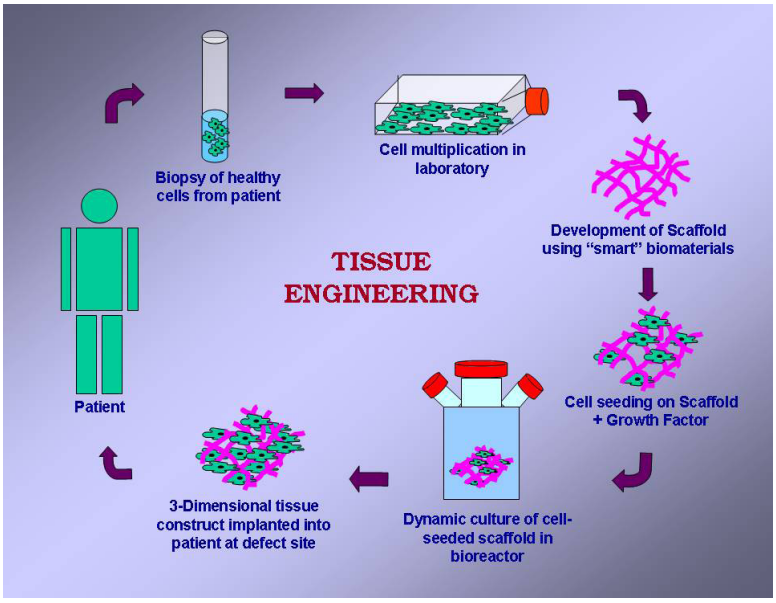

Figure 3. Fabrication of tissue engineering scaffolds (Aher *et al.*, 2015)

2. Structure and function of cartilage

Figure 4 shows the structure of cartilage, which is a specialized connective tissue found in various parts of the body, such as joints, ears, nose, and the respiratory tract. It is characterized by its firm yet flexible consistency, which allows for smooth joint movement and structural support. The primary cellular component of cartilage is chondrocytes. These specialized cells are embedded within the extracellular matrix of cartilage and are responsible for producing and maintaining the cartilaginous tissue. The ECM of cartilage consists of a gel-like substance called ground substance and fibers. The ground substance is composed of proteoglycans, glycosaminoglycans (GAGs), and water, providing resilience and compressibility of the tissue. Collagen fibers, primarily type II collagen, provide tensile strength to the cartilage. There are many types of cartilage: The most common type, hyaline cartilage, is found in weight-bearing joints, the respiratory tract, and the embryonic skeleton. It has a smooth, glassy appearance and provides support, cushioning, and low-friction surfaces for joint movement. Elastic cartilage contains elastic fibers in addition to collagen fibers. It is found in the outer ear, the epiglottis, and the larynx. Elastic cartilage provides strength, flexibility, and shape maintenance.

Fibrocartilage has a dense arrangement of collagen fibers, which makes it more resistant to tension. It is found in structures like intervertebral disks, pubic symphysis, and certain tendons. Fibrocartilage provides cushioning, shock absorption, and stability to joints [22,23].

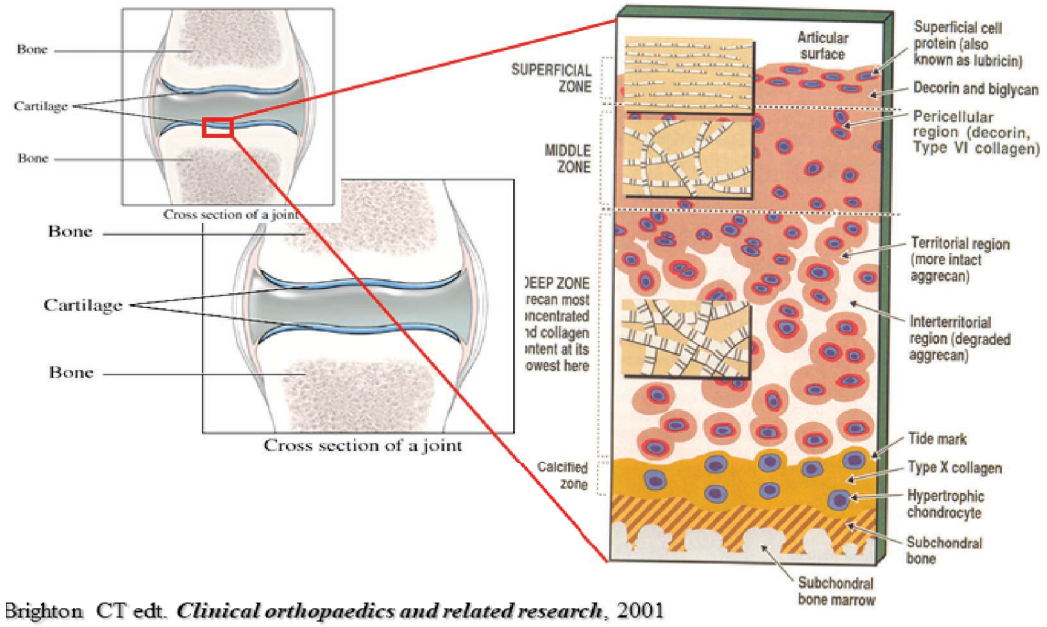

Figure 4. Structure and function of cartilage (Brighton, 2001)

Cartilage has limited regenerative capacity, which means that when it is damaged or injured, it often does not heal completely on its own. However, there are several approaches being explored for cartilage repair and regeneration. Tissue engineering approaches aim to create functional cartilage in the laboratory for transplantation. This typically involves seeding cells (such as chondrocytes or stem cells) onto biocompatible scaffolds and providing the appropriate growth factors and mechanical stimulation to promote cartilage formation [24]. This paper presents the tissue engineering of cartilage using a familiar biofabrication technique called electrospinning. The current scientific investigations reveal the tissue engineering construct via various biomimetic approaches for improving the cell fate process in the regeneration of tissues.

3. Fabrication of PLGA/PPG electrospun scaffold

A syringe pump (Harvard Apparatus, USA), a high voltage power supply (Glassman High Voltage, Inc.), and a speed-adjustable rotary mandrel coated in a copper metal sheet for fiber collection made up the customized electrospinning setup used in this study. PLGA 85:15, 24.71% (w/w) [22% (w/v)] was dissolved in a 3:1 ratio of THF:DMF (tetrahydrofuran:N,N-dimethylformamide) and mixed with different concentrations of polypropylene glycol (PPG), specifically 0.5%, 1.0%, 1.5%, and 2.0% (w/w) [0.5%, 1.0%, 1.5%, and 2.0% (w/v)] to create the polymer solution for electrospinning. Before electrospinning, polymer solutions were created using a magnetic stirrer for 24 hours. The needle gauge was 22G (internal diameter = 0.394 mm), the distance between electrodes was 22 cm, the voltage generated between electrodes was 1.2 kV/cm, and the rotary mandrel speed was set at 1.25 m/s for the electrospinning of PLGA or its blends with Pluronic® F-108 (PF-108). After that, a syringe pump was used to eject the polymer solution at a flow rate of 0.5 ml/h. A non-woven fibrous mesh was created when the polymer solution was exposed to the previously mentioned conditions, and

it was then collected on the rotating mandrel in a dry state. Following synthesis, the resulting fibrous mesh was lyophilized for 48 hours before being used in additional tests [16]. **Figure 5** shows the experimental setup for the fabrication of the nanofibrous scaffold.

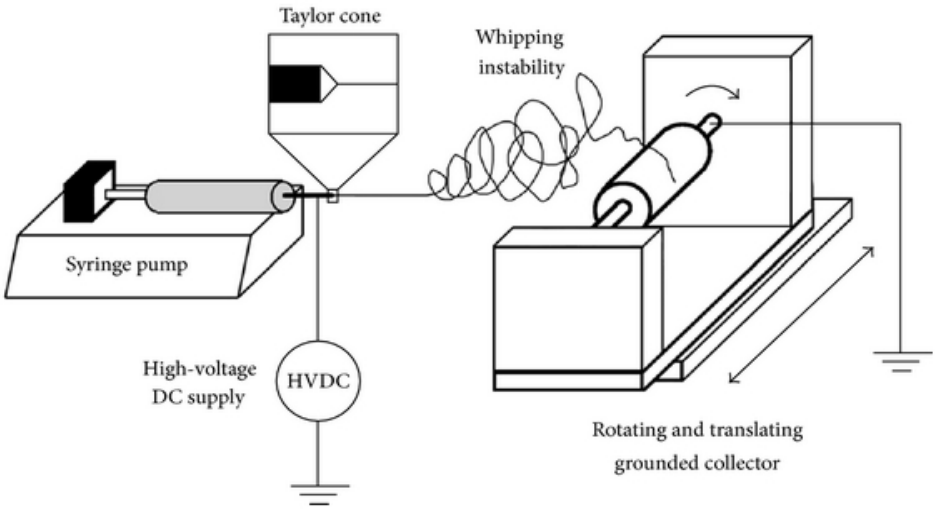

Figure 5. Electrospinning experimental setup (Liu *et al.*, 2013)

Figure 6 reveals the morphology and topography of the electrospun scaffold. The morphology and topography of an electrospun nanofibrous scaffold refer to the physical characteristics and surface features of the scaffold. The morphology of an electrospun nanofibrous scaffold refers to the overall structure and appearance of the fibers that make up the scaffold. Typically, these fibers are very thin and have a high aspect ratio, meaning they are much longer than they are wide. The size and shape of the fibers can vary depending on the electrospinning process parameters, such as the polymer solution viscosity, the applied voltage, and the distance between the spinneret and the collector. The fibers can range in diameter from a few nanometers to several micrometers. The morphology of the scaffold can be observed using various microscopic techniques, such as scanning electron microscopy (SEM).

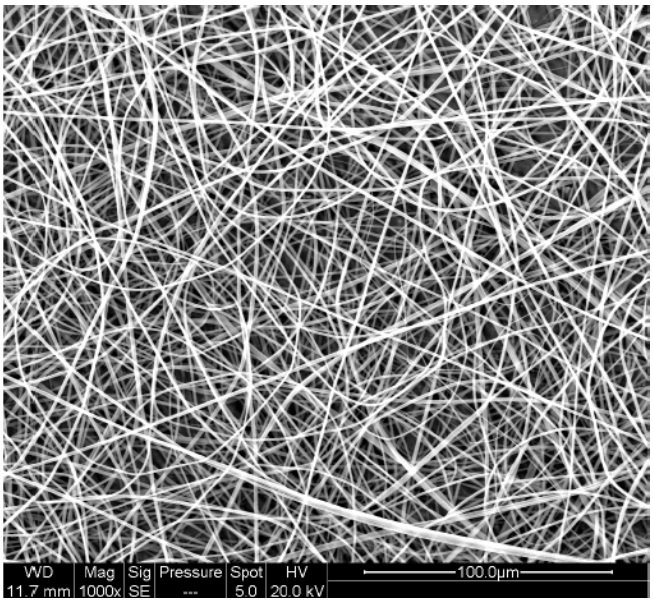

Figure 6. Electrospun PLGA nanofibrous scaffold for tissue engineering constructs

The topography of an electrospun nanofibrous scaffold refers to the surface features and characteristics of the scaffold. The topology can be smooth, rough, or have specific patterns. The topography of the scaffold is mainly determined by the arrangement and alignment of the fibers. The alignment can be random or controlled by using techniques such as multi-needle electrospinning or collector design modifications. The topography can greatly influence cell behavior, including cell adhesion, proliferation, migration, and differentiation. Therefore, controlling the topography of the scaffold is important for achieving desired cellular responses. Overall, the morphology and topography of an electrospun nanofibrous scaffold play crucial roles in its performance as a tissue engineering scaffold. By tailoring these characteristics, it is possible to create scaffolds with specific properties suitable for various tissue engineering applications [25].

4. Biomimetic approach for the development of tissue engineering construct

A biomimetic approach in tissue engineering aims to produce constructs that closely mimic the extracellular environment of the target tissue, thereby promoting better integration, functionality, and regeneration. This approach takes inspiration from the structure, composition, and mechanical properties of native tissues, and seeks to replicate them in engineered constructs [26]. Some key aspects of a biomimetic approach in tissue engineering are as follows. The first aspect is scaffold design, the scaffold serves as the structural framework for cell attachment, growth, and tissue formation. Biomimetic scaffolds aim to mimic the natural ECM of the target tissue, both in terms of composition and architecture. This includes replicating the fibrous structure, pore size and distribution, and mechanical properties of the native tissue. The second aspect is biomaterial selection, choosing the appropriate biomaterials is crucial for a biomimetic approach. Ideally, the selected biomaterials should possess biocompatibility, biodegradability, appropriate mechanical properties, and the ability to support cell adhesion, migration, and tissue formation. Natural polymers, such as collagen, chitosan, and hyaluronic acid, are often used due to their similarity to native ECM components. The third aspect is cell source. Biomimetic tissue engineering often involves using cells that closely resemble the target tissue. This can include primary cells, stem cells, or progenitor cells. The cells are seeded onto the scaffold and encouraged to differentiate and proliferate in a way that mirrors the natural tissue development and repair processes [27]. Another aspect is bioactive molecules. Growth factors, cytokines, and other bioactive molecules play a crucial role in tissue development and regeneration. In a biomimetic approach, these molecules are incorporated into the scaffold or delivered in a controlled manner to guide cellular behavior, promote tissue-specific differentiation, and facilitate the regeneration process. Mechanical stimulation is another aspect of biomimetic tissue engineering. Native tissues experience mechanical forces and stimuli that influence their development and maintenance. Biomimetic tissue engineering seeks to replicate these mechanical cues by applying appropriate mechanical stimulation to the engineered constructs. This can include the use of bioreactors, stretching devices, or other mechanical loading techniques to enhance cellular function, organization, and tissue maturation. By adopting a biomimetic approach, tissue engineering constructs can better mimic the complex microenvironment of native tissues, promoting cell viability, differentiation, and tissue regeneration. This approach holds great promise in developing more effective and clinically relevant tissue engineering strategies for a wide range of applications, including bone, cartilage, skin, and organ regeneration [28,29].

Biomimetic of cartilage tissue in tissue engineering aims to replicate the structure, composition, and mechanical properties of native cartilage. These mimetic approaches involve various strategies to create constructs that closely resemble the characteristics of natural cartilage tissue. There are physical, chemical, and biological approaches to restoring native cartilage. It has a zonal organization, with distinct regions of different cell densities and ECM compositions. In mimetics, efforts are made to create constructs with zonal organization [30].

5. Physical approach for mimetic of cartilage tissue engineering constructs

A physical approach for mimicking tissue engineering constructs of cartilage involves utilizing various physical techniques to create structures that resemble the characteristics of native cartilage tissue [31]. Electrospinning is an appropriate approach for the fabrication of tissue engineering constructs. This method can be employed to fabricate scaffolds with a fibrous structure similar to the size of collagen fibers found in native cartilage. By controlling factors such as polymer concentration, electric field strength, and collector design, the diameter and alignment of the electrospun fibers can be adjusted to mimic the organization of collagen fibers in cartilage. Electrospinning has the capacity to tailor the orientation and alignment of the electrospun nanofibers to mimic the structure of cartilage [29].

5.1. Shape and size-based mimetic

In electrospinning, the shape and size of nanofibers can be controlled through various factors and parameters. The key considerations for controlling the shape and size of nanofibers in electrospinning are as follows.

(1) Polymer solution properties: The properties of the polymer solution used in electrospinning can significantly influence the fiber morphology. Factors such as polymer concentration, viscosity, surface tension, and conductivity play a role in determining the final fiber diameter. Higher polymer concentrations generally result in thicker fibers, while lower concentrations tend to produce finer fibers.

(2) Electric field parameters: The electric field applied during electrospinning affects the stretching and elongation of the polymer solution, thus influencing the fiber diameter. Increasing the electric field strength generally leads to thinner fibers, while reducing the field strength can result in thicker fibers. The distance between the needle orifice and the collector, known as the needle-to-collector distance, also affects fiber morphology, with longer distances typically producing larger-diameter fibers.

(3) Needle and collector setup: The design and configuration of the electrospinning setup can influence the shape and size of the nanofibers. Factors such as the size and shape of the spinneret needle, its tip shape, and the geometry of the collector can impact the fiber morphology. For example, a needle with a smaller diameter or a finer tip can produce finer fibers.

(4) Processing parameters: Additional processing parameters, such as the flow rate of the polymer solution, the spinning time, and the rotational speed of the collector, can also affect the fiber diameter and shape. Higher flow rates generally result in thicker fibers, while lower flow rates produce finer fibers. Adjusting the spinning time and rotational speed can allow for control over the alignment and organization of the fibers.

(5) Additives and blends: Incorporating additives, such as surfactants or plasticizers, into the polymer solution can modify the solution's properties and influence the fiber morphology. Additives can help reduce the surface tension of the solution, improve its conductivity, or enhance its spinnability, resulting in different fiber shapes and sizes. Blending different polymers can also allow for control over fiber morphology and properties. By carefully adjusting these factors and parameters, researchers can achieve control over the shape and size of nanofibers in electrospinning, enabling the production of tailored scaffolds for various tissue engineering applications [32,33].

5.2. Alignment of fibers

Controlling the alignment of fibers in electrospinning is important for mimicking the organized structure of native tissues and enhancing the functionality of tissue engineering constructs [32,33]. The following are some strategies for achieving fiber alignment in electrospinning.

(1) Electrospinning setup: The configuration of the electrospinning setup can influence fiber alignment. Using a rotating collector, such as a drum or mandrel, can promote fiber alignment along the axis of rotation. As the fibers are deposited on the rotating collector, the centrifugal force can align the fibers in the same direction [34].

(2) External forces: Applying external forces during electrospinning can help align the fibers. For example, a uniaxial tensile force can be applied to the polymer solution or the collected fibers to encourage alignment. This can be achieved by attaching one end of the fiber to a fixed point and applying a controlled tensile force to the other end.

(3) Template-assisted electrospinning: Templates or substrates with predefined patterns or grooves can be used to guide fiber alignment. The polymer solution is electrospun onto these templates, and the resulting fibers conform to the pattern, leading to aligned fibers. After electrospinning, the fibers can be transferred from the template or used as a template itself for further processing.

(4) Magnetic field alignment: Incorporating magnetic nanoparticles or using magnetic fields during electrospinning can enable the alignment of the fibers. Magnetic nanoparticles are added to the polymer solution, and an external magnetic field is applied during electrospinning, guiding the alignment of the nanoparticles and, consequently, the fibers.

(5) Electric field alignment: In addition to the electric field used for electrospinning, an additional electric field can be applied to align the fibers. By introducing a secondary electric field perpendicular to the primary field, the charged fibers experience lateral forces that align them in the desired direction [35].

(6) Coaxial electrospinning: Coaxial electrospinning involves using a coaxial needle setup with a core-shell structure. The polymer solution is electrospun through the core needle, while a sheath fluid is electrospun through the outer shell. The sheath fluid can act as a guiding medium, controlling the alignment of the core fibers. By implementing these strategies, researchers can achieve fiber alignment in electrospinning, leading to the fabrication of tissue engineering constructs with enhanced structural organization and functional properties [36,37].

5.3. Architecture

Controlling the architecture of fibers in electrospinning refers to manipulating their spatial arrangement and organization to create desired structures and patterns. The approaches for controlling the architecture of fibers in electrospinning are as follows.

(1) Collector design: The design of the collector can influence the architecture of the electrospun fibers. By using collectors with specific geometries, such as rotating drums, mandrels, or patterned substrates, different fiber architectures can be achieved. For example, using a collector with grooves or ridges can result in fibers arranged in specific patterns or orientations [38].

(2) Electrospinning technique variations: Various electrospinning techniques can be employed to control the architecture of the fibers. These include multi-jet electrospinning, needleless electrospinning, and near-field electrospinning. Each technique offers unique possibilities for creating specific fiber architectures, such as aligned, random, or patterned structures.

(3) Template-assisted electrospinning: Templates or sacrificial materials with predetermined shapes or patterns can be used to guide the architecture of the fibers. The polymer solution is electrospun onto the template, conforming to its shape, resulting in fibers with corresponding architectural features. Once the electrospinning is complete, the template can be removed, leaving behind the desired fiber architecture.

(4) Coaxial electrospinning: Coaxial electrospinning can be employed to create fibers with core-shell architectures. By using a coaxial needle setup, a different polymer solution or functional material can be electrospun as the core, surrounded by another polymer solution as the shell. This allows for the creation of fibers with distinct layers or encapsulation capabilities [37].

(5) Blend electrospinning: Blending different polymer solutions or incorporating functional additives can influence the architecture of the electrospun fibers. By blending polymers with different properties, such as varying viscosities or solubilities, fibers with heterogeneous architectures can be obtained. Additionally, incorporating functional materials, such as nanoparticles or bioactive molecules, into the polymer solution can create fibers with specific architectural features and functionalities.

(6) Post-electrospinning processing: After electrospinning, post-processing techniques can be used to further control the architecture of the fibers. These techniques may include heat treatment, stretching, ultraviolet crosslinking, or chemical treatments. These processes can modify the morphology, alignment, or structure of the electrospun fibers to achieve the desired architectural characteristics. By leveraging these techniques, researchers can have greater control over the architecture of electrospun fibers, enabling the fabrication of the right scaffolds [39,40].

6. Chemical approach for mimetic of cartilage tissue engineering constructs

Chemical mimetic in tissue engineering constructs of cartilage aims to replicate the biochemical composition and signaling cues found in native cartilage tissue. These mimetic approaches involve incorporating certain chemical factors into the constructs to enhance chondrogenesis and promote the formation of cartilage-like ECM. The following are some key aspects of chemical mimetics in cartilage tissue engineering.

(1) Growth factors and cytokines: Growth factors and cytokines play crucial roles in regulating cellular processes and tissue development. In cartilage tissue engineering, growth factors such as transforming growth factor-beta (TGF-β), insulin-like growth factor (IGF), and bone morphogenetic proteins (BMPs) are commonly used to stimulate chondrocyte proliferation, differentiation, and ECM synthesis. These factors can be incorporated into the scaffolds or delivered through controlled release systems to mimic the natural signaling environment of cartilage.

(2) ECM components: The ECM of cartilage contains various components that provide structural support and signaling cues for chondrogenesis. Mimicking the ECM composition is vital in cartilage tissue engineering. Chondroitin sulfate, hyaluronic acid, collagen, and other cartilage-specific matrix molecules can be incorporated into the scaffold materials to replicate the biochemical environment. Synthetic ECM analogs, such as peptide-based hydrogels or self-assembling peptides, can also be used to mimic the cartilage ECM.

(3) Small molecule modulators: Small molecules can be used as mimetics to regulate specific biological processes in cartilage tissue engineering. These molecules can modulate key signaling pathways and cellular activities involved in chondrogenesis. For example, small molecule agonists or antagonists of specific receptors or transcription factors, such as the Wnt/β-catenin pathway or the Sox9 transcription factor, can be used to promote or inhibit chondrocyte differentiation, respectively.

(4) Mechanical loading mimetics: Mimicking the mechanical cues experienced by cartilage tissue can be achieved through chemical means. Certain compounds, such as calcium channel agonists or cyclic adenosine monophosphate (cAMP) inducers, can be used to mimic the mechanical strain and stimulate chondrogenic responses. These chemicals activate intracellular signaling pathways that regulate gene expression and ECM synthesis in response to mechanical loading.

(5) Oxygen mimetics: Oxygen tension plays a critical role in cartilage physiology and chondrogenesis. In mimetics, hypoxia-mimicking strategies can be employed to create a low-oxygen environment similar to native cartilage [41].

6.1. Matching chemical content in chemical mimetic of electrospun nanofiber

When designing chemical mimetics in electrospun nanofibers, the goal is to match the chemical content to replicate the desired properties or functions of a target material or biological structure. There are some factors to consider for matching chemical content in the mimetic.

(1) Polymer selection: The choice of polymer used in electrospinning plays a crucial role in determining the chemical composition of the nanofibers. Different polymers offer distinct properties and characteristics. For example, polylactic-co-glycolic acid (PLGA) is commonly used for tissue engineering applications due to its biocompatibility and biodegradability. Other polymers, such as polyethylene oxide (PEO), polycaprolactone (PCL), or polyvinyl alcohol (PVA), may be preferred for specific purposes [42].

(2) Incorporation of biomolecules: Mimicking the chemical content of natural tissues often involves the incorporation of specific biomolecules, such as growth factors, cytokines, or extracellular matrix components. These molecules can be added to the polymer solution before electrospinning or incorporated into the nanofibers through post-electrospinning modification techniques [43].

(3) Controlled release systems: To mimic the release of specific chemicals or drugs from the nanofibers, controlled release systems can be incorporated. This can involve the use of drug-loaded nanoparticles, microparticles, or encapsulation of the active compounds within the nanofiber matrices. The choice of release system will depend on the desired release kinetics and stability of the incorporated chemicals [44,45].

(4) Surface functionalization: The chemical content of the nanofiber surface can be modified through surface functionalization techniques. This may involve grafting specific functional groups, such as –COOH or $–NH_2$, onto the nanofiber surface to enable further chemical reactions or to provide specific functionalities [46].

(5) Nanoparticle or nanocomposite incorporation: To introduce specific chemical content, nanoparticles or nanocomposites can be incorporated into the nanofibers. These nanoparticles can provide additional properties, such as enhanced mechanical strength, conductivity, or targeted drug delivery capabilities. Examples include incorporating silver nanoparticles for antimicrobial activity or magnetic nanoparticles for targeted drug delivery.

Matching the chemical content in chemical mimetics of electrospun nanofibers involves a careful selection of polymers, incorporation of biomolecules, controlled release systems, surface functionalization, and nanoparticle incorporation. These strategies allow for the replication of desired chemical properties and functions, making electrospun nanofibers versatile and customizable [47].

6.2. Manipulation of chemical composition in chemical mimetic of electrospun nanofiber

The chemical composition of electrospun nanofibers can be manipulated through various techniques to achieve desired properties and functions. Some methods to manipulate the chemical composition in chemical mimetics of electrospun nanofibers are as follows.

(1) Polymer blending: By blending different polymers with complementary properties, nanofibers with unique compositions and properties can be produced. For example, blending a biodegradable polymer like PLGA with a conductive polymer like polyaniline can result in nanofibers with combined biodegradability and electrical conductivity [48,49].

(2) Multi-layer electrospinning: In multi-layer electrospinning, multiple layers of different polymers or polymer solutions are sequentially deposited during the electrospinning process. This technique enables the creation of nanofibers with layered structures and varying chemical compositions. Each layer can serve a specific purpose or provide different functionalities.

(3) Surface modification: Surface modification techniques, such as plasma treatment or chemical grafting, can be used to introduce specific functional groups or chemical moieties onto the surface of electrospun nanofibers. This allows for the manipulation of the surface chemistry and composition, enabling interactions with biological molecules or targeted drug delivery [50].

(4) Encapsulation of additives: Additives, such as nanoparticles, drugs, or biomolecules, can be encapsulated within the electrospun nanofibers to alter their chemical composition. By incorporating these additives during the electrospinning process, desired properties or functions can be introduced to the nanofibers.

(5) Chemical doping: Chemical doping involves introducing small amounts of a dopant material into the polymer solution before electrospinning. The dopant can modify the chemical composition and enhance specific properties, such as conductivity or mechanical strength. These methods provide ways to manipulate the chemical composition of electrospun nanofibers, allowing for customization and tailoring of their properties and functions. Depending on the desired outcome, one or a combination of these techniques can be employed to achieve the desired chemical composition in the nanofibers [51].

6.3. Surface mimetics

Surface mimetics in chemical mimetics of electrospun nanofibers involves modifying the surface properties to replicate or mimic specific features found in natural surfaces. The following are some techniques for incorporating surface mimetics into electrospun nanofibers.

(1) Surface texturing: Electrospun nanofibers can be designed to mimic the surface texture of natural structures. By controlling the parameters during electrospinning, such as the collector design or the addition of sacrificial templates, nanofibers with surface features like ridges, grooves, or pores that resemble natural surfaces can be created.

(2) Surface functionalization: Surface functionalization involves attaching specific functional groups or molecules onto the surface of electrospun nanofibers. This can be achieved through techniques such as chemical grafting, physical adsorption, or covalent bonding. By introducing functional groups like –COOH, $–NH_2$, or –OH, the surface chemistry found in natural materials can be mimicked.

(3) Biomineralization: Mimicking the mineralization found in natural structures, such as bone or teeth, can be achieved by promoting the deposition of minerals onto the surface of electrospun nanofibers. This can be done by incorporating mineral precursors into the electrospinning solution or through post-electrospinning mineralization processes. The resulting mineralized surface mimics the composition and structure of natural mineralized tissues [52].

(4) Biomolecule immobilization: To replicate the interactions between natural surfaces and biomolecules, specific biomolecules can be immobilized onto the surface of electrospun nanofibers. This can be done through techniques like physical adsorption, covalent bonding, or layer-by-layer assembly. By immobilizing proteins, growth factors, or other bioactive molecules, nanofiber surfaces that mimic the bioactivity and signaling capabilities of natural surfaces can be created.

(5) Surface patterning: Patterning techniques, such as microcontact printing or photolithography, can be used to create specific patterns or motifs on the surface of electrospun nanofibers. This allows for the replication of surface features found in natural structures, including directional cues, topographical patterns, or microscale designs. By incorporating surface mimetics into electrospun nanofibers, you

can replicate or mimic the surface properties and functionalities of natural materials. These approaches enable the development of biomimetic materials with tailored surface characteristics, which have applications in tissue engineering, drug delivery, biosensing, and other fields [53].

(6) Surface functionality: Tailoring the surface functionality of electrospun fibers is crucial for many applications, as it can influence cell-material interactions, protein adsorption, and overall biomaterial performance. There are some strategies for achieving surface functionality in electrospun fibers. The first strategy is surface modification. After electrospinning, the fibers can undergo various surface modification techniques to introduce functional groups or specific chemical moieties. Common methods include plasma treatment, ultraviolet/ozone treatment, and chemical grafting. These techniques can alter the surface chemistry of the fibers, enabling the attachment of bioactive molecules, such as peptides or growth factors, or providing functional groups for subsequent reactions. Secondly, electrospun fibers can be functionalized by immobilizing biomolecules directly onto their surfaces. This can be achieved through physical adsorption, covalent binding, or layer-by-layer assembly. Biomolecules, including peptides, proteins, enzymes, or DNA, can be attached to the fiber surface to impart specific functionalities, such as cell adhesion, bioactive signaling, or antimicrobial properties. By employing these strategies, the surface functionality of electrospun fibers can be tailored to meet specific requirements, enabling enhanced biocompatibility, controlled drug delivery, cell adhesion, and other desirable properties for various biomedical applications [46].

Figure 7 reveals the surface functionalization of PLGA nanofibers with sodium hydroxide (NaOH) treatment to activate the carboxyl/hydroxyl group of the PLGA. By grafting –COOH or –NH_2 groups onto the electrospun PLGA fibers, the functional groups that can enable further chemical reactions can be introduced, such as covalent coupling with biomolecules or attachment to other surfaces, for enhanced bioactivity, cell adhesion, or drug delivery capabilities. The grafting of –NH_2 on the PLGA nanofibers is also known as aminolysis and can be carried out with PLGA fibers treated with ethylenediamine (ED), N-aminoethyl-1,3-propanediamine (AEPDA). These amine-functionalized fibers can provide opportunities for bioconjugation and customization of the fiber surface for specific applications in tissue engineering or drug delivery [46].

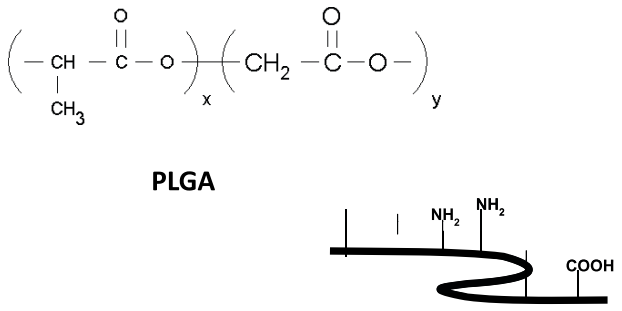

Figure 7. Surface functionalization of PLGA nanofibers

The toluidine absorbance assay is a commonly used method for quantifying the sulfated glycosaminoglycan (GAG) or carboxyl group content in biological samples or biomaterial after functionalization. The toluidine absorbance assay is widely used in various fields, including cartilage tissue engineering, osteoarthritis research, and glycosaminoglycan analysis. This assay was used to evaluate the carboxyl group in PLGA nanofibers after being treated with NaOH solutions. The prolonged treatment of fibers with NaOH affects the fibers' morphology and topography. **Figure 8** shows the toluidine absorbance assay for the quantified amount of carboxyl group on the scaffolds.

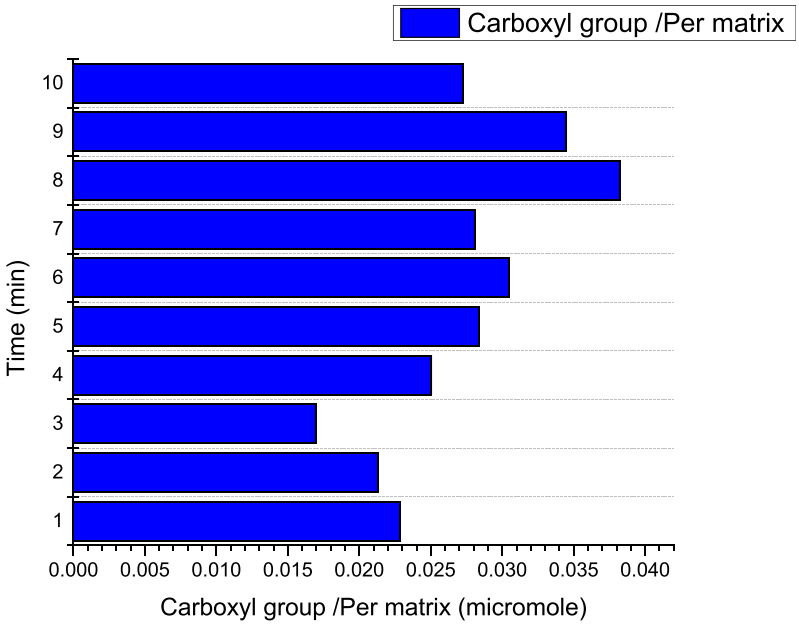

Figure 8. Toluidine absorbance assay

7. Biological approach for mimetic of cartilage tissue engineering constructs

Biological mimetic plays a crucial role in tissue engineering electrospun scaffolds as it aims to replicate the structural and functional properties of natural tissues. Some examples of biological mimetics used in tissue engineering electrospun scaffolds are as follows.

(1) ECM mimetics: The ECM provides a supportive microenvironment for cells in natural tissues. Electrospun scaffolds can be designed to mimic the composition and structure of the ECM by incorporating natural or synthetic polymers that resemble ECM components. For example, collagen, elastin, or hyaluronic acid can be electrospun to create scaffolds that mimic the ECM of specific tissues.

(2) Nanofiber alignment: Natural tissues often exhibit anisotropic properties due to the aligned arrangement of their structural components. Electrospinning techniques can be used to align the nanofibers in a specific direction, mimicking the organization found in native tissues. This aligned nanofiber structure can guide cell orientation, promote tissue alignment, and enhance mechanical properties.

(3) Growth factor mimetics: Growth factors play a crucial role in tissue development and regeneration. Electrospun scaffolds can be designed to incorporate growth factors or their mimetics, such as peptide sequences, that can guide cellular behavior and promote tissue regeneration in a controlled manner. Controlled release systems can also be incorporated to provide sustained delivery of growth factors.

(4) Cell-adhesive mimetics: Cell-adhesive molecules found in the ECM, such as fibronectin or laminin, can be incorporated into electrospun scaffolds to create cell-friendly environments. This can be achieved through surface functionalization or by blending the polymer solution with cell-adhesive peptides. Mimicking cell-matrix interactions can enhance cell adhesion, migration, and overall tissue integration.

(5) Vascular network mimetics: Vascularization is critical for the survival and function of engineered tissues. Electrospun scaffolds can be designed to mimic the architecture of blood vessels by

incorporating sacrificial templates or creating interconnected channels. These scaffolds can provide a framework for the formation of a functional vascular network, enabling nutrient and oxygen delivery to cells within the engineered tissue.

(6) Mechanical mimetics: Mimicking the mechanical properties of native tissues is essential for successful tissue engineering. Electrospun scaffolds can be tailored to match the mechanical properties of specific tissues by selecting appropriate polymer compositions, adjusting fiber diameter and density, or incorporating reinforcing materials like nanoparticles or nanofibers. By incorporating these biological mimetics into tissue engineering electrospun scaffolds, researchers can create novel tissue engineering scaffolds [54].

7.1. Protein adsorption (adhesive protein)

Electrospun nanofibrous tissue engineering scaffolds have the capability to mimic adhesive proteins found in the extracellular matrix of natural tissues. Electrospun nanofibrous scaffolds can exhibit adhesive protein capabilities through the methods below.

(1) Surface functionalization: Electrospun nanofibers can be surface-functionalized with adhesive proteins, such as fibronectin, laminin, or collagen. This can be achieved through various techniques, including physical adsorption, covalent bonding, or layer-by-layer assembly. The immobilization of these adhesive proteins on the nanofiber surface enhances cell attachment and promotes cellular interactions, mimicking the adhesive properties of natural tissues.

(2) Peptide incorporation: Synthetic peptides derived from adhesive proteins, such as the cell-binding domains of fibronectin (e.g., arginine-glycine-aspartate peptide [RGD]), can be incorporated into the polymer solution before electrospinning. These peptides provide specific sites for cell adhesion and can enhance the adhesive capabilities of the nanofibers.

(3) Bioactive molecule release: Electrospun scaffolds can also be designed to incorporate bioactive molecules, including adhesive proteins or their fragments, for controlled release. This can be achieved by encapsulating the bioactive molecules within nanoparticles or microparticles, which are then dispersed within the nanofiber matrix. Controlled release of these molecules from the scaffolds can promote cell adhesion, migration, and tissue integration.

(4) Nanofiber alignment: Electrospinning techniques can be used to align nanofibers in a specific direction, creating a biomimetic topography that enhances cell adhesion. The aligned nanofibers provide guidance cues for cell attachment and alignment, replicating the natural alignment of cells in tissues.

(5) Cell-adhesive polymer blending: Electrospinning allows for the blending of different polymers with cell-adhesive properties. By incorporating polymers with inherent adhesive capabilities, such as gelatin or chitosan, into the electrospun nanofibers, the scaffold's adhesive capabilities can be enhanced.

The adhesive protein capabilities of electrospun nanofibrous tissue engineering scaffolds promote cell attachment, spreading, and proliferation, which are crucial for successful tissue regeneration. These capabilities improve the integration of the scaffold with surrounding tissues and facilitate the formation of functional engineered tissues [55].

7.2. Protein delivery

Electrospun nanofibrous scaffolds can be utilized for the delivery of proteins to promote cartilage growth in tissue engineering applications. Protein delivery can be achieved using electrospun nanofibrous scaffolds for cartilage regeneration as follows.

(1) Encapsulation within nanofibers: Proteins relevant to cartilage growth, such as growth factors (e.g.,

TGF-β, BMPs) or cartilage-specific proteins (e.g., collagen type II), can be encapsulated within the electrospun nanofibers during the fabrication process. This can be achieved by incorporating the proteins into the polymer solution before electrospinning. The proteins are then distributed throughout the nanofiber matrix, allowing for sustained release over time.

(2) Coating of nanofibers: Electrospun nanofibers can be coated with protein-loaded films or layers. This can involve techniques like dip-coating or layer-by-layer assembly, where the protein solution is applied to the surface of the nanofibers. The coating acts as a reservoir for protein release, enabling controlled and localized delivery.

(3) Surface functionalization: The surface of electrospun nanofibers can be functionalized with proteins using techniques like physical adsorption or covalent bonding. The protein-coated surface provides a direct interface for interaction with cells, promoting cartilage growth. Functionalization can be achieved by incubating the nanofiber scaffold with a protein solution or by modifying the nanofiber surface with specific reactive groups for protein attachment.

(4) Micro- or nanoparticle encapsulation: Proteins can also be encapsulated within micro- or nanoparticles that are subsequently incorporated into the electrospun nanofibers. These particles can release proteins gradually as they degrade or when triggered by specific stimuli. The combination of electrospun nanofibers and protein-loaded particles allows for sustained protein release and localized delivery within the scaffold. The controlled release of proteins from electrospun nanofibrous scaffolds promotes cartilage growth by providing a bioactive environment for cells and facilitating tissue regeneration. The released proteins can stimulate cell proliferation, differentiation, and extracellular matrix production, aiding in the development of functional cartilage tissue [56].

Figure 9 shows the bovine serum albumin from PLGA/PPG electrospun nanofibrous scaffold. Pure PLGA scaffold is highly hydrophobic when compared with other scaffolds and PPG addition improves the protein adsorption and release from the scaffolds. It concludes that the hydrophobicity of PLGA can be reduced by the incorporation of PPG in the scaffolds.

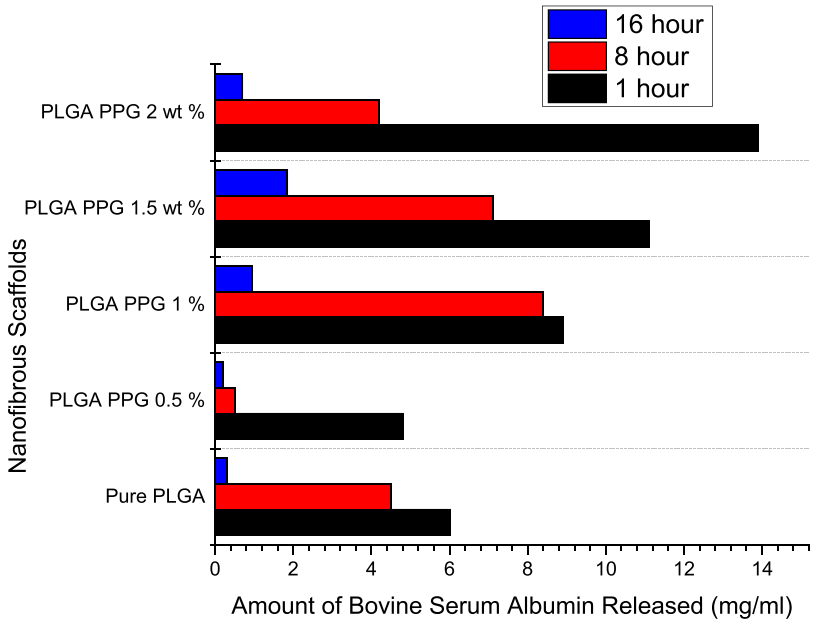

Figure 9. Protein release from PLGA/PPG electrospun nanofibrous scaffold

7.3. Cell behavior

Cells exhibit specific behaviors on electrospun nanofibrous scaffolds designed for cartilage repair. The key behaviors observed are as follows.

(1) Cell adhesion: Electrospun nanofibrous scaffolds provide a favorable surface for cell adhesion. The nanofiber structure mimics the extracellular matrix and offers physical cues for cells to attach. Cells, such as chondrocytes or mesenchymal stem cells, adhere to the nanofibers through integrin-mediated interactions, promoting cellular attachment and spreading.

(2) Cell migration: Electrospun nanofibrous scaffolds with aligned nanofiber architecture can guide cell migration. Cells tend to align and migrate along the direction of the aligned nanofibers, mimicking the natural alignment of cells in cartilage tissue. This alignment facilitates cell migration and tissue regeneration within the scaffold.

(3) Cell proliferation: Electrospun nanofibrous scaffolds can support cell proliferation. The nanofiber architecture provides a high surface area-to-volume ratio, allowing for efficient nutrient and oxygen exchange. The three-dimensional porous structure of the scaffold also allows cells to proliferate and populate throughout the scaffold, promoting tissue regeneration.

(4) ECM production: Cells cultured on electrospun nanofibrous scaffolds for cartilage repair show the ability to produce cartilage-specific ECM components, such as collagen type II and proteoglycans. The nanofiber structure promotes cell-secreted ECM deposition and organization, leading to the development of a cartilage-like matrix within the scaffold.

(5) Differentiation potential: Electrospun nanofibrous scaffolds can induce chondrogenic differentiation of stem cells. The nanofiber architecture, combined with appropriate biochemical cues such as growth factors or specific culture conditions, can drive MSCs toward a chondrogenic lineage, enabling the generation of functional cartilage tissue.

(6) Integration with surrounding tissue: Electrospun nanofibrous scaffolds can facilitate integration with surrounding tissue upon implantation. The nanofiber structure allows for cellular infiltration and vascularization, promoting the integration of the scaffold with the host tissue. This integration is crucial for the long-term stability and functionality of the repaired cartilage.

The behaviors exhibited by cells on electrospun nanofibrous scaffolds for cartilage repair are essential for successful tissue regeneration. Through adhesion, migration, proliferation, ECM production, differentiation, and integration, the cells contribute to the formation of functional cartilage tissue within the scaffold, aiding in the repair and regeneration of damaged cartilage [57].

8. Conclusion

Electrospinning is a flexible biofabrication method for developing tissue engineering scaffolds for cartilage repair. These works conclude the modification strategies for electrospun PLGA scaffolds. Tissue engineering involves using cells, engineering methods, and materials to improve or replace biological functions at an injured site. Biodegradable polymer nanofibers fabricated by electrospinning have great potential for tissue engineering applications, as they mimic the natural extracellular matrix and provide a favorable microenvironment for cells. The addition of a small amount of hydrophilic polymer to a biodegradable hydrophobic polymer can improve the hydrophilicity of electrospun nanofibers and can be used for nanofiber-based tissue engineering constructs. Physical, chemical, and biological mimicking promotes tissue engineering applications for cartilage repair. Tissue engineering offers the potential to create effective novel treatments, known as “biological substitutes,” for structural and functional ailments in human health, which have historically posed challenges

that conventional medical approaches have struggled to overcome.

Disclosure statement

The author declares no conflict of interest.

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Surgery for Spinal Deformities in Patients with Osteoporosis — A Secondary Publication

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Abstract: *Objective:* This review aims to present relevant considerations for the surgical treatment of spinal deformities accompanied by osteoporosis, how surgeons are trying to overcome the challenges posed by osteoporosis in patients with spinal deformities, and directions for further development. *Summary of literature review:* Various trials have been carried out to overcome the short- and long-term complications associated with osteoporosis in order to achieve successful clinical results in the surgical treatment of spinal deformities. *Methods:* A comprehensive review of relevant articles was conducted. *Results:* The surgical goal of treating spinal deformities is to reverse neurological compromise and restore balanced spine alignment. To achieve these goals, several surgical considerations should be kept in mind. Osteoporosis is an important issue related to early and long-term complications following surgery. Methods of overcoming the challenges posed by osteoporosis such as rigid fixation techniques, proper selection of the fusion levels, perioperative medical treatment, and effective bone grafting materials are described herein; however, further development in these areas is also necessary. *Conclusions:* Osteoporosis may be a major obstacle in spinal deformity surgery. Although several effective attempts have been made to overcome these limitations, further research and trials are necessary to obtain better results.

Keywords: Spine; Deformity; Osteoporosis; Kyphosis; Scoliosis

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1. Introduction

In the treatment of spinal disorders that have all three components of musculoskeletal symptoms including pain, paralysis, and deformity, the goal of surgical treatment is to treat neuropathy caused by nerve compression and, if necessary, decompress the nerves through fusion. The goal is to achieve a balanced spinal alignment through the correction of deformities. As life expectancy increases due to advances in medicine, the number of people suffering from musculoskeletal disorders is gradually increasing and the demand for active treatment is rising. In the case of spinal deformity, surgical treatment requires fusion of the long segments to achieve correction of the deformity. Osteoporosis, which is particularly associated with short-term and long-term prognosis of surgical treatment, is a common limitation for clinicians, and many attempts have been made to overcome this. This review article aims to address the issue of osteoporosis in the surgical treatment of spinal deformity by

summarizing the existing studies on this topic.

2. Spinal deformities

Among spinal deformities, adult spinal deformities are congenital and developmental spinal deformities that occur in the adult forms of spinal deformity, secondary degenerative spine diseases that develop later in life, deformities associated with infection, trauma, or surgery, and systemic conditions such as ankylosing spondylitis. It occurs for various reasons, such as deformation of the spine that occurs in connection with the disease (**Table 1**). Surgical treatment consists of treatment for neuropathy and correction of the deformity in conjunction with the purpose of restoring a balanced alignment of the spine in the sagittal and coronal planes. The definition and classification of these adult spinal deformities was first proposed by Aebi in 2005, focusing on coronal plane deformities [1], followed by Glassman [2] in 2007, who recognized that sagittal plane imbalances were more clinically significant than coronal plane imbalances. Since its publication, studies have reported on the importance of restoring and maintaining pelvic spinal alignment and alignment of the entire spine along with sagittal balance, and classifications of adult spinal deformity based on sagittal balance have been proposed [3]. Since this article is limited in scope to provide a comprehensive classification of these adult spinal deformities and their treatment, we would like to present points to consider when planning surgical treatment for spinal deformities accompanied by osteoporosis.

Table 1. Classification of adult spinal deformities according to causes

Type	Examples
Type I: Adult form of developmental deformity	Adult form of AIS
	Adult form of congenital abnormality
	Adult form of Scheurmann's disease
Type II: De novo spinal deformity	Degenerative kyphosis/ Scoliosis
	Senile kyphosis
	Hip/knee spine syndrome
Type III: Secondary deformity	Post-traumatic
	Post-infection
	Post-surgery
Type IV: Systemic condition related	Ankylosing spondylitis
	Parkinsonism
	Connective tissue disorders

3. Preoperative evaluation and preparation

When it comes to the assessment of osteoporosis, bone mineral densitometry (BMD) has been the most utilized test, and it is used as the standard for treatment of osteoporosis based on the T-score. However, due to insurance coverage of the test in limited cases and factors that affect the measurement of degenerative changes in the spine and aortic calcification, questions about clinical reliability and meaning, as well as problems with discrepancies in hip joint and spine have been raised. However, as there is currently no indicator that can be used as an alternative, it has been used as a standard for preoperative evaluation [4]. In addition to the preoperative evaluation of osteoporosis, it is also important to evaluate for factors associated with previous

osteoporosis, such as vertebral compression fractures. Many of these adult spinal deformities with osteoporosis are accompanied by degenerative sagittal imbalance, and one of the pathological mechanisms is suggested to be a decrease in the central trunk muscles, including the erector spinae, so it is also necessary to evaluate sarcopenia through analysis of muscle mass, strength, and walking ability [5,6]. The diagnostic criteria of sarcopenia are based on imaging studies such as MRI/Dual-energy x-ray absorptiometry (DEXA), measurement of muscle mass, gait speed, and assessment of muscle strength using instruments such as dynamometers [5]. However, considering that in many cases of patients with degenerative sagittal imbalance in clinical practice, grip strength, which is used as a measure of muscle contractility, does not decrease, and the contractility of the central muscles of the trunk is significantly reduced, it is believed that more research is needed on this. In addition, there is some controversy regarding the treatment of osteoporosis before surgery. There are reports that the use of osteogenesis stimulants is more beneficial than bone resorption inhibitors in the initial treatment of osteoporotic vertebral body fractures, and that it promotes union when used after fusion surgery [7,8]. Although more research needs to be done on its use before and after surgery, given the fragmentary but consistent results reported in these studies, the preoperative use of osteogenesis stimulants is recommended. However, there is insufficient evidence to support the use of bone resorption inhibitors and their replacement, so it is difficult to draw conclusions about the choice of osteoporosis medication in relation to surgery.

4. Intraoperative considerations

During surgical treatment of spinal deformity accompanied by osteoporosis, the expected complications related to osteoporosis are the problems of loosening of the internal fixation within the first 3 months, leading to loss of reduction of the deformity, causing recurrence of neurological symptoms or nonunion. Long-term problems can be caused by failure of fusion, which manifests itself in the form of damage to the internal fixation and is often accompanied by worsening clinical symptoms. Additionally, increased dynamic stress on adjacent segments due to osteoporosis or fusion may lead to fractures of adjacent segments. In an effort to reduce the morbidity of early internal fixation, the most commonly used methods are UIV (upper instrumented vertebra) and LIV (lower instrumented vertebra) with osteosynthesis of either polymethyl methacrylate (PMMA) or calcium-based bone cement. Biomechanical studies have shown that in the case of vertebrae without osteoporosis, this method of reinforcement makes a difference in the resistance to traction force of the internal fixator. However, in the case of vertebral bodies with osteoporosis, it is reported that the addition of reinforcement procedures increases the resistance to traction force by about 1.5 to 2 times [9]. Some studies report similar results in studies of the toggling load applied to internal fixation due to the effects of repetitive axial compression. In a study on the amount of bone cement inserted in such reinforcement surgery, the amount of 2–3 cc of bone cement was sufficient for the fixation within each corner [10], and in case of a larger volume, the risk of complications such as leakage of bone cement following insertion is increased, but the mechanistic benefit is not high. The timing of the insertion of the internal fixture after the injection of the bone cement is important. In many cases, the internal fixture is inserted after the injection of cement and before the hardening of the bone cement (soft cement technique), but in some cases, the internal fixture is inserted after the cement has solidified (hard cement technique). In studies comparing the two techniques, the mechanics are similar, but the risk of fixation failure due to crossing the stress point is higher in the soft cement technique. In the case of fixation failure with soft cement, the failure may be due to dissociation between the osteoid and trabecular bone. The number of internal fixture inserted using the soft cement technique is lower. It is believed that the soft cement technique has the advantage of reducing the number of internal fixture insertions and obtaining initial fixation between bone cement and internal fixture [11,12]. In a study on the use of fenestrated pedicle screws and regular screws,

fenestrated internal fixators have the advantage of reducing the insertion time. In addition, the method of inserting an internal fixation after cement injection may require a long insertion time and has disadvantages in terms of leakage of bone cement, but the results of research so far show that the difference in mechanics is not significant [13,14]. In the case of bone cement used, when comparing PMMA and calcium-based cements such as calcium sulfate and calcium phosphate, PMMA has higher initial strength, but it has the disadvantage of a higher risk of leakage. In addition, calcium-based cements have the advantage of osteogenic ability, but the hardening process of inserted calcium-based cement requires time. It is disadvantageous in terms of stability of the initial internal fixation because it requires time to harden and set. The design of the internal fixation may also have an impact, and there are design changes that seek to increase the initial fixation force by making a difference in the screw lines of the vertebral body and pedicle positions through changes in the design of the pedicle screw line, and other changes in the internal fixation. Studies are being conducted to overcome this problem by changing the internal fixation. In addition, proximal fixation with hooks other than pedicle screws, such as ultrahigh molecular weight polyethylene (UHMWPE) and UIV +1 vertebroplasty have been attempted, but reports on long-term outcomes are required [15-17].

In adult spinal deformities, restoring coronal and sagittal plane balance is an important factor in the maintenance of initial fixation and the success rate of fusion. The selection of an appropriate range of fusion is critical, and there is much more to this topic than can be covered here. However, in general, current research suggests that restoration of the sagittal plane is more important. A method has been proposed to predict and restore appropriate lumbar lordosis and thoracic lordosis by taking into account the spine-pelvis relationship completed during the individual's growth. In many cases of degenerative kyphosis, the posterior dislocation of the pelvis is the main change, so it is necessary to correct it to restore the normal sagittal plane. For this purpose, correction between the spine and pelvis is often required, and it is necessary to select the extent of distal fusion using iliac screws, etc. (**Figure 1**) [18,19].

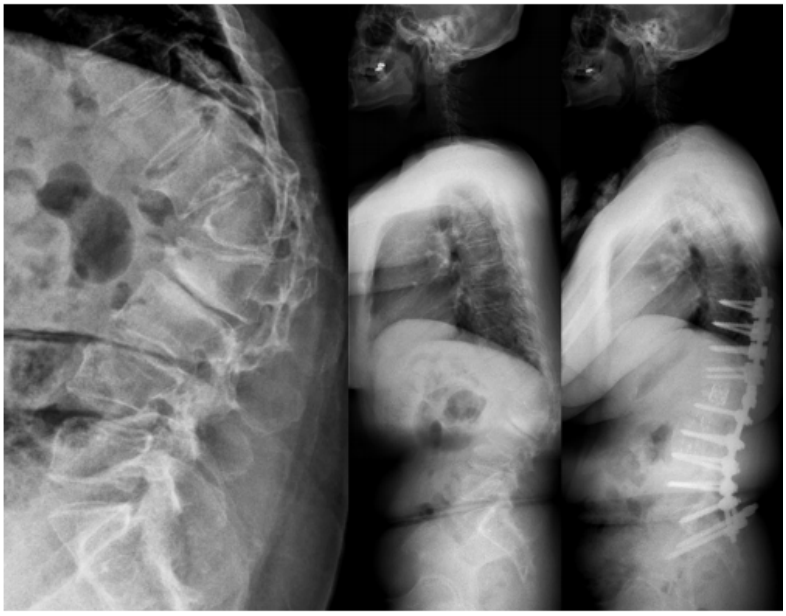

Figure 1. A 65-year-old woman underwent anterior-posterior reconstructive surgery for secondary kyphosis related to congenital anomaly. To prevent pseudoarthrosis at the osteotomy site, anterior fusion was also performed.

The selection of the proximal fusion site beyond the thoracolumbar transition area is the most common method to date. However, there are relatively many proximal transitional kyphotic deformities and the problems

resulting from them. Recently, there have been claims that it is necessary to select the upper thoracic spine as the proximal fusion range due to the occurrence of such cases. In adolescent spinal deformity or neuropathic spinal deformity, for which surgical treatment is performed at a relatively young age, the frequency of nonunion is 1.4 to 2.0%. However, in adult spinal deformities, many of which are accompanied by degenerative changes, osteoporosis, and sarcopenia, a higher rate of nonunion (6.3%) has been reported [20]. Therefore, in the surgical treatment of adult spinal deformities, analysis of the cause and extent of the deformity and the selection of an appropriate fusion range are also important to achieve good clinical outcomes.

5. Efforts to prevent misalignment

As described above, surgical treatment for spinal deformities arising from a variety of causes takes into account a number of factors such as osteoporosis, degenerative changes in the spine, and sarcopenia, and more efforts are made to achieve correction and fusion of the deformity. Among these, in cases of union that are related to long-term prognosis, the presence of osteoporosis is associated with an increase in nonunion along with the dissociation of the initial internal fixation [20,21]. In the presence of concurrent osteoporosis, nonunion is more likely to occur in association with decreased osteogenic capacity. In addition, failure of initial internal fixation may also be associated. Anterior intervertebral fusion is used as a method to overcome this problem, and it has been shown to be effective in correcting deformity [19,22] and its active use is needed to achieve a more robust correction and union (**Figure 2**). Posterior correction and posterior or posterolateral fusion, which are commonly performed, are not complete unions, so in the case of long-segment fusions, even if fusion is confirmed radiologically, anterior motion remains, which can lead to nonunion and rupture of the internal fixator. In one study, posterior fusion for adult spinal deformity was associated with radiographic nonunion and internal fixation failure. In one study, posterior fusion for adult spinal deformity was radiologically determined to be fusion, but it was reported that rupture of the internal fixation and nonunion occurred in 9.5% of cases during follow-up [23]. In the surgical treatment of adult spinal deformity, active anterior fusion is necessary in cases where lumbar and sacral fusion is required; where trilaminar osteotomy is required; and where intervertebral disc gap remains at the site of fusion. As alternative method for posterior fixation, fixation using multiple steel rods and different types of rods has been proposed [24]. In addition, considering the material properties of steel wires, more solid fixation and steel wire of various materials are used for stronger fixation and durability. Bone grafting is the most important element of bone fusion, autologous bone grafting is the best method, but in most cases, the use of bone substitutes is often necessary for long segmental fusion, osteoporosis, and lack of sufficient autologous bone. To date, among the commercially available bone substitutes, bone morphogenetic proteins (BMPs) are the most effective [25], but its general use is limited due to several problems. In addition, research and experiments on the development and commercialization of bone graft materials using autologous cells are underway [26], so it is expected that more diverse bone graft materials will be available to choose from in the future. Although much research is still needed on the use of osteoporosis drugs, most clinical studies report that the use of bisphosphonate, the most commonly used osteoporosis medication, has no clinical impact on bone union. However, laboratory studies, including animal studies, have reported negative effects on early bone union, thus further studies are needed to confirm this conclusion [8,27,28]. Among osteoporosis treatments, the use of osteogenic agents can be considered as it has been reported that they can promote bone union and reduce loosening of internal fixation when used in early fusion [7,8,27]. Furthermore, the long-term outcome remains to be studied.

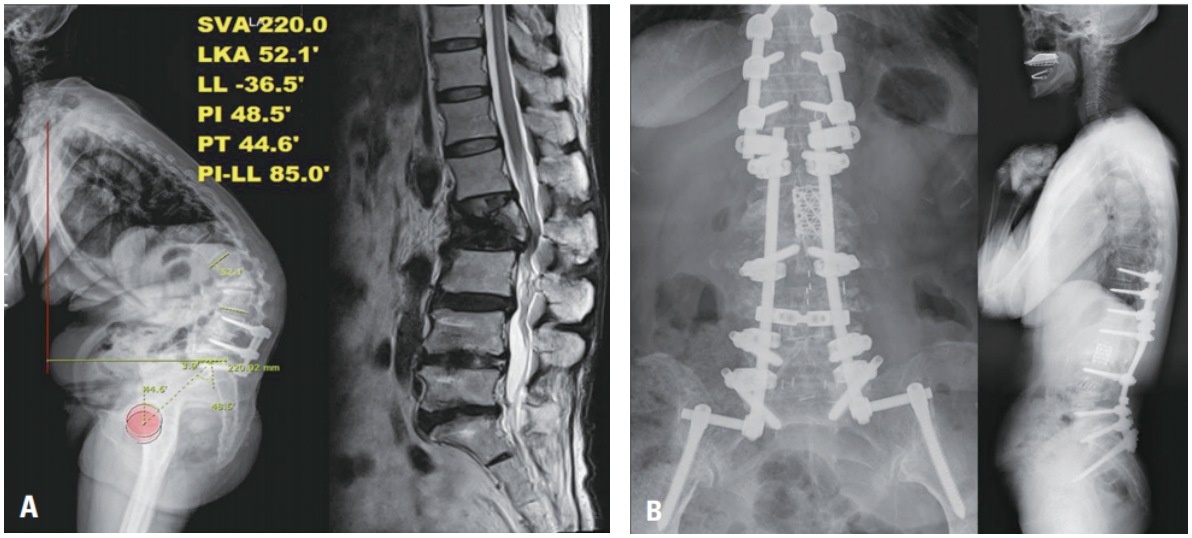

Figure 2. A 76-year-old woman presented with lumbar degenerative kyphosis combined with post-traumatic kyphosis. To restore the sagittal alignment, posterior 3-column osteotomy was done with interbody fusion for the lumbar lesions.

6. Conclusion

Surgical treatment of spinal deformity is aimed at improving neurological symptoms and restoring sagittal and coronal plane balance. Preoperative, postoperative, short- and long-term problems associated with osteoporosis should be recognized and efforts should be made to prevent them. To this end, more research on the scope, method, and selection of appropriate fusion, internal fixation, and bone graft materials is needed.

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Disclosure statement

The authors declare no conflict of interest.

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Analysis of the Effect of Rehabilitation Nursing Intervention on Functional Recovery in Patients with Rheumatoid Arthritis

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Abstract: *Objective:* To explore and analyze the effect of rehabilitation nursing intervention on functional recovery in patients with rheumatoid arthritis. *Methods:* From May 2020 to May 2023, 150 patients with rheumatoid arthritis who received integrated treatment of Tibetan and Western medicine in the rheumatology department were selected as the research subjects. They were divided into the rehabilitation group and the reference group according to the double-blind mechanism, with 75 cases in each group. The rehabilitation group received rehabilitation nursing intervention and the reference group received basic nursing. The standard of living, joint function recovery, and nursing satisfaction were compared between the two groups. *Results:* Before the intervention, there was no statistically significant difference ($P > 0.05$) in living standards such as physiology, mental outlook, emotional performance, and social culture between the groups. After the intervention, the standard of living such as culture, of the rehabilitation group was significantly better than that of the reference group ($P < 0.05$). Before the intervention, there was no statistically significant difference ($P > 0.05$) in the recovery of joint functions such as the number of joint tenderness, grip strength of both hands, duration of morning stiffness, and number of joint swelling among the groups. After the intervention, the number of joint tenderness, hand grip strength, duration of morning stiffness, number of joint swelling, and other joint function recovery in the rehabilitation group were significantly better than those in the reference group ($P < 0.05$). The nursing satisfaction of the rehabilitation group was significantly higher than that of the reference group ($P < 0.05$). *Conclusion:* Rehabilitation nursing intervention can accelerate the recovery of joint function and improve the living standard of patients with rheumatoid arthritis.

Keywords: Rehabilitation nursing intervention; Rheumatoid arthritis; Functional recovery effect

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1. Introduction

Rheumatoid arthritis is a common autoimmune disease in the immunology department. The disease can cause joint pain, swelling, and stiffness in the morning and affects 80% of women [1]. The age of disease onset ranges relatively wide, the genetic predisposition is obvious, and its pathogenesis still requires further study [2]. The onset of rheumatoid arthritis is relatively insidious. Symptoms appear first in the joints of the upper extremities,

which can lead to severe joint deformities in patients in the late stage [3]. At present, the disease can be controlled with treatment. After treatment, patients' work and life will not be greatly affected, but it cannot be completely cured. The main treatment principles are to control the development of the disease and improve the range of motion of joints [4]. Rehabilitation nursing is a nursing model with physical rehabilitation as the core. Patients with rheumatoid arthritis who receive rehabilitation nursing while receiving treatment will have more significant control over their disease [5]. The purpose of this paper is to study and analyze the effect of rehabilitation nursing intervention on the functional recovery of patients with rheumatoid arthritis.

2. General information and methods

2.1. General information

From May 2020 to May 2023, 150 patients with rheumatoid arthritis who received integrated treatment of Tibetan and Western medicine in the rheumatology department were selected as the research subjects. They were divided into the rehabilitation group and the reference group according to the double-blind mechanism, with 75 cases in each group. In the rehabilitation group, there were 32 males and 43 females; aged 35–77 years old, with an average of 56.27 ± 1.63 years old; the duration of illness was 1–10 years, with an average of 5.32 ± 1.22 years. In the reference group, there were 31 males and 44 females; aged 36–78 years old, with an average of 56.42 ± 1.72 years old; the duration of illness was 1–11 years, with an average of 5.44 ± 1.29 years. There was no statistically significant difference ($P > 0.05$) in general information such as gender, age, and duration of illness between the groups.

2.2. Methods

The reference group was provided with routine nursing care. The rehabilitation group received rehabilitation nursing intervention:

(1) Joint activities: When the patient's joint pain was alleviated, the joint activities were guided within the patient's tolerance. It first involved moving the small joints, then moving the large joints; first flexing and extending the joints, and then carrying out stretching and rotation. Afterward, a hot towel was applied to the joints, once a day for half an hour.

(2) Muscle strengthening: After the joints had recovered to a certain extent, muscle strengthening training was performed to improve muscle endurance. The patient was guided to perform muscle contraction and relaxation activities twice a day, about 15 minutes each time.

(3) Psychological counseling: Patients were provided with general rheumatoid arthritis knowledge to correctly understand the disease. They were encouraged to actively cooperate with the treatment of the disease and avoid being too anxious and worried. The doubts raised by patients are answered in detail.

(4) Sleep intervention: Before going to bed, patients avoided food that stimulates nerves, such as strong tea, coffee, etc. Patients with serious sleep disorders followed the doctor's advice to take some sedative drugs to allow patients to sleep normally.

(5) Auxiliary measures: Tibetan medicine bath treatment, oral administration of Tibetan medicine for 15 days after the end of the treatment, combined with auxiliary exercise and self-maintenance measures were performed to speed up the blood circulation of the limbs, reduce joint pain, swelling, stiffness and other symptoms.

2.3. Observation indicators

(1) The living standards between the groups were compared and assessed with the Brief Life Evaluation

Scale (SF-36), including physiology, mental outlook, emotional performance, and social culture.

(2) The recovery of joint function between the groups was compared, including the amount of joint tenderness, grip strength of both hands, duration of morning stiffness, and amount of joint swelling.

(3) The nursing satisfaction between the groups was evaluated and compared using the self-made scale, including very satisfied, generally satisfied, and dissatisfied.

2.4. Statistical analysis

SPSS21.0 statistical software was selected to process and analyze the data. The count data were expressed by the number of cases (n) and percentage (%), the χ^2 test was implemented; the measurement data were expressed by the mean ± standard deviation (SD), and the *t*-test was implemented. $P < 0.05$ indicated a statistically significant difference.

3. Results

3.1. Comparing the living standards between the rehabilitation group and the reference group

Before the intervention, there was no statistically significant difference ($P > 0.05$) in living standards such as physiology, mental outlook, emotional performance, and social culture between the groups. After the intervention, the standard of living of the rehabilitation group was significantly better than that of the reference group ($P < 0.05$). The details are shown in **Table 1**.

Table 1. The comparison of living standards between groups (mean ± SD, points)

Group	Number of cases	Physiology		Mental outlook		Emotional performance		Social culture	
		Before intervention	After intervention	Before intervention	After intervention	Before intervention	After intervention	Before intervention	After intervention
Rehabilitation group	75	70.24 ± 3.54	86.97 ± 3.61	69.75 ± 3.24	85.44 ± 3.51	68.12 ± 3.27	84.37 ± 3.91	70.28 ± 3.51	87.55 ± 3.62
Reference group	75	70.54 ± 3.69	81.57 ± 3.52	69.84 ± 3.65	80.96 ± 3.67	68.27 ± 3.69	79.55 ± 3.18	70.96 ± 3.67	82.75 ± 3.16
t value	-	0.5080	9.2750	0.1596	7.6399	0.2634	8.2824	1.1596	8.6508
P value	-	0.6122	0.0000	0.8733	0.0000	0.7926	0.0000	0.2481	0.0000

3.2. Comparing the recovery of joint function between the rehabilitation group and the reference group

Before the intervention, there was no statistically significant difference ($P > 0.05$) in the recovery of joint functions such as the number of joint tenderness, grip strength of both hands, duration of morning stiffness, and number of joint swelling among the groups. After the intervention, the number of joint tenderness, hand grip strength, duration of morning stiffness, number of joint swelling, and other joint function recovery in the rehabilitation group were significantly better than those in the reference group ($P < 0.05$). The results are presented in **Table 2**.

3.3. Comparing the nursing satisfaction between the rehabilitation group and the reference group

The nursing satisfaction of the rehabilitation group was significantly higher than that of the reference group ($P < 0.05$), as shown in **Table 3**.

Table 2. The comparison of joint function recovery between groups (mean ± SD)

Group	Number of cases	Number of joint tenderness (pieces)		Grip strength of both hands (mmHg)		Duration of morning stiffness (minutes)		Number of swollen joints (number)	
		Before intervention	After intervention	Before intervention	After intervention	Before intervention	After intervention	Before intervention	After intervention
Rehabilitation group	75	6.27 ± 3.24	4.01 ± 1.52	76.21 ± 19.24	90.27 ± 25.51	43.27 ± 15.26	17.24 ± 11.52	5.27 ± 3.21	1.96 ± 1.25
Reference group	75	6.31 ± 3.22	5.67 ± 1.33	76.32 ± 19.65	80.33 ± 21.85	43.61 ± 15.98	30.54 ± 15.63	5.36 ± 3.58	4.32 ± 1.62
t value	-	0.0758	7.1178	0.0346	2.5628	0.1332	5.9320	0.1620	9.9884
P value	-	0.9397	0.0000	0.9724	0.0114	0.8942	0.0000	0.8715	0.0000

Table 3. The comparison of nursing satisfaction between groups [n (%)]

Group	Number of cases	Very satisfied	Generally satisfied	Dissatisfied	Total satisfaction rate
Rehabilitation group	75	52 (69.33)	22 (29.33)	1 (1.33)	74 (98.67)
Reference group	75	50 (66.67)	18 (24.00)	7 (9.33)	68 (90.67)
χ^2 value	-	-	-	-	4.7535
P value	-	-	-	-	0.0292

4. Discussion

The main symptom of rheumatoid arthritis is erosive arthritis, with synovitis as a pathological feature. Symptoms are not obvious in the early stage, but can lead to joint deformity and loss of function in the later stage [6,7]. Rheumatoid arthritis is a systemic disease, and its main therapy is drug treatment. Surgical treatment is used if drug treatment is ineffective, but it cannot be completely cured. Treatment can relieve joint symptoms and delay the occurrence of joint deformity [8,9]. Studies have found that the disease will affect other body tissues, causing complications in different parts of the body, such as heart, lungs, blood vessels, blood, and kidneys, and carries a risk of death. Rehabilitation care for patients with rheumatoid arthritis can be provided to further control the development of the disease [10]. After symptomatic treatment, patients should carry out joint activity training according to the recovery of their joints. The intensity of the training should meet the patient's tolerance, increase muscle stimulation, improve muscle stretching and contraction capabilities, and maintain the normal function of joints and muscles [11,12]. Some patients with rheumatoid arthritis have a certain degree of sleep disturbance. Food intake should be restricted before going to bed. If necessary, some drugs can be used appropriately to help patients fall asleep [13,14]. Rehabilitation care can improve the patient's symptoms, enhance the patient's grip strength, and restore the patient's standard of living [15].

Based on the results, before the intervention, there was no statistically significant difference ($P > 0.05$) in living standards such as physiology, mental outlook, emotional performance, and social culture between the groups; after the intervention, the physiology, mental outlook, emotional performance, and social culture of the rehabilitation group were significantly better than the reference group ($P < 0.05$). Before the intervention, there was no statistically significant difference ($P > 0.05$) in the recovery of joint functions such as the number of joint tenderness, grip strength of both hands, duration of morning stiffness, and number of joint swelling among the groups; after the intervention, the number of joint tenderness, hands grip strength, duration of morning stiffness, number of joint swelling, and other joint function recovery in the rehabilitation group were

significantly better than those in the reference group ($P < 0.05$). The nursing satisfaction of the rehabilitation group was significantly higher than that of the reference group ($P < 0.05$). After rehabilitation nursing intervention, the joint functions of patients with rheumatoid arthritis have recovered to a certain extent. This intervention can delay the development of the disease, allow patients to return to normal life, and improve nursing satisfaction.

5. Conclusion

In summary, the application of rehabilitation nursing in patients with rheumatoid arthritis can effectively promote the recovery of joint function, and it is worthy of promotion and clinical application.

Disclosure statement

The author declares no conflict of interest.

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The Impact of Toe Amputation on the Quality of Life of Diabetic Foot Patients: A Cardiff Wound Impact Schedule (CWIS) Evaluation

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Abstract: *Background:* The treatment and management of diabetic foot significantly impact the quality of life (QoL) of patients, yet studies concerning the effects of toe amputation on QoL are relatively limited. *Methods:* This study included 12 diabetic foot patients with Wagner Grade 4 who underwent toe amputation. Using the Cardiff Wound Impact Schedule (CWIS), we systematically assessed their QoL before and after the surgery. *Results:* Data indicated that there were significant improvements in multiple areas of QoL post-surgery. Particularly in the domains of "overall quality of life" and "well-being," average scores demonstrated noticeable declines compared to pre-surgery levels. Statistical analysis further confirmed the significance of these results. *Conclusion:* Toe amputation holds significant value in enhancing the QoL for diabetic foot patients. This study provides robust evidence for clinical decision-making, emphasizing that treatment choices should consider the QoL of the patient in addition to physiological outcomes.

Keyword: Cardiff Wound Impact Schedule; Diabetic foot; Toe amputation

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1. Introduction

Diabetes is a global public health issue that places enormous stress on healthcare systems and individual patients alike [1]. Diabetic foot complications, in particular, are of high concern. According to global diabetes research reports, approximately 15–25% of diabetic patients will experience at least one foot complication in their lifetime [2]. These complications often lead to more severe issues, such as infections, ulcers, and even toe or limb amputations.

Although prevention and early intervention are the preferred strategies for treating diabetic foot, toe amputations or even more advanced forms of amputation may be inevitable in cases with advanced disease or severe complications [3,4]. Such surgeries are generally performed in situations graded as Wagner 4, accompanied by osteomyelitis or gangrene [5].

Increasingly, research is focusing on patients' quality of life (QoL) post-medical intervention, especially after major surgeries like toe amputation. Understanding how surgeries impact QoL not only aids physicians in

making more comprehensive and personalized treatment decisions but also provides patients with more realistic and complete prognostic information [6].

To accurately assess the post-operative QoL of diabetic foot patients who have undergone toe amputation, we chose the Cardiff Wound Impact Schedule (CWIS) for evaluation [7]. CWIS is a validated, highly reliable, and effective scoring tool that comprehensively considers multiple aspects like "overall quality of life," "well-being," "physical symptoms and daily living," as well as "social life" [8].

2. Methods

2.1. Study design

This study aims to evaluate the changes in the QoL of diabetic foot patients post-toe amputation by comparing pre- and post-surgery CWIS scores, intending to explore whether QoL significantly improves after toe amputation.

2.2. Study population and inclusion and exclusion criteria

The study selected diabetic foot patients aged between 40 and 80 years. Inclusion criteria were those graded as Wagner 4, accompanied by osteomyelitis or gangrene. Exclusion criteria included patients who failed to follow up after six weeks. In total, 12 eligible patients were included, six of whom were male and six were female.

2.3. Application of the CWIS score

The CWIS scoring system was utilized as the assessment tool [9]. This scoring system includes four aspects [10]:

(1) "Overall quality of life" contains two items scored out of 10 (total score of 20).
(2) "Well-being" contains seven items scored on a scale from 1 ("not at all") to 5 ("always"), totaling 35.
(3) "Physical symptoms and daily living" are divided into experiences and stress, totaling 24 items scored out of 5 (total score of 120).
(4) "Social life" is divided into experiences and stress, totaling 14 items scored out of 5 (total score of 60).

Higher scores correspond to lower well-being. All participants completed the score both pre-amputation and six weeks post-amputation.

2.4. Data collection and processing

Data were primarily collected at two time points (pre-surgery and six weeks post-surgery), patients were guided by professional medical staff to fill in the CWIS. All data were anonymized to ensure participant privacy. Subsequently, the data were entered into a spreadsheet and cleaned for statistical analysis.

2.5. Statistical analysis

Initially, a descriptive statistical analysis was performed for all variables, including the calculation of mean and standard deviation (SD). Paired sample *t*-tests were then employed to compare pre- and post-surgery CWIS scores. Lastly, *t*-distribution tables were consulted to ascertain the *t*-values for each aspect of the CWIS score.

3. Results

3.1. Patient information

A total of 12 patients with diabetic foot were included in this study, ranging in age from 40 to 80 years. All

patients had a Wagner classification of Grade 4, accompanied by osteomyelitis or gangrene. The sample comprised 6 males and 6 females. All patients successfully completed the 6-week follow-up.

3.2. Changes in CWIS scores

To accurately assess the changes in the QoL in diabetic foot patients following toe amputation, the Cardiff Wound Impact Schedule (CWIS) was employed. The detailed data and differences in CWIS scores before and after the surgery are summarized in **Table 1**. The two groups of data in the table are the average and variance of the scores and total scores in four aspects of CWIS before and after the surgery.

Table 1. CWIS scores before and after the surgery

Parameters	Before treatment		After treatment		Variation	
	Mean	SD	Mean	SD	Mean	%
Overall quality of life	17.08	1.38	14.58	1.62	-2.50	12.50
Well-being	29.08	1.68	26.25	1.82	-2.83	8.09
Physical symptoms and daily living	107.92	4.74	98.67	6.21	-9.25	7.71
Social life	47.67	2.77	43.00	3.67	-4.67	6.67
Total score	201.75	10.46	182.50	13.19	-19.25	8.19

According to **Table 1**, the pre-surgery average score for "overall quality of life" was 17.08 (SD = 1.38), which reduced to 14.58 (SD = 1.62) post-surgery, a mean decrease of 2.5, or 12.5%. The pre-surgery average score for "well-being" was 29.08 (SD = 1.68), and it was 26.25 (SD = 1.82) post-surgery, marking a mean decrease of 2.83, or 8.09%. For "physical symptoms and daily living," the pre-surgery mean score was 107.92 (SD = 4.74), and the post-surgery mean score was 98.67 (SD = 6.21), representing a mean decrease of 9.25, or 7.71%. "Social life" had a pre-surgery mean score of 47.67 (SD = 2.77), which dropped to 43 (SD = 3.67) post-surgery, a mean decrease of 4.67 or 6.67%. The total score dropped from a pre-surgery mean of 201.75 (SD = 10.46) to a post-surgery mean of 182.50 (SD = 13.19), a mean decrease of 19.25, or 8.19%. The most substantial decline in scores was observed in the "overall quality of life" aspect, while the least decline was seen in "social life."

3.3. Statistical analysis

Paired samples *t*-tests were performed on the collected data to determine its statistical significance, and the results are visually represented in **Figure 1**.

For "overall quality of life," $t = 7.461$, $df = 11$, $P < 0.0001$; for "well-being," $t = 9.530$, $df = 11$, $P < 0.0001$; for "physical symptoms and daily living," $t = 9.172$, $df = 11$, $P < 0.0001$; and for "social life," $t = 5.897$, $df = 11$, $P < 0.0001$. For the overall CWIS score, $t = 8.184$, $df = 11$, $P < 0.0001$. All these results showed statistically significant differences between the two sets of scores. The paired samples *t*-test was the best choice for analyzing this type of data because it compares the scores of the same patients at different points in time. According to the CWIS, a higher score indicates poorer well-being. Therefore, the statistically significant decrease in average scores in all four aspects and the total score post-surgery suggests a substantial improvement in the patients' quality of life.

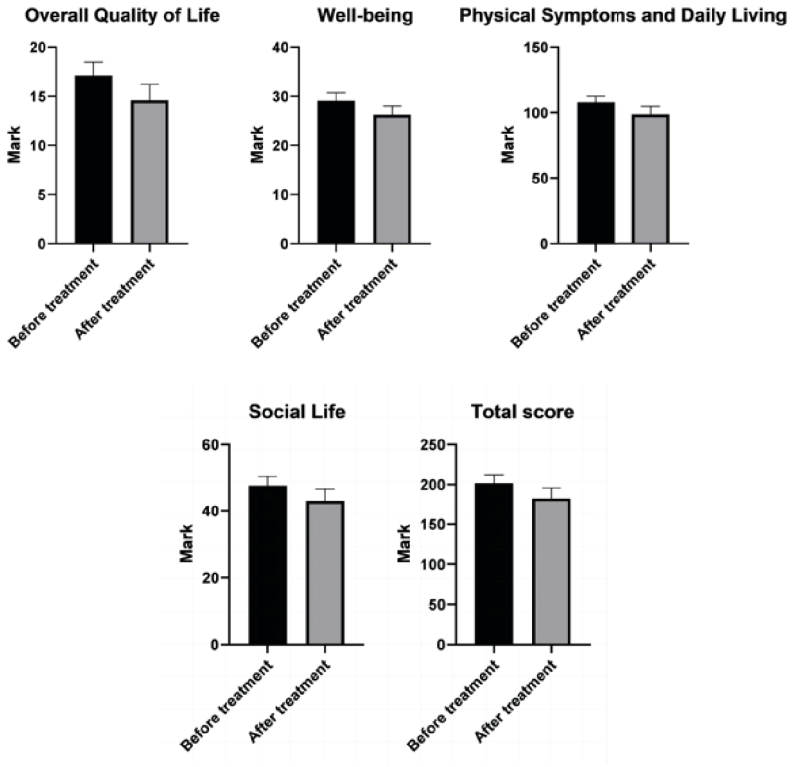

Figure 1. Paired samples *t*-tests for the four aspects of CWIS scores and the total score, before and after the surgery

4. Discussion

In this study, we observed a significant improvement in the quality of life of diabetic foot patients following toe amputation. Firstly, the most noticeable decrease in "overall quality of life" scores was 12.5%, suggesting that patients experience not only an improvement in physical comfort but also increased psychological and emotional satisfaction after undergoing toe amputation. This is crucial for the overall well-being and recovery process of the patients. Physical discomfort often negatively influences emotional states, leading to issues like anxiety and depression. Our data suggest that toe amputation could be an important intervention for enhancing the overall quality of life in patients with diabetic foot.

Scores in "physical symptoms and daily life" and "social life" both decreased by 6.67%, a smaller margin. This suggests that, although the surgery provides some physical benefits, there may still be some limitations or challenges in social interaction and daily activities. These differences may be due to various factors, such as individual differences among patients, the surgical technique employed in toe amputation, and postoperative rehabilitation treatments.

Diabetic foot is a global public health concern that significantly impacts the quality of life and survival rates of a large number of diabetic patients. Against this backdrop, focusing on the quality of life of diabetic foot patients becomes particularly important. An improved quality of life is not only beneficial for the psychological well-being of patients but is also closely related to better disease management and prognosis. The findings of this study further highlight the pivotal role of medical interventions like toe amputation in improving the quality of life of patients with diabetic foot.

However, the study does have some limitations. Firstly, the sample size is relatively small and may not be reflective of the broader diabetic foot population. Additionally, while the CWIS is a well-recognized evaluation tool, its adaptability to different cultural and geographical contexts requires further investigation [11].

Based on these findings and limitations, we recommend that future research should expand the sample size and include participants from diverse cultural and geographical backgrounds to obtain more comprehensive data.

5. Conclusion

Utilizing the Cardiff Wound Impact Schedule (CWIS), we systematically evaluated the changes in the quality of life of diabetic foot patients before and after toe amputation. The data indicates a significant improvement in various aspects of life quality post-surgery, especially in the dimensions of "overall quality of life" and "well-being."

These findings provide valuable insights for clinicians. When determining treatment plans, physicians should take into account not only physiological factors and therapeutic efficacy but also the patient's quality of life and its changes. The conclusion of this study emphasizes the importance of surgical intervention in enhancing patients' quality of life.

Moreover, these findings have significant implications for diabetic foot patients and their family members. Knowing the positive changes post-surgery can help patients and their families set more optimistic expectations, further promoting the recovery process and improving treatment adherence. However, it should be noted that each patient's situation is different. While the overall quality of life has improved, some patients may still face difficulties or challenges. Therefore, physicians should closely monitor each patient's individual needs and responses during the decision-making and treatment processes.

Disclosure statement

The authors declare no conflict of interest.

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Advances in the Treatment of Bone Nonunion in Limb Fractures

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Abstract: Limb fractures are a common disease type in clinical practice caused by incidents such as traffic accidents and work-related injuries in daily life. Most patients gradually recover after receiving internal fixation treatment, and the treatment effect is relatively significant. According to relevant surveys and studies, the probability of bone nonunion in postoperative patients is 5–10%, which is a common complication. Nonunion is a condition where the fractured bone has not healed after an extended period of time, e.g. 9 months after treatment, and there is no sign of improvement for 3 consecutive months, necessitating timely treatment. This article reviews the research progress in the treatment of nonunion in limb fractures.

Keywords: Nonunion; Limb fractures; Treatment method; Research progress

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1. Introduction

From the analysis of clinical practice, bone nonunion is one of the main topics in clinical orthopedic research at this stage. With the improvement of medical and hygiene levels, the probability of bone nonunion has a marked downward trend compared with before. Clinical diagnosis of bone nonunion is based on X-ray and corresponding symptoms and also requires the assessment of the healing situation. In order to reduce the incidence of bone nonunion, it is of great significance to carry out corresponding treatment.

2. Etiological analysis of nonunion in limb fractures

2.1. Iatrogenic factors

Bone nonunion is commonly seen in fractures of the extremities, and iatrogenic factors refer to the medical procedures or treatments that result in bone nonunion. Some common causes and preventive measures for iatrogenic factors of bone nonunion in a limb fracture are described below.

(1) Surgical procedures: Incorrect surgical procedures can lead to bone nonunion. Improper bone

reduction or fixation during surgery can interfere with the healing process and increase the risk of nonunion [1]. Therefore, surgical procedures must be performed carefully to ensure that the bone is properly reduced and appropriate internal fixation devices are used to ensure the stability of the bone.

(2) Soft tissue injury: Soft tissue injury around the bone, such as breaking or contusion of muscles, blood vessels, nerves, etc., can also lead to the occurrence of bone nonunion. Damage to soft tissue can result in a blockage of blood circulation and a reduction in the nutrients and oxygen supply to the bones, which can affect bone healing [2]. Therefore, when dealing with limb fractures, the protection and repair of the surrounding soft tissues must be considered at the same time to avoid excessive injury.

(3) Infection: Postoperative infection is another iatrogenic factor that can lead to bone nonunion. Postoperative infections can cause an enhanced inflammatory response and produce pus and scar tissue, which can affect bone healing. Therefore, it is very important to prevent and manage infections promptly after surgery and administer antibiotics if necessary.

2.2. Systemic factors

Systemic factors may also lead to the occurrence of bone nonunion, mainly including the following aspects.

(1) Disease effects: Some systemic diseases can also lead to the occurrence of nonunion [3]. For example, chronic diseases such as diabetes and rheumatoid arthritis can affect the metabolism and repair ability of bones, increasing the risk of bone nonunion.

(2) Age factors: The ability of bone tissue to grow and repair gradually diminishes with age, resulting in longer healing times for fractures. Hence, older people have a higher probability of bone nonunion [4].

2.3. Drug factors

Certain drugs that have a negative effect on the skeletal system can cause fractures of the extremities and bone nonunion. The following are some medications that can cause bone nonunion.

(1) Anticoagulants: Anticoagulants are used to prevent the formation of blood clots, but excessive anticoagulation can result in inadequate blood supply to the fracture site, affecting the healing process of the fracture.

(2) Certain antitumor drugs: Some drugs used in chemotherapy, such as methotrexate, etoposide, etc., may cause damage to the skeletal system and interfere with the normal healing of the fracture [5].

(3) Certain antibiotics: Long-term or high-dose use of certain antibiotics, such as fluoroquinolones, may interfere with bone cell metabolism and affect the healing process at the fracture site.

3. Physical therapy for bone nonunion in limb fractures

3.1. Low-intensity pulsed ultrasound

Low-intensity pulsed ultrasound is a type of physical therapy often used to treat nonunion after a fracture of the extremities. This therapy promotes the repair process of bone by using low-frequency, low-intensity pulsed ultrasound to stimulate the regeneration and healing of bone tissue [6]. It takes a certain amount of time for bone tissue to heal after a fracture. However, there are cases where the fracture site may not heal properly due to a variety of reasons, leading to the appearance of bone nonunion. At this point, low-intensity pulsed ultrasound can provide a non-invasive treatment to help promote bone regeneration and healing [7]. The principle of low-intensity pulsed ultrasound is to transmit pulsed ultrasound waves to the fracture to promote bone regeneration by stimulating the metabolic activity of bone cells and increasing intracellular signaling and protein synthesis. The vibration effect of ultrasound can increase the fluidity of intracellular fluid, enhance the supply of nutrients and the

exclusion of metabolites, and promote the repair and regeneration of bone tissue. Low-intensity pulsed ultrasound has a very low power density and does not cause any damage or pain sensation to the surrounding tissue [8]. During treatment, the patient only needs to place the ultrasound probe over the fracture and follow the doctor's instructions. The whole procedure is safe, easy, and painless, and is suitable for patients of different ages.

3.2. Extracorporeal shock wave

Extracorporeal shock wave therapy is a method of treating bone disorders using pressure waves generated by high-intensity sound waves. These shock waves are delivered to the patient's bone area via an external device and promote healing and regeneration at the fracture site by stimulating and regulating the physiological processes of cells and tissues [9]. Extracorporeal shock wave therapy offers a number of advantages over traditional surgical therapies. Firstly, it is a non-invasive treatment that does not require cutting through the patient's skin, thus reducing the risk of surgery and the occurrence of complications. Secondly, extracorporeal shock wave therapy can be applied topically to precisely stimulate the fracture and avoid damage to the surrounding healthy tissue. In addition, extracorporeal shock wave therapy is simple to operate and patients can be treated in the outpatient department without the need for hospitalization, reducing the burden on patients and the pressure on medical resources.

4. Local treatment of bone nonunion in limb fractures

4.1. Percutaneous autologous bone marrow transplantation

Percutaneous autologous bone marrow transplantation is a currently widely used topical treatment for fractures of the extremities where the bones are not connected. This treatment promotes the regeneration and healing of the bone by extracting bone marrow from the patient's own body and injecting it into the injured site after processing [10]. The advantage of this treatment is that it is a non-invasive procedure that does not require surgery, and that autologous bone marrow can be delivered directly to the fracture site in need of healing during a local injection. During the injection, the doctor will usually inject the bone marrow between the fracture end and the surrounding soft tissue via a guide needle, thus stimulating and promoting the regeneration and healing of the bone. This treatment works by stimulating the regeneration of bone through stem cells and osteoblasts in the bone marrow [8]. Stem cells are pluripotent cells that have the ability to self-renew and differentiate into other cell types. Osteoblasts, on the other hand, are a special cell type whose primary function is to synthesize and secrete bone matrix, which helps in the regeneration and healing of bones. Percutaneous autologous bone marrow transplantation is a relatively simple procedure that can often be done under local anesthesia. The recovery period is relatively short, and patients can usually quickly return to their normal lives and work. In addition, during treatment, the patient's autologous bone marrow does not require an outside donor, reducing the risk of rejection.

4.2. Injectable bone growth factor

Injectable bone growth factor is a locally injected therapy used to treat fractures of the extremities with bone nonunion. In this therapy, bone growth factor is injected into the fracture site to promote healing of the fracture and regeneration of the bone. The principle of injectable bone growth factor is to use the properties of growth factors to stimulate the proliferation and differentiation of bone cells and promote the formation of new bone [11]. These growth factors can include, but are not limited to, bone morphogenetic protein, bone hematopoietic factor, and angiogenic factor, among others. In injectable therapy, the doctor will first identify the fracture site and administer local anesthesia [12]. An injection needle will then be inserted into the exact area of the fracture or bone nonunion to inject bone growth factor into the bone tissue. These factors will promote the formation and healing of new bone

by locally stimulating the proliferation and differentiation of bone cells as well as angiogenesis. Injectable bone growth factor therapy has many advantages. Firstly, it is a non-invasive treatment that does not require surgical procedures, reducing pain and recovery time for patients. Secondly, since the drug is injected directly into the bone tissue, the growth factor can work locally efficiently and improve the treatment effect. In addition, the therapy can also be used to treat some difficult-to-operate locations, such as the spine and joints [13].

4.3. Exosome

Exosome therapy is a method of using the body's own biogenic substances to promote fracture healing. It works by injecting substances rich in growth factors and extracellular matrix into the fracture site to stimulate bone cell proliferation and differentiation, thus speeding up the healing process. Exosomes can be derived from many types of cells, including bone marrow mesenchymal stem cells, fat stem cells, platelets, and others. After being cultured and treated, these cells release bioactive extracellular vesicles containing a large number of substances such as growth factors, extracellular matrix, and regulatory factors. Exosome therapy has certain advantages and characteristics [14]. Firstly, exosomes can promote the proliferation and differentiation of bone cells, thus accelerating the healing rate of fracture. Secondly, exosomes can provide rich biological substances, including growth factors and extracellular matrix, etc., to help improve the blood supply and repair process at the fracture site. In addition, exosome therapy is a local treatment with less impact on surrounding tissues and higher safety.

5. Surgical treatment

5.1. Bone graft treatment

Bone grafting is a common surgical treatment for bone nonunion in limb fractures. Fracture nonunion is a condition in which the fracture surface fails to heal, or a hole or defect is formed between the fracture and the nonunion. In response to this condition, bone grafting is widely used to repair and promote healing of fracture surface. The basic principle of bone grafting is to transplant the patient's own or external bone tissue to the bone nonunion to promote fracture healing and repair of bone defects. Specifically, bone grafting can be divided into two methods: autogenous bone grafting and allogeneic bone grafting. Autogenous bone grafting refers to the grafting of the patient's own bone tissue to the bone nonunion [15]. The advantage of this method is that there is no risk of graft rejection because the patient's own tissue is used. Common autogenous bone graft materials include bone marrow, bone slices, and bone. Allogeneic bone grafting involves the grafting of bone tissue from a person other than the patient into the bone nonunion. The advantages of this method are that it can provide a large amount of bone tissue for transplantation and the operation time is relatively short [16]. Common bone allogeneic grafts include bone from a donor of the same animal or human species. The basic procedure is roughly the same for both autogenous and allogeneic bone grafts. Firstly, the doctor will accurately locate and measure the bone nonunion to determine the exact location and size of the graft [17]. The bone graft is then fixed to the nonunion, usually with a metal plate, steel nail, or screw. Lastly, the patient goes through a period of rehabilitation and bone healing. Bone grafting has a wide range of applications in the repair of nonunion in limb fractures. It can effectively promote the healing of fractures and the repair of bone defects, and greatly shorten the recovery time. However, bone graft therapy also has certain risks and complications, such as infection, graft rejection, and graft fracture. Therefore, before performing bone graft surgery, doctors will comprehensively consider the specific situation of the patient and choose the most appropriate treatment.

5.2. Internal fixation treatment

Internal fixation treatment is a common surgical treatment for limb fractures and nonunion of the bone at the

site of the fracture. The main principle of internal fixation treatment is to fix and stabilize the broken end of the fracture through the use of metal internal fixation at the fracture end (including steel plates, steel nails, screws, etc.) to promote the healing of the bone pieces and the bony connection.

The operation of internal fixation surgery generally requires the following steps.

(1) Preoperative preparation: This includes general examination to ensure that the patient has no contraindications and general cleaning and disinfection.

(2) Anesthesia: According to the specific situation of the patient and the location of the fracture, the anesthesia methods of local anesthesia or general anesthesia is determined.

(3) Incision and exposure: According to the specific conditions of the fracture, the doctor makes one or more incisions on the skin, exposes the fracture site, and cleans up the broken end of the fracture and the surrounding soft tissue [18].

(4) Internal fixation device selection: According to the type of fracture, location, the age of the patient, and other factors, the appropriate internal fixation device is selected, such as plate, steel nail, or screw.

(5) Fixation of the broken end of the fracture: The doctor places the selected internal fixation device on the broken end of the fracture, and fixes the fracture end stably through screws or steel plates to maintain the correct position and alignment of the fracture end.

(6) Intraoperative examination: After the placement of the internal fixation device, the doctor performs an intraoperative X-ray to ensure that the fracture end is stable and properly aligned.

(7) Incision closure: The surgical incision is sutured layer by layer to avoid infection and bleeding [19].

After the internal fixation surgery, the patient needs to strictly follow the doctor's postoperative care instructions, including keeping the incision clean, avoiding weight bearing on the injured area, and appropriate activities to promote blood circulation and muscle function recovery. Routine postoperative review and rehabilitation training are also an important part to ensure fracture healing and function recovery.

6. Conclusion

To sum up, at this stage, there are various treatment methods for limb fracture nonunion. In clinical practice, doctors will take corresponding treatment methods according to the specific situation of patients with bone nonunion. The most important thing is choosing the right treatment method. Among many treatment approaches, surgical treatment is still the most important treatment method, through bone grafting and internal fixation treatment, the most ideal treatment outcomes can be obtained. For some patients with mild disease, physical therapy and local injection therapy can be applied. In the future, the treatment of the symptoms of bone nonunion in the limbs will be more diverse and the treatment effect will improve.

Disclosure statement

The authors declare no conflict of interest.

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Application Effects of Light Lumbar Anesthesia and Nerve Block Anesthesia in Elderly Hip Joint Surgery

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Abstract: *Objective:* To analyze the application effects of light lumbar anesthesia and nerve block anesthesia in elderly hip joint surgery. *Methods:* A total of 40 patients indicated for hip joint surgery from February 2021 to February 2022 were randomly divided into the control group and the observation group, each with 20 patients. The control group received nerve block anesthesia and the observation group was given light lumbar anesthesia. *Results:* Based on the results, the anesthetic effect in the observation group was better than that in the control group ($P < 0.05$), the difference was statistically significant. *Conclusion:* Compared with nerve block anesthesia, light lumbar anesthesia can achieve better analgesic effects and stable blood circulation in elderly patients undergoing hip joint surgery.

Keywords: Light lumbar anesthesia; Nerve block anesthesia; Elderly hip joint surgery

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1. Introduction

Femoral neck and intertrochanteric fractures are common in elderly patients. The tolerance of the elderly to anesthesia surgery is much lower than that of the younger population due to the decline in body function and the presence of cardiovascular, respiratory, and central nervous system diseases [1]. Therefore, for elderly patients, as long as it is not absolutely contraindicated, anesthesia methods that have the least impact on the functions of the respiratory, circulatory, and other systems will generally be chosen. A nerve block is a minimally invasive surgical procedure with less impact on the respiratory and circulatory systems. It is suitable for elderly and critical patients, but incomplete block may still occur due to differences in surgical procedures, surgical methods, and neuroanatomy [2]. Light lumbar anesthesia is simple, fast, effective, and has less impact on the patient's circulatory and respiratory functions [3]. This paper compares the application effects of lumbar anesthesia and nerve block anesthesia in elderly patients indicated for hip surgery.

2. General information and methods

2.1. General information

From February 2021 to February 2022, 40 patients indicated for hip joint surgery were randomly divided into

the control group and the observation group, with 20 cases in each group.

2.2. Methods

Patients in the observation group were treated with light lumbar anesthesia. On the left or right decubitus position of the affected hip joint, the subarachnoid was punctured by using a 22G puncture needle (Camel Medical Instrument Group Co., Ltd.), and the main L3–4 space was used as the puncture point. Subsequently, 12 mg of 0.5% light ropivacaine (AstraZeneca, Netherlands) was slowly injected, its total capacity was 2.5 mL, and the specific proportion of preparation method was: 1.5 mL 1% ropivacaine + 1.5 mL for sterilization and injection (Qilu Pharmaceutical, China).

In the control group, the patients were anesthetized with lumbar plexus block and sciatic nerve block. Taking the lateral position of the patient's hip joint upward, the Winnie method was used to locate the lumbar plexus puncture point and routine disinfection was applied. A 22G needle (Stimuplex, Braun, Germany) was used to perform lumbar plexus puncture under the guidance of the puncture needle and ultrasound with the nerve stimulator. After reaching the target puncture point and drawing the plunger back to confirm that there was no blood, 30 mL of 0.4% ropivacaine was injected; followed by flexion of the patient's hip at 45° and flexion of the knee at 70°. The sacrum parasacral approach was used to puncture the sciatic nerve under the guidance of ultrasound and 20 mL of 0.4% ropivacaine was injected into the target puncture point.

2.3. Observation indicators

The onset time of anesthesia, duration of sensory block, and duration of motor nerve block were compared between the observation group and the control group.

2.4. Statistical methods

The data were processed and analyzed by using SPSS21.0 software. The measurement data were represented by mean ± standard deviation (SD) and *t*-test was performed; the counting data were represented by % and χ^2. $P < 0.05$ indicated there was a statistically significant difference.

3. Results

Table 1 shows the comparison of anesthetic effects between the control group and the observation group. The anesthesia effect in the observation group was significantly better than that in the control group ($P < 0.05$).

Table 1. Comparison of anesthetic effects between the groups (mean ± SD)

Group	Number of cases	Onset time of anesthesia (min)	Duration of sensory block (min)	Duration of motor nerve block (min)
Observation group	20	2.9 ± 0.6	211.2 ± 32.5	72.4 ± 16.4
Control group	20	17.5 ± 2.1	450.65 ± 86.6	303.4 ± 74.5
t	-	29.8957	11.5771	13.5424
P	-	0.0000	0.0000	0.0000

4. Discussion

Elderly patients often have many chronic diseases, such as hypertension, coronary heart disease, diabetes, and so on, in addition to the deterioration of body function. Hip joint surgery is one of the most common operations

for elderly patients. The safety and efficacy of hip joint anesthesia have been the focus of discussion. With the improvement of the quality of life and long-term survival rate of elderly patients, the safe and effective implementation of anesthesia in elderly patients is required. Studies have shown that for elderly patients, the use of nerve block anesthesia or lumbar anesthesia can shorten the recovery time during surgery and improve postoperative recovery. However, the need for nerve block anesthesia or lumbar anesthesia in performing surgery for hip diseases has been controversial.

4.1. Epidemiology of hip diseases in elderly patients

With the aggravation of the aging society, the incidence of hip joint diseases is increasing in the elderly. According to the American Hip Association, about 50% of people over 80 have hip diseases. Among them, the rate of hip diseases in the elderly over 60 was 51%.

4.2. Characteristics of hip surgery in the elderly

With the increase in the elderly population, people's demands for quality of life and physical health are increasingly higher. Perioperative complications are important factors affecting the prognosis of elderly patients. Due to aging of the body, the elderly are often presented with a variety of chronic diseases, such as hypertension, coronary heart disease, diabetes, etc. These patients are prone to hypotension, hypoglycemia, and so on, thus affecting the smooth operation of anesthesia and surgery.

4.3. Application of nerve block anesthesia and lumbar anesthesia in elderly hip joint surgery

At present, general anesthesia, lumbar anesthesia, and nerve block anesthesia are commonly used in clinics. General anesthesia is suitable for patients with small operation ranges and mild conditions, while lumbar anesthesia is suitable for patients with large operation ranges and severe conditions. Both general anesthesia and lumbar anesthesia pose certain risks for the elderly. Along with the decline of the body function of elderly patients, many of them have common diseases, such as hypertension, diabetes mellitus, and so on. In addition, elderly patients have a lack of pain threshold due to impaired neurological function and poor perception of pain. General anesthesia and lumbar anesthesia may increase intraoperative risk in the elderly.

4.4. Comparison of advantages and disadvantages between nerve block anesthesia and lumbar anesthesia

In clinical work, nerve block anesthesia and lumbar anesthesia are often used as two different anesthetic methods. Nerve block anesthesia refers to the use of local anesthetics on the corresponding parts of the nerve block, so that in the course of surgery, patients have no pain and sensory abnormalities, can remain awake, and have a lowered risk of accidents. Its advantages are lowering the patient's stress response caused by surgery; reducing the postoperative pain and lower limb muscle tension; decreasing the secretion of antidiuretic hormone; reducing postoperative complications; and shortening the recovery time. However, clinical work also found that nerve block anesthesia can lead to certain complications, such as hypotension, bradycardia, hypoxemia, and so on. Therefore, choosing the appropriate anesthesia should be based on the actual situation in clinical work.

Lumbar anesthesia, lumbar plexus nerve block, and sciatic nerve block are the main anesthetic methods in orthopedic surgery, with each having its specific characteristics. Light lumbar anesthetic can block sensory, motor, and sympathetic nerves in a short time and reduce the stress response of patients. Based on the literature and our practice, we suggest that anesthesiologists should control the concentration of local anesthetics between 0.3% and 0.5%, and dosage between 10–12 mg. Ropivacaine has lower fat solubility, less motor block, and less myocardial toxicity, and improves the safety of the perioperative period, making it suitable for elderly patients.

Therefore, on the basis of previous research, this study intended to further explore the influence of different anesthetic methods and postures on blood circulation [4].

5. Conclusion

To sum up, light lumbar anesthesia can exert better anesthetic and analgesic effects on the limb of the operation side, and has good perioperative hemodynamic stability, especially with cardiovascular and cerebrovascular diseases in the elderly, hence having high clinical value. At present, the clinical application of light lumbar anesthesia and nerve block anesthesia needs to be further studied to determine the need for nerve block anesthesia or lumbar anesthesia in elderly hip surgery [5]. Currently, there is little research in this area, and there is still a lot of research space in the future [6]. Although some scholars have proposed a variety of nerve block anesthesia or lumbar anesthesia for surgery, but there is a lack of large sample, multicenter, randomized controlled trials to verify these views, necessitating further research. However, no matter what anesthesia method is used, it is essential to ensure the safety of elderly patients so that the operation can be completed successfully [7].

Disclosure statement

The author declares no conflict of interest.

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The Effect of Arthroscopic Microfracture in the Treatment of Ankle Osteoarthritis Combined with Cartilage Damage

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Abstract: *Objective:* To observe the specific effect of arthroscopic microfracture treatment on patients with ankle osteoarthritis and cartilage damage. *Methods:* 60 patients with ankle osteoarthritis combined with cartilage damage treated in our hospital from January 2022 to December 2022 were selected and divided into the control group and the experimental group using the random number table method, each with 30 cases. Subjects in the experimental group were treated with arthroscopic microfracture, while subjects in the control group were treated with conventional surgery. *Results:* After the intervention, the total treatment effectiveness of the experimental group was higher than that in the control group ($P < 0.05$); the inflammatory factor levels in the experimental group were lower than those in the control group ($P < 0.05$); the pain scores of the experimental group were lower than those in the control group ($P < 0.05$); the quality of life in the experimental group were higher than those in the control group ($P < 0.05$). *Conclusion:* During the treatment process of the experimental group, patients with ankle osteoarthritis combined with cartilage damage were given arthroscopic microfracture therapeutic intervention, and the post-treatment effect was relatively good. After treatment and intervention, the patients' symptoms were significantly relieved, the inflammatory reaction was improved, the pain was reduced, and the quality of life was enhanced.

Keywords: Arthroscopic microfracture; Treatment effect; Ankle osteoarthritis and cartilage damage; Pain level

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1. Introduction

Ankle osteoarthritis is clinically a multiple chronic joint disease [1]. The disease mainly manifests as degenerative lesions of articular cartilage, and it is often accompanied by limb dysfunction. As the disease progresses, it will gradually worsen, seriously affecting the patient's health. Patients require timely and active therapeutic intervention, and drug therapeutic intervention is often used in clinical practice. Although it can alleviate the patient's symptoms to a certain extent, the prognosis is poor. Conventional joint debridement also fails to achieve the ideal therapeutic effect, and patients often suffer from various complications after surgery. As an emerging treatment method, arthroscopic microfracture has relatively tiny wounds, patients generally

have good recovery after surgery and improved symptoms and joint function [2,3]. This paper aims to study the specific effect of this treatment measure on patients with ankle osteoarthritis and cartilage damage.

2. General information and methods

2.1. General information

The research subjects were 60 patients with ankle osteoarthritis and cartilage damage treated in our hospital from January 2022 to December 2022. After enrollment, the patients were divided into the experimental group and the control group using a random number table method, each with 30 patients. There were 16 males and 14 females in the control group, the age range was 41 to 80 years old, with an average of 67.69 ± 3.64 years old; the disease duration ranged from 1 to 5 years, with an average of 3.02 ± 0.24 years. The; In the experimental group, 17 cases were male, and 13 were females; the age range was 42 to 79 years, with an average age of 67.71 ± 3.69 years old; the disease duration ranged from 2 to 6 years, with an average of 3.13 ± 0.17 years. The basic information (gender, age, disease duration) of the observed subjects was compared and analyzed by statistical software. There was no difference in the results ($P > 0.05$).

Inclusion criteria included patients with good mental state and communication skills; patients who voluntarily participate in the study, are informed of its content, and provide their consent. Exclusion criteria were patients with other malignant tumors; patients with other hematological diseases and major infections; patients with other serious heart, liver, and kidney diseases, and those with contraindications for surgery.

2.2. Methods

In the control group, conventional surgical intervention was implemented. After a detailed and comprehensive examination, routine joint debridement treatment and intervention was carried out based on the actual condition. The patient was assisted to assume a prone position, and after the administration of general anesthesia or epidural anesthesia, a standard three-portal scope was selected to perform the entrance. The corresponding water cannula, arthroscope, and other instruments and equipment were placed, and a curette under the arthroscope, probes, etc., were used to perform corresponding cleaning of the patient's articular cartilage defect, the loose cartilage was removed, the defect edge and lower bone surface were cleaned, then the joint cavity was flushed until clean, and then the debris was cleaned up [4]. After the surgery, ice packs were applied to the affected area intermittently for 24 to 48 hours.

The experimental group implemented arthroscopic microfracture treatment intervention. The patient was put in the supine surgical position, and after performing general anesthesia or epidural anesthesia, a standard three-portal scope was selected to perform the entrance. Arthroscopy was used to sequentially explore the patient's medial recess, medial cartilage, joint capsule, lateral cartilage, lateral recess, and other parts to comprehensively understand the patient's cartilage and ankle joint injuries. Under arthroscopy, the patient's cartilage damage site was treated, the site of synovial hyperplasia was excised, the periphery of the cartilage defect was selected in the vertical direction, and the surrounding normal cartilage tissue was shaped to remove the damaged basal calcified tissue altogether. The vertebral tip of the microfractured vertebra was used to perform the drilling operation in the vertical direction from the edge. It should be noted that the center of the same hole is the center of a circle, and the distribution from the center to the edge is circular, and that there should be three to four holes per centimeter. During the drilling operation, the bone marrow and blood leaking out of the bone cavity can effectively promote the formation of new articular cartilage with blood clots in the defective location. After the fluid in the joint was drained, normal saline was used to flush the joint, and the arthroscope was withdrawn to close the wound. After the surgery, ice packs were applied to the affected area

intermittently for 24 to 48 hours.

2.3. Observation indicators

(1) Total effective rate of treatment: Through the observation and evaluation of the patient's symptoms, such as pain, swelling, joint effusion, etc., the results were divided into markedly effective, effective, and ineffective. The significant relief of symptoms was assessed as markedly effective, and the relief of symptom was effective. Still, it was ineffective if there was no symptom relief or the symptoms worsened. Total effective rate of treatment = Markedly effective + Effective

(2) Levels of inflammatory factors: The specific changes in patients' IL-6 (interleukin-6), TNF-α (tumor necrosis factor-α), and CRP (C-reactive protein) were recorded during the study process.

(3) Pain score: The patient's pain level changes were recorded using the VAS (visual analog scale), with 0–10 points. The score was directly proportional to the pain experience.

(4) Quality of life: The SF-36 (36-Item Short Form Health Survey) scale was used to analyze and understand the specific changes in patients' mental health scores, physiological function scores, and social function scores. Each dimension was scored from 0 to 100, with the scores directly proportional to the results.

2.4. Statistical analysis

SPSS26.0 was used for statistical analysis, the enumeration data between groups were compared using the chi-square test, the measurement data conformed to the normal distribution was mean ± standard deviation (SD), *t*-test was used as the test method, and the statistical difference was based on $P < 0.05$.

3. Results

3.1. Total treatment effectiveness

Table 1 shows the changes in the total treatment effectiveness of the two groups of patients after treatment. The experimental group (96.67%) had a significantly higher total treatment effectiveness than the control group (70.00%) ($P < 0.05$).

Table 1. Comparison of total treatment effectiveness [n (%)]

Group	Markedly effective	Effective	Ineffective	Total effective rate
Control group (n = 30)	8 (26.67)	13 (43.33)	9 (30.00)	21 (70.00)
Experimental group (n = 30)	14 (46.67)	15 (50.00)	1 (3.33)	29 (96.67)
χ^2	-	-	-	7.680
P	-	-	-	0.006

3.2. Levels of inflammatory factors

Table 2 shows the changes in the levels of inflammatory factors in the two groups of patients after treatment. The levels of IL-6, TNF-α, and CRP of the experimental group were lower than those of the control group ($P < 0.05$).

3.3. Pain scores

Table 3 shows the changes in pain scores of the two groups of patients after treatment. The pain scores of the experimental group were lower than those of the control group ($P < 0.05$).

Table 2. Comparison of inflammatory factor levels (mean ± SD)

Group	IL-6 (ng/L)	TNF-α (ng/L)	CRP (mg/L)
Control group (n = 30)	56.43 ± 13.47	112.25 ± 61.51	60.39 ± 17.31
Experimental group (n = 30)	48.27 ± 12.84	79.63 ± 32.42	30.26 ± 8.34
t	2.402	2.570	8.589
P	0.020	0.013	0.000

Table 3. Comparison of pain scores (mean ± SD, points)

Group	Before intervention	After intervention
Control group (n = 30)	7.36 ± 4.15	6.12 ± 3.18
Experimental group (n = 30)	7.28 ± 4.28	4.38 ± 2.07
t	0.073	2.512
P	0.942	0.015

3.4. Quality of life measurements

Table 4 shows the changes in the quality of life measurements of the two groups of patients after treatment. The mental health score, physiological function score, and social function score of the experimental group were higher than those of the control group ($P < 0.05$).

Table 4. Comparison of quality of life measurement (mean ± SD, points)

Group	Mental health score		Physiological function score		Social function score	
	Before intervention	After intervention	Before intervention	After intervention	Before intervention	After intervention
Control group (n = 30)	57.23 ± 5.34	71.37 ± 4.64	56.68 ± 5.67	72.13 ± 4.62	55.31 ± 3.65	70.92 ± 3.13
Experimental group (n = 30)	57.79 ± 5.35	80.16 ± 4.28	56.93 ± 5.72	81.28 ± 4.61	55.37 ± 3.69	80.13 ± 3.24
t	0.406	7.627	0.170	7.679	0.063	11.198
P	0.686	0.000	0.866	0.000	0.950	0.000

4. Discussion

Ankle osteoarthritis combined with cartilage damage is a common disease. This disease has a serious impact on patient's daily life and work, causing a sudden drop in their quality of life and often bringing varying degrees of pain to patients. The patients are mainly middle-aged and older adults. Their articular cartilage degenerates, gradually exposing the lower bones, causing cartilage destruction and contracture of tissues around the joint capsule [5], creating a vicious cycle. Patients will develop limb movement disorders as the disease progresses. To improve this condition, timely and active treatment is necessary. There are many available clinical treatment approaches, including drug treatment and surgical treatment. Although conventional joint debridement can relieve the patient's symptoms, its long-term effect is poor. Arthroscopic microfracture treatment can improve the patient's symptoms [6,7], relieve the patient's pain, promote the recovery of ankle joint function to the greatest extent, and has a better prognosis.

In this study, the experimental group underwent arthroscopic microfracture treatment intervention. The symptoms of the patients in this group were better improved after treatment. Compared with the control

group, the total effective rate of treatment in the experimental treatment group was higher ($P < 0.05$); the IL-6, TNF-α, and CRP in the experimental group were lower ($P < 0.05$) and the patients' inflammatory response was improved; the pain score of the experimental group was lower ($P < 0.05$), and their pain was relieved; the mental health, physiological, and social function scores of the experimental group were higher ($P < 0.05$), the patients' quality of life was improved. This is similar to the results reported by Shi [8], indicating that the effect of arthroscopic microfracture treatment was better after intervention. As an emerging bone marrow stimulation technology, arthroscopic microfracture treatment can better treat localized cartilage damage while protecting joint function. The application of cellulose blood clots to fill cancellous bone marrow mesenchyme can effectively promote the production of local growth factors, further repair the cartilage [9,10], and achieve the purpose of replacing articular cartilage. The microfracture awl used in the operation does not release too much heat when drilling. With many angles, it is more conducive to performing surgical operations perpendicular to the bone surface in the ankle joint, making it easier to drill holes by hand. Deep control can effectively maintain good limb mechanical balance and stability and improve clinical symptoms.

5. Conclusion

The above comprehensive evidence proves that arthroscopic microfracture treatment is more effective when treating ankle osteoarthritis with cartilage damage. The treatment can improve the patient's symptoms, inflammatory response, pain, and quality of life. Compared with conventional surgical treatment measures, arthroscopic microfracture is suitable for widespread promotion.

Disclosure statement

The author declares no conflict of interest.

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Treatment Efficacy of CT-Guided Percutaneous Kyphoplasty Combined with Three-Dimensional Coordinate Guidance System on Osteoporotic Vertebral Compression Fracture

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Abstract: *Purpose:* To investigate the clinical effect of percutaneous kyphoplasty (PKP) guided by computed tomography (CT) combined with the three-dimensional coordinate guidance system on the treatment of osteoporotic vertebral compression fracture (OVCF). *Methods:* 32 cases of OVCF in the elderly admitted to our hospital from October 2019 to March 2021 underwent CT-guided PKP combined with the three-dimensional coordinate guidance system, and 36 vertebrae were treated. The patients' VAS pain scores (visual analog scale) and ODI (Oswestry disability index) were observed after surgery, and the paired *t*-test was used to compare these indexes. *Results:* The 36 vertebrae that were treated with CT-guided PKP combined with the three-dimensional coordinate guidance system underwent unilateral pedicle puncture according to the path planned by CT images. With the ideal position of the puncture needle and a high success rate of puncture, the puncture time was 1.2–2.6 minutes, with an average of about 1.5 minutes; the injected bone cement ranged from 3 to 5.5 mL, with an average of 4.2 mL, and there were no spinal nerve injuries or leakage of the cement in the canal. VAS score decreased from 7.65 ± 0.60 before the operation to 2.59 ± 0.28 one day after the operation ($P < 0.01$); ODI decreased from 62.3 ± 2.18 before the operation to 27.91 ± 1.32 after the operation ($P < 0.01$). *Conclusion:* The application of CT-guided PKP combined with the three-dimensional coordinate guidance system has the advantages of accurate puncture, short operation time, less intraoperative bleeding, and low complications. This treatment is safe, reliable, and satisfactory for patients, and is worthy of clinical promotion.

Keywords: Computed tomography; Three-dimensional coordinate guidance system; Percutaneous kyphoplasty

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1. Introduction

With the aging of society, the prevalence of osteoporosis is rapidly increasing. Osteoporotic vertebral

compression fracture (OVCF) is the most common fracture, and it has become one of the major diseases that seriously threaten the health of the elderly. As an emerging minimally invasive technique for the treatment of OVCF in recent years, percutaneous kyphoplasty (PKP) has been gradually popularized and applied for its advantages of rapid pain relief, improvement of kyphotic deformity, and relatively less cement leakage [1,2]. As PKP surgery requires several adjustments of the angle of the C-arm X-ray in the prone position for surgical positioning [3], elderly patients often have spinal deformities, severe spinal degeneration, and other pathological changes, which make it difficult for them to tolerate being in the prone position for a long period. Therefore, completing the surgical operation as soon as possible, reducing surgical complications, and minimizing intraoperative accidents are the keys to treating elderly OVCF. Conventional PKP surgery involves vertebral puncture and cement injection under C-arm X-ray monitoring, which is complex and requires a physician with surgical experience. Therefore, the risk of vertebral body puncture and intraoperative complications such as cement leakage are still important factors affecting the surgical results at present. Operators are exposed to ionizing radiation and surgeons have a long learning curve. In order to improve the accuracy of targeted puncture and puncture efficiency in vertebroplasty, PKP surgery was guided by computed tomography (CT) with the help of the three-dimensional coordinate guidance system, which can achieve fast and precise puncture and better observation of cement dispersion during cement injection, greatly reducing the risks of spinal cord and nerve injury and cement leakage, and shortening the operation time.

2. Structure and working principle of three-dimensional coordinate guidance system

The guiding instrument is composed of body frame, head frame, and guiding system, which is a "three-dimensional coordinate body," utilizing precise micro-angular displacement sensors to realize the digital display of any three-dimensional angle of the X-axis, Y-axis, and Z-axis. In the process of specific puncture diagnosis and treatment, with the help of CT scanning, the puncture path from the body surface to the deep target point is planned in advance on the CT image, and the data of the two-dimensional or three-dimensional angle of the puncture path is measured by the CT measurement software. The above data is presented in three dimensions through the guiding instrument, so it can be accurately guided in accordance with the pre-designed puncture path and facilitate the puncture operation, so that it can be completed in a simple, easy-to-grasp, safe, and error-free manner.

3. General information and methods

3.1. General information

From October 2019 to March 2021, 32 cases of osteoporotic vertebral compression fracture in the elderly admitted to our hospital were selected. Among them, 8 cases were male and 24 cases were female; their age ranged from 56–91 years old, with an average age of 74 years old; there were 29 cases of single-segment fracture, 2 cases of two-segment fracture, and 1 case of three-segment fracture, involving 23 lumbar vertebrae, 13 thoracic vertebrae.

Inclusion criteria included patients who agreed to the operation and signed the consent form for surgery; osteoporotic vertebral compression fracture confirmed by CT and magnetic resonance imaging (MRI); MRI showed that the fractured vertebral body had low signal in T1-weighted image and high signal in T2-weighted image and fat suppression; simple vertebral compression fracture, CT confirmed that there was no breakage of the posterior wall of vertebral body; normal laboratory results for blood routine, coagulation, and biochemistry.

Exclusion criteria were pathologic compression fracture of the vertebral body caused by primary tumor, hemangioma, tuberculosis, metastasis, etc.; accompanied by symptoms and signs of damage to the spinal cord and nerve roots; accompanied by severe cardiovascular disease and other basic diseases that cannot tolerate surgery;

coagulation dysfunction; skin infection at the surgical site; inability to tolerate a longer period of prone position.

3.2. Instruments and equipment

The instruments used included the three-dimensional coordinate guidance system, Germany Siemens Dual Source CT (Somatom Spirit), C-arm X-ray machine; percutaneous vertebral kyphoplasty instrumentation (provided by Shanghai Kelite Medical Technology Co., Ltd.); and MENDEC bone cement (provided by Tecres S.p.A., Italy).

3.3. Surgical method

The CT room was air sterilized before surgery, the patient was placed prone on the CT bed with the abdomen suspended in the air, and a metal positioning fence was placed in the roughly superficial area of the diseased vertebral body. A thin-layer CT scan of the diseased vertebrae was performed (1-mm tomography), which was positioned in the plane of the vertebral arch root. The transforaminal puncture path was planned on the CT tomographic images (middle and upper thoracic vertebrae via the extraforaminal route), which needed to cross the vertebral midline. Using the point where the CT infrared aperture intersected the metal fence, the projection point of the puncture path on the body surface was determined and a marking line was drawn. The medial inclination angle of the puncture path, the sagittal caudal inclination angle, and the distance from the skin puncture point to the target (pedicle base) were measured on the CT image, and the values were recorded.

A three-dimensional coordinate guidance system was installed in the patient's surgical area, and the above data were entered into the console to lock the puncture trajectory. The surgical area was routinely sterilized and toweled, and a disposable sterile protective sleeve was used to cover the guiding device. The laser light of the guiding system was turned on, the laser spot (0.5 mm in diameter) was made corresponding to the puncture point and then fixed, the puncture needle sleeve was installed (the inner diameter of which was the same as the outer diameter of the puncture needle). 1% lidocaine hydrochloride injection for local anesthesia was administered, an incision of about 0.6 cm was made on the skin, and the vertebroplasty-specific puncture needle was inserted into the puncture needle sleeve determined by the guiding instrument using a hammering method, and attention was paid to observing the scaling of the needle, reaching the pre-measured depth and the hammering method. A CT scan was performed to confirm that the needle was located in the pedicle and that the extension of the puncture path crossed the midline of the vertebral body. The core of the needle was removed, the guidewire was inserted, and the working sheath was replaced. The distal end of the working sheath was located in the middle and posterior third of the vertebral body on C-arm fluoroscopy. A bone drill was inserted and slowly advanced about 2.0 cm to the anterior middle third of the vertebral body. After the bone drill was removed, the uninflated balloon was inserted to the anterior middle third of the vertebral body. The balloon was inflated by injecting contrast medium (iohexol) until the height of the vertebral body was restored to a satisfactory level under the supervision of the C-arm, the contrast medium was withdrawn and the balloon was pushed out under the supervision of the C-arm; the cement was inserted under the supervision of the C-arm and the cement was distributed to a satisfactory level. Subsequently, a CT scan was performed to confirm that there was no leakage of the bone cement in the vertebral canal, and that the cement distribution was across the vertebral body midline to the contralateral side, and the working sheath was withdrawn. The sheath tube was removed and the incision was bandaged. The patient's blood pressure, heart rate, respiration, and oxygen saturation were monitored throughout the operation, and intravenous fluid access was established.

3.4. Evaluation of pain and mobility

The patients were evaluated before and after surgery using visual analog scale (VAS) and Oswestry disability index (ODI). The paired *t*-test was used to compare the above indexes, and there was a statistically significant

difference if $P < 0.01$.

3.5. Statistical analysis

All statistical data were analyzed using SPSS21.0 statistical software, and the quantitative data were expressed as mean ± standard deviation (SD) and *t*-test was performed. All count data were analyzed using χ^2 test, and $P < 0.05$ was considered statistically significant.

4. Results

All 32 OVCF patients with a total of 36 vertebrae were successfully treated with CT-guided PKP combined with the three-dimensional coordinate guidance system, and all of them underwent unilateral pedicle puncture according to the preoperative planning path (middle and upper thoracic vertebrae via the external pedicle route). The immediate intraoperative CT scanning confirmed that the bone cement was well distributed and crossed the vertebral body midline without any complications such as leakage of the cement into the vertebral canal or nerve injury. In two of the cases, due to changes in body position, the puncture path deviated from the preoperative plan. The angle of deviation was measured according to the CT images and adjusted accordingly in the three-dimensional coordinate guidance system to correct the direction of the puncture, and the operation was completed successfully without nerve injury. The puncture time for each vertebral body was about 1–2.6 minutes, with an average of 1.5 minutes. The amount of cement injected was 3.5–4.5 mL for lumbar vertebrae and 2.0–3.5 mL for thoracic vertebrae, and the statistical results of the preoperative and postoperative VAS and ODI scores are shown in **Table 1**. The preoperative, intraoperative, and postoperative pictures are displayed in **Figures 1** to **3**, showing the image data of L1 osteoporotic vertebral compression fracture undergoing PKP treatment with the 3D coordinate guidance system in a 72-year-old female.

Table 1. Preoperative and postoperative VAS scores and ODI index (mean ± SD)

Time	n	VAS score	ODI index (%)
Preoperative	32	7.65 ± 0.60	62.30 ± 2.18
1 day postoperative	32	2.59 ± 0.28*	27.91 ± 1.32*

*$P < 0.01$ compared with preoperative

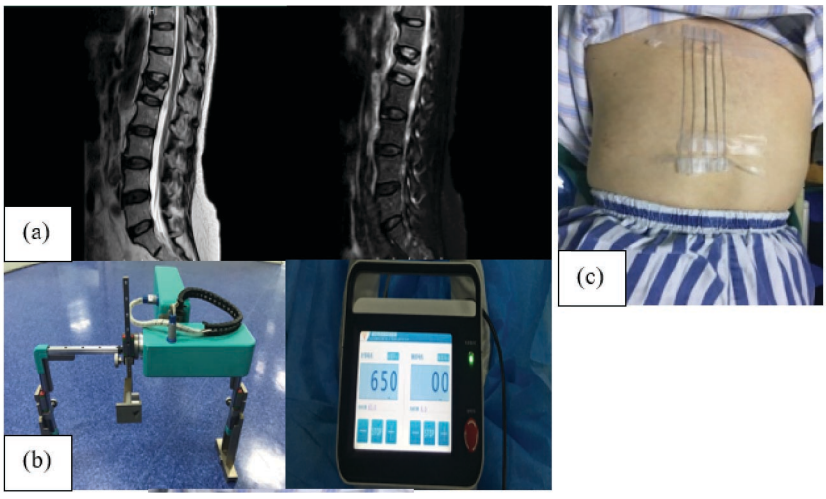

Figure 1. Preoperative pictures (a) Preoperative lumbar MRI (b) 3D coordinate guidance system and control console (c) Metal fencing placed on the body

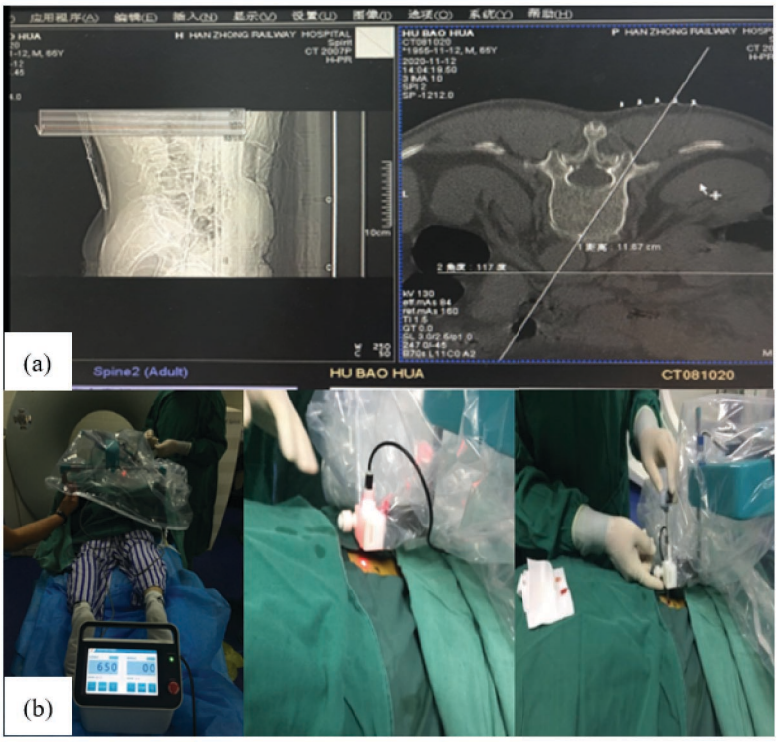

Figure 2. Intraoperative pictures (a) Intraoperative CT images for planning and designing the puncture route (b) 3D coordinate guidance system input data to determine the direction of puncture

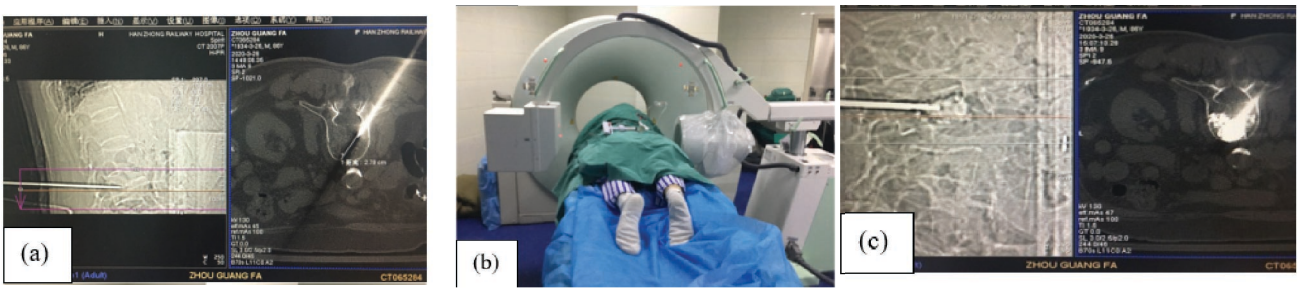

Figure 3. Intraoperative and postoperative pictures (a) Intraoperative CT scanning to verify the puncture route (b) Cement injection under C-arm monitoring (c) Satisfactory cement distribution observed on postoperative CT scanning

5. Discussion

Percutaneous vertebroplasty (PVP) has the advantages of low trauma and rapid pain relief, and is the primary means of treatment for OVCF [4-8]. Percutaneous kyphoplasty (PKP) is a modified technique developed on the basis of PVP, in which the vertebral body is inflated by a balloon, which can better restore the height of the injured vertebrae; at the same time, a cavity is formed in the vertebral body after the balloon is inflated, which can reduce the chances of cement leakage. Both PVP and PKP require the injection of polymethylmethacrylate (PMMA) bone filler into the diseased vertebrae through percutaneous puncture. This technique involves entering the vertebral body through the pedicles, which are lined with important spinal nerves and can lead to serious nerve damage if deflected, or nerve compression or nerve burns from leakage of the cement through the pedicles, as high temperatures can be generated by the polymerization of PMMA. Therefore, the surgery may be associated with a series of complications related to cement injection [9]. Hadjipavlou *et al.* [10] statistically analyzed the cement leakage rate of 2,729 vertebral bodies undergoing PVP and 1,279 vertebral bodies

undergoing PKP. The overall leakage rate was 29% for PVP and only 8.4% for PKP. Chen *et al.* [11] concluded that the overall leakage rate of unilateral and bilateral PKP surgery was 14.63%. Zheng *et al.* [12] suggested that the complexity of the PKP procedure increases the incidence of surgical complications. Bone cement leakage seems to be an insurmountable problem for both PVP and PKP and has been reported in almost every relevant literature. Numerous clinical studies have confirmed that there is no direct linear relationship between the amount of bone cement injected or the degree of filling and clinical pain relief. However, most clinicians still strive to fill the vertebral body as much as possible without causing leakage, which correspondingly increases the risk of cement leakage.

Bilateral pedicle puncture approach is the classic surgical approach for PKP, but bilateral puncture, which increases the operation time, the number of intraoperative fluoroscopy, and the surgical trauma, invariably increases the surgical risk. As the concept of minimally invasive surgery continues to deepen, the advantages of unilateral approach for the treatment of OVCF continue to be highlighted. It has been reported that as long as the puncture angle is well mastered, a satisfactory therapeutic effect can be achieved by a unilateral pedicle puncture approach [13,14]. More and more spine surgeons are attempting to choose the unilateral approach for the treatment of OVCF [15]. Papadopoulos *et al.* [16] reported the use of unilateral approach for the treatment of OVCF at an early stage, and demonstrated that the unilateral approach was as effective as the bilateral approach in relieving pain and restoring the height of the vertebral body. Song *et al.* [17] concluded in a retrospective study that there was no significant difference between unilateral and bilateral approaches in the recovery of vertebral height and lordosis, but the unilateral approach was superior to the bilateral approach in the relief of pain. It has been shown that if the puncture needle crosses the midline of the vertebral body and reaches the anterior third of the vertebral body at the distal end during the unilateral approach to PKP, the bone cement can be evenly distributed in the vertebral body to achieve a mechanical balance, so that the vertebral body can be uniformly strengthened [18,19]. Unilateral approach not only can achieve similar efficacy as bilateral puncture, but also offers the advantages of shorter operation time, less trauma, and fewer X-ray fluoroscopies, etc., and there are many clinical applications and studies conducted in this area. A meta-analysis by Cheng *et al.* [20] showed that the unilateral approach group was better than the bilateral approach group in terms of operation time, trauma to the patient, and radiographic exposure, etc.

OVCF is more common in the elderly, who often have heart disease, hypertension, diabetes mellitus, pulmonary disease, renal disease, and other multi-system diseases, and cannot tolerate being in a prone position for a long period. Thus, the longer the duration of the operation, the higher the risk it brings to the patient. Conventional PKP/PVP surgery is performed under the supervision of a C-arm X-ray machine, which requires repeated fluoroscopy to observe the puncture angle from the front and side, and to gradually guide the needle to the correct position, resulting in a long surgical learning curve. The arch root of the upper and middle thoracic spine is narrow and obscured by the heart, lungs, and other mediastinal tissues, coupled with severe osteoporosis, obesity, and other patient factors, the fluoroscopic image is often fuzzy, poorly layered, and unable to clearly display the anatomical structure of the spine. This issue seriously affects the accuracy of the angle and depth of the puncture needle, resulting in a decrease in the quality of the surgery, an increase in the medical staff's radiation exposure, and a higher risk of nerve damage and other complications. It is also difficult to detect the real leakage of bone cement from the lateral image alone during cement injection. Bone cement leakage should be prevented, and high-quality and clear imaging equipment is indispensable to minimize the occurrence of bone cement leakage.

In recent years, along with the rapid development of science and technology, the high-tech combination of computer-aided surgery navigation system (CASNS) came into being. Orthopedic navigation system, on

the other hand, can accurately provide the patient's preoperative or intraoperative image data and the patient's anatomical structure during surgery, track the surgical instruments during surgery, and display the position of the surgical instruments in real time on the image in the form of virtual probes, so that the surgeon can have a clear understanding of the positional relationship between the surgical instruments and the patient's anatomical structure, which can make the surgery more accurate, safer, and faster. Sun and Xu [21] reported that the use of navigation systems to guide vertebroplasty can significantly improve surgical accuracy and safety, and can shorten the operation time and reduce the number of fluoroscopy. However, the development of computer-aided navigation systems is relatively slow, and the following shortcomings exist: (1) the equipment is expensive with high costs of use and maintenance, which increases the medical burden of patients; hospitals below the tertiary level do not have sufficient purchasing power; (2) intraoperative acquisition of three-dimensional image data is required, and the transmission of the image data to the navigation system workstation for image registration is a relatively cumbersome and time-consuming operation; (3) intraoperative fixation of the dynamic reference base to the root of the spinous process requires an additional surgical incision, which increases the damage. (4) image drift, i.e., the error between the navigation system image and the real position caused by the displacement of tissue structures during surgery, is the biggest defect of the navigation system, and its incidence has been reported to be as high as 66% in foreign countries [22]; (5) as current navigation images can contain up to four vertebrae, a second image acquisition may be required in noncontiguous multi-segmental osteoporotic compression fracture cases, and even the position of the reference frame may need to be adjusted, which increases additional operation time.

Many literature reported that in CT-guided PKP surgery, the three-dimensional image of CT is used to reconstruct and localize the diseased vertebrae from multiple planes, which can more accurately determine the position and angle of the puncture needle, guide the puncture needle to reach the target position precisely, and monitor and observe the dispersion of the bone cement in real time from multiple perspectives, so as to reduce the rate of bone cement leakage [23-25]. Compared with conventional PKP surgery under C-arm, CT-guided surgery can significantly improve the precision of surgical operation, reduce complications such as nerve injury and cement leakage, and effectively improve the patient's pain and mobility, which is a safe and effective treatment method. According to Rauschmann *et al.* [26], the positioning and puncture under the guidance of a CT machine is accurate and easy to operate, and through multiple tomography scans, it is possible to grasp whether the tip of the needle enters the correct position and whether the depth is appropriate during the puncture process, and it can be adjusted according to the specific situation at that time until it is satisfactory. However, the CT-guided PKP operation is too cumbersome and repetitive, for each step, it is necessary to exit the CT examination bed, and then scan and adjust again after the operation, resulting in a time-consuming operation, which cannot provide real-time impact information and cannot guarantee the success of a puncture.

Three-dimensional coordinate guidance system is a completely mechanized, semi-automated new type of guiding system, the head frame part of which is a miniature angular displacement sensor with extremely high sensitivity. Through the control panel input data, it can realize the X-axis, Y-axis, Z-axis of any three-dimensional angle, and it can accurately present three-dimensional data such as the direction of the puncture, angle, etc., and provide intuitive guidance for the targeted puncture. The vertebroplasty performed under the joint guidance of CT and the three-dimensional coordinate guidance system offers the advantages of both approaches. By combining the advantages of the two, it overcomes the disadvantages of repeated fluoroscopy and poor image effect under the C-arm, as well as multiple step-by-step punctures under CT guidance alone, so as to complete the localization of the puncture quickly and avoid the damage caused by blind puncture and multiple adjustments of the puncture needle position. With the help of CT measurement software, the distance

from the skin puncture point to the target point of the pedicle root can be accurately measured, and under the guidance of the guiding instrument, it is generally possible to perform the puncture in place at one time. In addition, the guidance system is simple, low-cost, and easy to use, is not as cumbersome as the navigation system, and does not require an additional non-penetrating part of the incision. After the successful puncture, we still rely on C-arm fluoroscopy when injecting the bone cement, which can synchronize the dynamic monitoring of bone cement dispersion, avoiding the time loss caused by moving for CT scans. When there is a tendency of leakage of bone cement injection, real-time CT thin-layer scanning can provide information on the distribution of bone cement in time, and can better recognize the safety illusion under C-arm fluoroscopy, so as to determine the time window for the termination of bone cement injection and the effective injection dose. Surgical safety is effectively ensured and blindness in puncture and bone cement injection is reduced.

CT-guided PKP combined with three-dimensional coordinate guidance system offers the following advantages: (1) abstract data such as internal inclination and sagittal inclination measured by the patient's CT three-dimensional image are presented more intuitively, making the puncture easier, faster, safer, and more accurate; (2) the maximal internal inclination angle of the path is planned according to the CT image to obtain the optimal unilateral pedicle puncture path, which prevents the additional damage caused by bilateral puncture, and significantly shortens the operation time; (3) for adjacent multi-segment vertebrae (non-continuous vertebrae) surgery, the puncture can be completed quickly in the same time period under the guidance of the guiding system, eliminating the need for multiple scanning and image acquisition, and saving fluoroscopy time to the greatest extent possible; (4) the indications for the surgery are expanded, due to the precise positioning of the puncture, the ideal position of the puncture can also be obtained in patients with vertebral compression of more than 75%; (5) the equipment is easy to operate and master, which shortens the learning curve of PKP surgery; (6) the cost of the equipment is cheaper than that of the computerized navigation system, and the maintenance cost is low, which makes the medical burden borne by the patients light and acceptable.

6. Conclusion

In summary, CT-guided PKP combined with the three-dimensional coordinate guidance system is simple, fast, and highly accurate in puncture, which improves the safety of patients without increasing medical expenses, and reduces radiation exposure to medical staff. Thus, the clinical effect is satisfactory and worthy of popularization in clinical application.

Disclosure statement

The authors declare no conflict of interest.

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Clinical Efficacy of Needle-Knife Therapy Combined with Muscle Energy Technique in the Treatment of Lateral Epicondylitis of the Humerus

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Abstract: *Objective:* To observe the clinical efficacy of needle-knife therapy combined with muscle energy technique in treating external humeral epicondylitis and analyze its advantages. *Method:* 71 patients with lateral epicondylitis of the humerus were randomly divided into an experimental group (n = 36 cases, needle-knife therapy combined with muscle energy technique) and a control group (n = 35 cases, electroacupuncture therapy combined with muscle energy technique) using a random number method. The visual analog scale (VAS) scores, Mayo elbow performance score (MEPS), Barthel index (BI) scores, and self-rating anxiety scale (SAS) scores were compared between the two groups before and after treatment and during follow-up. *Results:* At the end of the treatment and follow-up period, within the same group, the VAS score decreased ($P < 0.05$), while the MEPS, BI index score, and SAS score increased ($P < 0.05$). In intergroup comparison, the VAS scores of the experimental group were lower than those of the control group; the MEPS, BI index score, and SAS score did not show statistically significant differences between groups at each time point ($P > 0.05$). *Conclusion:* The combination of needle-knife therapy and muscle energy technique in treating lateral epicondylitis of the humerus has advantages such as good analgesic effect, less treatment frequency, and consolidated long-term efficacy, which is worthy of further research and promotion.

Keywords: Lateral epicondylitis of humerus; Needle-knife therapy; Muscle energy technique; Clinical observation

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1. Introduction

Lateral epicondylitis (LE), also known as tennis elbow, belongs to the category of "injured tendons" and "elbow strain" in Chinese medicine. The disease can be caused by repeated stretching of the attachment point of the common extensor tendon of the forearm [1]. It is mainly characterized by localized pain at the lateral epicondyle of the humerus, accompanied by dysfunction of elbow extension and forearm rotation on the affected side. It is more likely to occur in people who rotate their forearms and flex and extend their elbow joints repeatedly and

for a long time, with the incidence rate in people who mainly work with their hands reaching 7% [2-5]. Clinical treatment of lateral epicondylitis generally adopts non-surgical treatment, which usually includes physical therapy, drugs, acupuncture, needle-knife, and other therapies [6]. Acupuncture treatment is a minimally invasive technology of traditional Chinese medicine. Compared with traditional Western medicine treatment methods, it has the advantages of simple operation, small side effects, high safety, and easy promotion. This article aims to observe the treatment of lateral humeral epicondylitis with needle-knife therapy combined with muscle energy technique.

2. General information and methods

2.1. General information

71 patients with lateral epicondylitis who were openly recruited from the Acupuncture Department and Rehabilitation Department of Mianyang Hospital of Traditional Chinese Medicine from September 2021 to January 2023 were divided into an experimental group (n = 36 cases, needle-knife therapy combined with muscle energy technique) and a control group (n = 35 cases, electroacupuncture therapy combined with muscle energy technique), according to the random envelope method. Among these, the subjects in the experimental group (No. 100) and the control group (No. 18, No. 54, No. 67) dropped out, and the dropout cases were not included. According to the final statistics, 67 subjects (35 in the experimental group and 32 in the control group) completed the experiment. There were no differences in age, gender, and duration of disease between the two groups of patients ($P > 0.05$), as shown in **Table 1**. This study was approved by the Medical Ethics Committee of Mianyang Hospital of Traditional Chinese Medicine (2022KL-9).

Table 1. Comparison of general information of the two groups of patients

Group	n	Age (years)	Gender		Duration of disease (weeks)
			Male	Female	
Experimental group	35	50.29 ± 3.770	16 (45.7%)	19 (54.3%)	21 (14–30)
Control group	32	49.75 ± 4.690	16 (50.0%)	16 (50.0%)	20 (15–30)

2.2. Diagnostic criteria

According to *Western Medicine Reference (Clinical Diagnosis and Treatment Guide: Pain Edition)*, the diagnostic criteria is elbow joint involvement leads to pain on the outside of the elbow joint, which worsens after extending the wrist, making a fist, internal rotation, extension, and exertion, and may be relieved by stopping elbow activity. It also includes obvious pain in the lateral epicondyle of the humerus, the radial head, and between the two; positive extensor radialis tendon stretch test; and no bony lesions in anteroposterior and lateral X-rays of the elbow joint. Traditional Chinese medicine refers to the syndrome classification of lateral epicondylitis issued by the Chinese Association of Traditional Chinese Medicine [7].

2.3. Inclusion and exclusion criteria

The inclusion criteria included patients with lateral epicondylitis who meet the diagnostic criteria and voluntarily join the trial with the consent form signed; aged between 18 and 60 years old, regardless of gender; duration of disease within 6 months; no other treatment within 7 days; no other injuries to the elbow joint [8].

The exclusion criteria were patients with mental disorders, pregnant women, damaged or deformed elbow skin, or those with pacemakers.

2.4. Methods

The experimental group was treated with needle-knife therapy combined with muscle energy technique. The operation was based on the "Clinical Diagnosis, Treatment and Operation Specifications of Needle Knife Medicine" [9]. The patient was positioned correctly, and the surgical area was anesthetized with 5 ml local lidocaine (50 mg, Suicheng Pharmaceutical Co., Ltd.), a needle knife (0.40 × 25 mm, Suzhou Medical Products Factory Co., Ltd.) was used to quickly insert the needle vertically along the direction of the muscle fibers at the tender point until it reached the lesion. Longitudinal dredging and peeling were performed 3 to 4 times, the angle of the needle tip was adjusted, and peeling was done 3 to 4 times horizontally close to the bone surface. After the operation, muscle energy technique was performed on the affected side. Treatment was done once a day, followed by a 6-day rest; 7 days constituted a course of treatment, with a total of 2 courses of treatment.

The control group was treated with electroacupuncture therapy combined with muscle energy technique. Point selection (refer to *Acupuncture and Moxibustion* [10]) was Shousanli, Quchi, Juliao, and Ashi points on the affected side. Specific operations were as follows. The patient was positioned correctly, a filiform needle (0.30 × 40 mm, Tianjin Yipeng Medical Equipment Co., Ltd.) was used to insert directly into the Ashi point. After getting Qi, four needles were inserted around the Ashi point up, down, left, and right using the oblique method. The Ashi and Shousanli points were connected to the electroacupuncture instrument (KWD-808I, Changzhou Wujin Great Wall Medical Equipment Co., Ltd.), selecting 5/100Hz density wave, and the treatment time was 30 minutes. After the operation, muscle energy technique was performed on the affected side. Treatment was once a day, continuous treatment for 5 days, and followed by a 2-day rest; 7 days constituted a course of treatment, totaling 2 courses of treatment.

The experimental and control groups were treated with muscle energy technique therapy. The specific operations were:

(1) Post Isometric Relaxation (PIR): The patient lied supine, with the affected arm naturally abducted, the forearm slightly pronated, and the wrist naturally resting on the edge of the bed. The patient's forearm was controlled with one hand and the wrist with the other to flex the palm until it reached the point of pain or resistance. The patient was asked to try to resist the operator to do dorsiflexion of the wrist, with a strength of about 20%, relaxing after maintaining for 5 seconds. Following complete relaxation, the patient's wrist was flexed to the new resistance point again and the above steps were repeated. The above operation was repeated a total of 3 times.

(2) Reciprocal Inhibition (RI): The same body position as the PIR was taken. The patient's forearm was controlled with one hand and the wrist with the other to flex the palm until it reached the point of pain or resistance. The patient was asked to resist the operator and do palm flexion with a strength of about 20%, relaxing after maintaining for 5 seconds. Following complete relaxation, the patient's wrist was flexed to the new resistance point again and the above steps were repeated. The above operation was repeated a total of 3 times.

2.5. Observation indicators

The main observation indicators included visual analog scale (VAS) score and Mayo elbow performance score (MEPS); secondary observation indicators were Barthel index (BI) score and self-rating anxiety scale (SAS) score.

There is currently no unified standard for evaluating the treatment efficacy of lateral humeral epicondylitis. This study divided the treatment efficacy into cured, effective, and ineffective by referring to the *Orthopedic Clinical Effectiveness Evaluation Standards* [11].

2.6. Statistical methods

SPSS25.0 statistical software was used to analyze the experimental data. The count data were described by the number of cases and percentages. In the measurement data, if the data conformed to a normal distribution or an approximately normal distribution and conformed to the homogeneity of variances, the mean ± standard deviation (SD) were used to describe the data, and the independent sample *t*-test was used for comparison; if the variances were uneven, the corrected *t*-test was used. If it did not meet the normal distribution, the data were described by the median and quartiles M (P25, P75) and compared using non-parametric tests. The test level was $\alpha = 0.05$. $P < 0.05$ means that the difference is statistically significant, $P > 0.05$ means the difference is not statistically significant, and $P < 0.01$ means the difference is highly statistically significant.

3. Results

3.1. Comparison of observation indicators between the two groups at each time point

There were statistically significant differences in VAS scores, MEPS, BI index scores, and SAS scores between the two groups before treatment ($P < 0.05$). Comparing before and after treatment, in the intra-group comparison, the differences in the scores of each observation indicator between the two groups were statistically significant ($P < 0.05$). Each indicator was improved compared with before treatment. In the comparison between groups, the VAS scores in the experimental group were significantly better than the control group ($P < 0.05$). There was no statistically significant difference in the MEPS, BI index score, and SAS score ($P > 0.05$). Comparing the follow-up period with that after the end of 2 courses of treatment, in the intra-group comparison, the differences in scores of each observation indicator between the two groups were statistically significant ($P < 0.05$), and each indicator was improved compared with that after the end of 2 courses of treatment. In the comparison between groups, the VAS scores in the experimental group were significantly better than the control group ($P < 0.05$). There was no statistical significance in the MEPS, BI index score, and SAS score ($P > 0.05$). The results are shown in **Tables 2** and **3**.

Table 2. Comparison of scores of various observation indicators after treatment (points, mean ± SD)

Observation indicators	Group	Before treatment	After treatment	*t*/*Z*	*P*
VAS score	Experimental group	6.14 ± 1.033	2.03 ± 1.043	7.851	< 0.01
	Control group	6.13 ± 1.129	2.56 ± 0.982	6.162	< 0.01
	t	0.068	2.153		
	P	0.946	0.035		
Mayo elbow performance score	Experimental group	69.00 ± 7.746	84.29 ± 5.443	4.955	< 0.01
	Control group	69.06 ± 7.771	82.81 ± 6.713	4.593	< 0.01
	Z	0.051	1.481		
	P	0.959	0.139		
BI index score	Experimental group	76.14 ± 8.409	95.43 ± 5.337	5.135	< 0.01
	Control group	75.63 ± 8.206	95.47 ± 7.866	4.599	< 0.01
	Z	0.275	1.069		
	P	0.783	0.258		
SAS score	Experimental group	32.14 ± 2.771	26.89 ± 2.152	4.816	< 0.01
	Control group	32.07 ± 3.276	27.03 ± 2.076	4.619	< 0.01
	Z	0.076	0.505		
	P	0.939	0.613		

Table 3. Comparison of each indicator score between the two groups during the follow-up period and the end of 2 courses of treatment (points, mean ± SD)

Observation indicators	Group	After treatment	Follow-up period	*t*/*Z*	*P*
VAS score	Experimental group	2.03 ± 1.043	0.74 ± 0.701	2.775	< 0.01
	Control group	2.56 ± 0.982	1.1 2 ± 0.878	2.574	0.014
	t/*Z*	2.153	2.020		
	P	0.035	0.043		
Mayo elbow performance score	Experimental group	84.29 ± 5.443	90.00 ± 7.952	4.595	< 0.01
	Control group	82.81 ± 6.713	87.34 ± 7.512	4.244	< 0.01
	Z	1.481	1.044		
	P	0.139	0.297		
BI index score	Experimental group	95.43 ± 5.337	98.86 ± 2.130	5.200	< 0.01
	Control group	95.47 ± 7.866	98.13 ± 4.160	5.211	< 0.01
	Z	1.069	0.339		
	P	0.258	0.735		
SAS score	Experimental group	26.89 ± 2.152	25.96 ± 1.054	4.728	< 0.01
	Control group	27.03 ± 2.076	26.17 ± 1.453	4.684	< 0.01
	Z	0.505	0.162		
	P	0.613	0.871		

3.2. Treatment efficacy

After the treatment, the effective rate (the proportion of cured and effective) in the experimental group was 88.89%, and the effective rate in the control group was 81.25%. The difference was not statistically significant ($P > 0.05$). During the follow-up period, the effective rate of the experimental group was 88.89%, and that of the control group was 78.13% ($P > 0.05$). The results are presented in **Tables 4** and **5**.

Table 4. Comparison of effective rates at the end of treatment between the two groups (%)

Group	Treatment effect			Total effective rate	Fisher's exact test	
	Cured	Effective	Ineffective		χ^2 value	*P* value
Experimental group (n = 35)	3	29	3	88.89%	1.489	0.292
Control group (n = 32)	2	24	6	81.25%		

Table 5. Comparison of effective rates between the two groups during the follow-up period (%)

Group	Treatment effect			Total effective rate	Fisher's exact test	
	Cured	Effective	Ineffective		χ^2 value	*P* value
Experimental group (n = 35)	13	19	3	88.89%	0.233	0.175
Control group (n = 32)	6	19	7	78.13%		

4. Discussion

It is believed in Chinese medicine that lateral epicondylitis of the humerus, also known as tennis elbow, can be called "paralysis, tendon injury, elbow strain, and elbow pain." Similar diseases have been recorded for elbow pain in ancient Chinese. This disease is one of the common diseases in the outpatient departments of acupuncture, rehabilitation, and orthopedics. Its basic pathogenesis is elbow strain. The treatment is based on removing blood stasis and promoting new growth, warming channel and relieve pain, regulating qi, and promoting blood circulation.

In modern research, the pathogenesis of lateral epicondylitis has not been fully understood. Most scholars believe that the cause of lateral epicondylitis is excessive movement of the elbow joint, and repeated stretching of the extensor carpi radialis brevis tendon and the extensor carpi radialis longus tendon. Friction with the lateral epicondyle of the humerus causes degeneration and tearing of the extensor tendon [12-15]. At present, Western medicine treatment of lateral epicondylitis is divided into non-surgical therapy and surgical therapy. Non-surgical therapy mainly includes extracorporeal shock waves, non-steroidal anti-inflammatory drugs, platelet-rich plasma injection, occlusion therapy, and other therapies [16]. Needle-knife is a minimally invasive technique in traditional Chinese medicine, which has the advantages of easy operation, small trauma, few side effects, and high quality. Studies have shown that needle-knife treatment can significantly increase the expression of transforming growth factor-β (TGF-β) and vascular endothelial growth factor (VEGF) in damaged tissue, reduce the infiltration of inflammatory cells, improve local blood circulation, and promote the healing of damaged tissue [17,18]. In this study, the needle is quickly inserted vertically along the direction of the muscle fibers at the tender point, and peeling is done horizontally close to the bone surface. The focus is on the common extensor tendon of the wrist. In actual operation, damage to other muscles, surrounding tissues, and primary lesions should be considered. After the operation, muscle energy technique therapy was performed on the affected side. It is said in *Suwen·Wuzang Shengcheng* that "all tendons belong to joints," so in the treatment of this disease, attention should be paid to "loosening tendons and resolving joints." This study used needle-knife therapy to release the origin and insertion points of the wrist extensor muscles, fascia, and adjacent muscles. It was also combined with muscle energy technique to use active movements of the damaged muscles to overcome external resistance. It can not only improve muscle strength but also effectively promote blood circulation in the elbow, enhance the absorption capacity of tissues, and facilitate the dissipation of inflammation and the loosening of adhesion tissues.

The research results of this paper showed that the VAS score, Mayo elbow performance score, BI index score, and SAS score of the two groups were improved before and after treatment, and during the follow-up period and after treatment, indicating that needle-knife and electroacupuncture therapies are effective in reducing pain in patients' elbow joints, improving elbow function, and relieving patients' emotions. In the comparison between groups, the VAS score of the experimental group was lower than that of the control group at each time point, indicating that the efficacy of needle-knife is better than that of electroacupuncture in reducing pain in the patient's affected elbow. The long-term efficacy of the experimental group is better than that of the control group. Still, the two groups had no significant difference in improving the Mayo elbow performance score, BI index score, and SAS score. It shows that although the number of treatments using needle-knife therapy combined with muscle energy technique for lateral epicondylitis is small, it can effectively improve the pain while enhancing its function, and the therapeutic effect on pain can achieve a long-term consolidated effect.

5. Conclusion

In summary, the application of needle-knife therapy combined with muscle energy technique in treating lateral humeral epicondylitis has the effect of fewer treatment times, good analgesic effects, and consolidated long-term efficacy. It is worthy of further research and promotion. At the same time, this paper also has some shortcomings. On the one hand, the sample size of this research is small. Further research can consider expanding the experimental region and increasing the sample size to improve the clinical treatment of lateral epicondylitis. There is no observation indicator for disease recurrence rate during the follow-up period. Further clinical trials can carry out observation on the disease recurrence rate. On the other hand, needle-knife operation can be combined with musculoskeletal ultrasound to achieve visualization effects, perform precise treatment of lesions, and optimize clinical treatment plans.

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Disclosure statement

The authors declare no conflict of interest.

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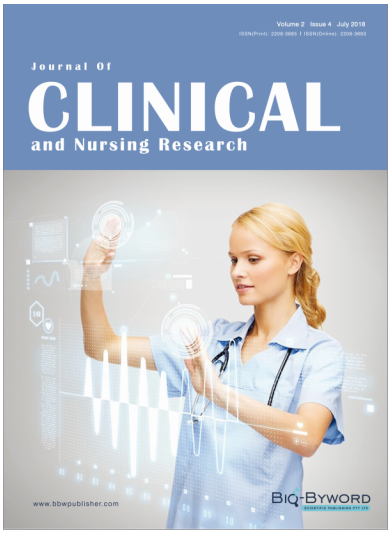

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