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*Original Article*

# Characteristics of MRI signal changes before and after surgery for kyphoplasty in osteoporotic vertebral compression fractures and its clinical significance

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**Abstract:** Objective: To analyze the characteristics of MRI signal changes and its clinical significance before and after osteoporotic vertebral compression fractures (OVCF). Methods: The kyphoplasty patients with osteoporotic vertebral compression fractures were selected. The MRI signal changes before and after surgery were retrospectively analyzed to explore its clinical significance. Results: The characteristics of MRI signal changed in fractured vertebrae were associated with the occurrence of the entire fracture and the final healing process of fracture repair after kyphoplasty, which also changed with time. The MRI signal in the vertebral body returned to normal 6 to 12 months after operation. Conclusion: The study indicated that the changes of MRI signal before and after kyphoplasty reflected the pathophysiological process of preoperative fracture and postoperative reconstruction of cancellous bone. It may be helpful for guiding the preoperative diagnosis and treatment of kyphoplasty, assessing the healing of postoperative fracture reconstruction, and guiding postoperative rehabilitation. Thus, MRI can be used as a reliable imaging tool to observe the clinical healing of osteoporotic intravertebral fracture after kyphoplasty.

**Keywords:** Osteoporosis, vertebral fractures, balloon dilatation, vertebroplasty

## Introduction

Osteoporotic Vertebral Compressive Fracture (OVCF) is one of the most common fracture types of osteoporotic fractures. However, OVCF is the most reported but least known fracture in all osteoporotic fractures [1].

There are usually no specific symptoms in the clinic because patients with OVCF often do not have a clear cause of traumatic violence. Conventional X-ray examination is not easy to find the OVCF at the early stage before vertebral body deformation, or hard to be distinguished from the original osteoporotic vertebral wedge deformation, so that there is no internationally accepted diagnostic criteria for OVCF [2]. Understanding the changes of magnetic resonance (MRI) signals in the fractured vertebral body is of great significance in determining new vertebral fractures.

Kyphoplasty (Kp) is a method for the treatment of OVCF. It has a lot of advantages, including well tolerated, relieves pain quickly, restores vertebral body height, improves mechanical load, and has relatively low complications [3, 4], etc. For these reasons, it has been widely used in clinical practice at home and abroad and achieved satisfactory results [5]. However, because the healing of cancellous bone fractures in the vertebral body and the cortical bone fractures in the extremities is different, there was no obvious callus formation on the X-ray film at follow-up. Therefore, it is difficult to judge the change and healing regularity of the cancellous bone after kyphoplasty [6-8], including whether there are changes in the interface of the cancellous bone cement.

In this study, the perioperative period of kyphoplasty was analyzed via MRI signal changes in order to define preoperative diagnosis, and to guide the kyphoplasty segment. It is anticipated to find the reconstruction law of cancellous bone after vertebral surgery and penetrate the clinical significance of MRI application to kyphotic kyphosis after surgery. In addition, the mechanism of analgesia for kyphoplasty is not yet clear [9]. It may be helpful to explain the analgesic mechanism through the characteristics of MRI signal changes.

## Materials and methods

### *General information*

The clinical data of 58 patients with vertebroplasty who were admitted to the Department of Orthopaedics in Beijing Hospital from January 2004 to June 2007 due to "vertebral body compression fractures" was summarized and analyzed. The X-ray and MRI examinations were analyzed pre- and post-operation. Inclusion criteria contained osteoporotic vertebral compression fracture treated by balloon dilatation vertebroplasty with complete MRI examination data. Exclusion criteria were vertebral body compression fractures caused by etiology of inflammation, tumors, tuberculosis (according to preoperative medical history, laboratory tests, imaging examinations, and postoperative pathology) or incomplete MRI examination data. 41 patients with osteoporotic vertebral compression fractures (OVCF) were selected, and actually 14 cases were analyzed (17 vertebrae). The preoperative clinical and imaging diagnoses were osteoporotic vertebral compression fractures. Pathological reports postoperatively excluded other pathological factors leading to fractures. There were 4 males and 10 females, with an average age of 69.9 years between 62 and 78 years old. A total of 17 cases of OVCF occurred in 14 patients. The vertebral body was distributed in $_{10}$3 cases of chest, $_{11}$2 cases of chest, $_{12}$8 cases of chest, $_{1}$3 cases of waist, and $_{2}$1 cases of waist. All patients underwent kyphoplasty. The selected balloon and tools were all from Kyphon Inc., USA, and the bone cement was made of domestic acrylic resin bone cement III (Tianjin Institute of Synthetic Materials Industry). MRI features and changes were compared before and after operation of 2 weeks, 2 weeks to 3 months, 3 months to 6 months, and 6 to 12 months in order to understand the MRI signal change features and patterns before and after kyphoplasty.

### *Videography examination*

MR examination: A GE 1.5T MRI scanner was used to scan the $T_1$WI, $T_2$WI, and $T_2$WI+FS (fat-lipid image) fat-reduced images and cross-sectional $T_2$WI+FS (pressure lipographic image) of the sagittal plane. The corresponding scanning parameters are as follows:

Sagittal scan: layer thickness 4 mm, layer spacing 0.4 mm, layer number 12 layers, FOW field of view: 270×270 mm, resolution: 352×280.

Coronal scan: layer thickness 4 mm, layer spacing 1 mm, layer number 4-6 layers, FOW field of view: 180×180 mm, resolution: 256×256.

### *Videography analysis*

The MRI images of 17 vertebrae in 14 patients were analyzed by a radiologist and an orthopedist respectively. Because of the high cost and time-consuming of MRI, the same patient could not receive multiple consecutive preoperative and postoperative procedures. MRI examination. However, all collected cases were osteoporotic fractures, although not the same patient throughout the entire course of treatment data, but there should be similar imaging findings due to the postoperative fracture healing process. Therefore, analysis and summary of MRI signal changes before and 2 weeks, 2 weeks to 3 months, 3 months to 6 months, and 6 to 12 months after vertebral fracture in different patients could still reflect the law of fracture healing process.

Vertebral fractures occur when bone marrow edema occurs. Bone marrow edema was characterized by low signal intensity on $T_1$WI, high signal on $T_2$WI, and significantly increased $T_2$WI+FS. MRI is very sensitive to reflect bone marrow edema, and MRI signals can show characteristic changes of bone marrow. In elderly patients, the vertebral body contains more intra-fat, and adipose tissue also shows high signal on $T_2$WI. In order to better observe the hematoma signal, fat suppression test needs to be performed, i.e. short $T_2$ inversion recovery sequences, so that intravertebral hematomas show high signals on the $T_2$WI+FS sequence while fat signals are suppressed. The $T_2$WI+FS sequence is similar to the STIR signal, and it can sensitively reflect intra-vertebral hemorrhage or edema [10-12]. The detailed information is listed in **Table 1**.

## Results

### *Reconstruction observation*

The MRI signal changes at different times in the collected cases were analyzed and summa-

**Table 1.** Changes of MRI signals of cancellous bone and cement in vertebral body during Kyphoplasty in osteoporotic compression fractures (OVCF). There were $_{10}$1 cases of chest, $_{11}$2 cases of chest, $_{12}$5 cases of chest, $_{1}$6 cases of waist, and $_{2}$3 cases of waist

| No. | Age (Y) Gender (F/M) | Medical history | Segments | Preoperative vertebral bone marrow signal changes | Changes of bone marrow signal around bone cement and VAS score in postoperative vertebral body | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | 2 weeks after surgery | 2 weeks to 3 months after surgery | 3 months to 6 months after surgery | 6 months to 12 months after surgery |
| 1 | 71/M | 3 days | Waist 1 | Low $T_1$WI, high $T_2$WI, and significantly increased $T_2$WI+FS<br>8 points | Low $T_1$WI, high $T_2$WI, and significantly increased $T_2$WI+FS<br>2 points | 2 points | 1 point | $T_1$WI, $T_2$WI, and $T_2$WI+FS are all equal signals, which are the same as those of unbroken vertebrae<br>1 point |
| 2 | 62/F | 1 week | Chest 11 | Low $T_1$WI, high $T_2$WI, and significantly increased $T_2$WI+FS<br>9 points | Low $T_1$WI, high $T_2$WI, and significantly increased $T_2$WI+FS<br>3 points | Levels of $T_1$WI, $T_2$WI level, $T_2$WI+FS signal, and reduction of 2 weeks after operation<br>2 minutes | 1 point | 1 point |
| 3 | 69/F | 5 days | Chest 10<br>Waist 1 | Low $T_1$WI, low $T_2$WI, and increased $T_2$WI+FS<br>8 points | 2 points | 2 points | 2 points | $T_1$WI, $T_2$WI, and $T_2$WI+FS are all equal signals, which are the same as those of unbroken vertebrae<br>2 minutes |
| 4 | 72/M | 10 days | Waist 1 | $T_1$WI level mixed, $T_2$WI level mixed, $T_2$WI+FS increase<br>8 points | 3 points | 3 points | The level of $T_1$WI signal is mixed, the level of $T_2$WI signal is mixed, and the signal of $T_2$WI+FS signal is further enhanced<br>2 minutes | 2 points |
| 5 | 63/F | 1 days | Waist 2 | Low $T_1$WI, low $T_2$WI, and increased $T_2$WI+FS<br>9 points | 2 points | $T_1$WI high/low mixed, $T_2$WI mixed high, $T_2$WI+FS high signal enhancement<br>3 points | 3 points | 3 points |
| 6 | 74/M | 2 weeks | Chest 12 | Low $T_1$WI, low $T_2$WI, and increased $T_2$WI+FS<br>6 points | 2 points | 1 point | The level of $T_1$WI signal is mixed, the level of $T_2$WI signal is mixed, and the signal of $T_2$WI+FS signal is further enhanced<br>1 point | 2 points |
| 7 | 79/F | 2 days | Chest 11 | Low $T_1$WI, High $T_2$WI, Significantly increased $T_2$WI+FS<br>7 points | Low $T_1$WI, High $T_2$WI, Significantly increased $T_2$WI+F<br>2 points | 2 points | 2 points | $T_1$WI, $T_2$WI, $T_2$WI+FSAll are equal signals, same as those without fractured vertebrae<br>1 point |
| 8 | 72/M | 2 days | Waist 1 | High $T_1$WI, High $T_2$WI, $T_2$WI+FS Significantly increased<br>8 points | 3 points | Mixed High and Low $T_1$WI, Mixed High and Low $T_2$WI, Mixed High and Low $T_2$WI+FS<br>Signal increased<br>2 points | 2 points | 1 point |
| 9 | 65/F | 5 days | Waist 2<br>Chest 12 | Low $T_1$WI, High $T_2$WI, $T_2$WI+FS Significantly increased<br>8 points | 2 points | 2 points | 1 point | $T_1$WI, $T_2$WI, $T_2$WI+FS All are equal signals, same as those without fractured vertebrae<br>2 points |
| 10 | 67/F | 1 month | Waist 1<br>Chest 12 | Mixed High and Low $T_1$WI, Mixed High and Low $T_2$WI, Significantly signal increased $T_2$WI+FS<br>9 points | 4 points | 4 points | Mixed $T_1$WI, Mixed $T_2$W, Significantly signal increased $T_2$WI+FS<br>2 points | 3 points |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 11 | 71/F | 5 days | Chest 12 | Low $T_1$WI, High $T_2$WI, Significantly increased $T_2$WI+FS<br>8 points | Low $T_1$WI, High $T_2$WI, Significantly increased $T_2$WI+FS<br>3 points | 2 points | 0 point | 1 point |
| 12 | 66/F | 3 days | Waist 2 | Low $T_1$WI, High $T_2$WI, Significantly increased $T_2$WI+FS<br>9 points | 2 points | Mixed High and Low $T_1$WI, Mixed High and Low $T_2$WI, Signal increased $T_2$WI+FS<br>1 point | 0 point | 0 point |
| 13 | 78/F | 1 week | Waist 1 | Low $T_1$WI, High $T_2$WI, Significantly increased $T_2$WI+FS<br>8 points | 2 points | Mixed High and Low $T_1$WI, Mixed High and Low $T_2$WI, Signal increased $T_2$WI+FS<br>3 points | 3 points | $T_1$WI, $T_2$WI, $T_2$WI+FS All are equal signals, same as those without fractured vertebrae<br>3 points |
| 14 | 70/F | 1 day | Chest 12 | Low $T_1$WI, High $T_2$WI, Significantly increased $T_2$WI+FS<br>7 points | 3 points | Mixed High and Low $T_1$WI, Mixed High and Low $T_2$WI, Signal increased $T_2$WI+FS<br>3 points | 2 points | 3 points |

**Table 2.** Summary of MRI signal changes in the vertebral body

| Time and number of cases | Comparison of Signal Changes in Fracture Vertebrae with Intrabody Signals in Adjacent Unbroken |
|---|---|
| Preoperative (14 cases) | Low $T_1$WI (or mixed high and low), High $T_2$WI (or mixed high and low) Significantly increased $T_2$WI+FS |
| 2 weeks after operation (4 cases) | Vertebral cancellous bone, low $T_1$WI, high $T_2$WI, Significantly increased $T_2$WI+FS |
| Postoperative 2 weeks to 3 months (6 cases) | Mixed high and low $T_1$WI, mixed high and low $T_2$WI, Significantly increased $T_2$WI+FS |
| 3 months to 6 months after operation (3 cases) | Mixed high and low $T_1$WI, mixed high and low, Significantly increased high $T_2$WI+FS |
| 6 months to 12 months after operation (5 cases) | The signals of $T_1$WI and $T_2$WI $T_2$WI+FS of the bone around the bone cement recovered to normal, and the signal intensity was not significantly different from the surrounding bone and adjacent normal vertebral bodies |

rized in **Table 2**. The MRI signals in the 17 vertebral segments of the 14 patients were characterized by low signal on $T_1$WI, high signal on $T_2$WI, and markedly elevated $T_2$WI+FS. In the acute stage of fracture, it is the hemorrhage and edema in the vertebral body of the fracture. The MRI signal changes in the vertebral body within 4 weeks after operation in 4 segments of 4 patients were as follows: low signal on $T_1$WI, hyperintensity on $T_2$WI, and apparent increase on $T_2$WI+FS. In contrast, the signal enhancement is even more pronounced compared with preoperation, which indicated that there was a new hemorrhage and edema in the vertebral body within 2 weeks after operation, and hemorrhage and edema were more obvious than before surgery. The MRI signal of 6-segment fracture vertebral body of 6 patients changed after 2 to 3 months and was characterized by: $T_1$WI with low signal, $T_2$WI with mixed high and low signal, $T_2$WI+FS with enhanced high signal, suggesting that the vertebral hemorrhage edema began to absorb, and the cancellous bone began to rebuild.

*Long term follow-up observation*

The MRI signal changes in fractured vertebrae at 3 to 6 months after operation in 4 segments of 3 patients were as follows: low signal on $T_1$WI, equal signal on $T_2$WI, low signal mixed, high signal on $T_2$WI+FS, and high signal range in the vertebral body reduced, suggesting that the reconstruction of the vertebral body was in progress. The MRI signal changes in the vertebral body at 6 to 12 months in 6 segments of 5 patients were as follows: equal signal on $T_1$WI, equal signal on $T_2$WI, equal signal on $T_2$WI+FS. It is suggested that the reconstruction of cancellous bone in the vertebral body was completed, which is converted to normal signal (compared with the nuclear magnetic signal of the fractured vertebral body) after a certain period (**Figure 1**).

At 2 weeks, 2 weeks to 3 months, 3 months to 6 months, and 6 to 12 months after operation, the bone cement in the vertebrae showed low signal in black regardless of $T_1$WI, $T_2$WI, and $T_2$WI+FS. I.e. the bone cement signal does not change over time. The bone cement component contains polymethyl methacrylate polymer and barium sulphate developer granules, which do not contain hydrogen ions and are therefore low signals in either the $T_1$ or $T_2$ phase.

## Discussion

The characteristics of MRI signal changes in the fractured vertebrae were associated with the entire repair and reconstruction process of the vertebral body fracture [13-15]. After kyphoplasty, the MRI signal intensity in the fractured vertebral body changed with time, and the signal intensity in the vertebral body was the strongest within 2 weeks after operation, but then gradually weakened. The repair reconstruction of vertebral body fracture was finished until 6 to 12 months, and the same signals appeared as the non-fractured vertebral body. The change of MRI signal in the vertebral body exists for a long time after surgery, which is longer than the time for clinical fracture healing and accompanied by the entire absorbed and reconstructed process of fracture. It reflects the process of osteoporotic vertebral body fracture healing, i.e. the cancellous bone reconstruction [16, 17]. Postoperative bone cement signals do not change with the time.

Currently, in addition to the clinical signs and symptoms assessment after OVCF Kp surgery, postoperative imaging evaluation routinely using X-ray or CT examination can only assess the vertebral morphological changes and bone

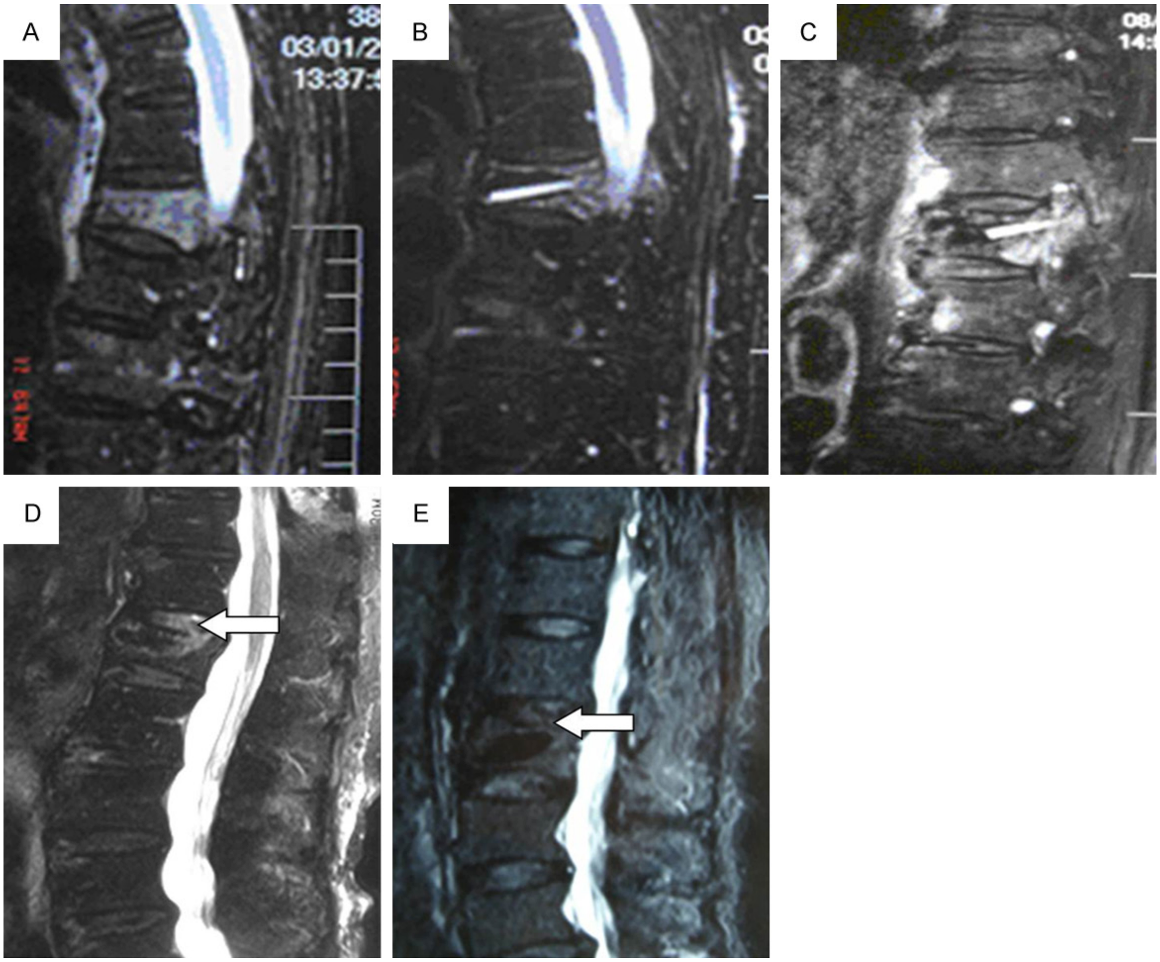


**Figure 1.** MRI examination of perioperative vertebral body. (A) Preoperative $T_2$WI+FS hyperintense edema in the vertebral body. (B) $T_2$WI+FS hyperintensity in the vertebral body around the bone at 2 weeks postoperation. (C) High signal still exists in $T_2$WI+FS vertebral body at 3 months after operation but significantly decreases. (D) High signal in $T_2$WI+FS vertebral reduces but still exists at 6 months after operation. (E) Signals in $T_2$WI+FS vertebral body disappeared completely after 10 months of surgery, and no high signal detected in comparison with the surrounding vertebral body. Note: bone cements in (B-E) are all low signal, the slash-like body high signal in (B, C) is the bone tunnel after Kp puncture.

cement filling [18, 19]. However, it is difficult to reflect changes in the repair and reconstruction of cancellous bone inside the vertebral body and the clinical correlations. The changes of vertebral cancellous bone repair and reconstruction and its clinical significance after Kp analyzed by MRI signal changes have not been reported in domestic and foreign literature.

Osteoporotic vertebral compression fractures include vertebral endplate cortical bone fractures and vertebral body cancellous bone fractures. Clinically, there may be the integrity of the vertebral cortical bone and endplate, but the vertebral cancellous bone fracture. Therefore, vertebral cancellous bone fractures are the basic pathological changes of osteoporotic vertebral compression fractures. X-ray and CT are not sensitive to vertebral cancellous bone fractures [20, 21].

The basic principle of MRI is to use a high magnetic field to send radio frequency waves and detect RF signals of excited hydrogen protons. Then the complex processing of the received RF signals is performed to form images using a computer system. Generally, it is an imaging technique using hydrogen atom. As a basic structure of cancellous bone, although trabecular bone itself has no proton component, MRI does not generate a signal, and thus there is no signal area on $T_1$WI and $T_2$WI. Although the

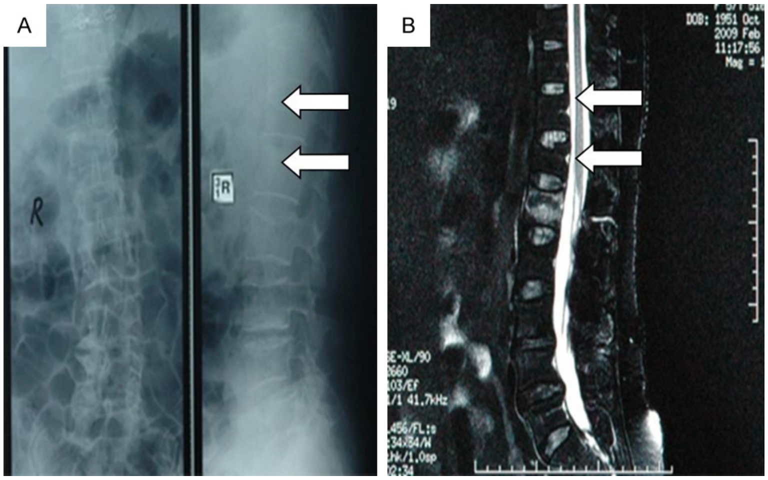


**Figure 2**. Imaging observation of fracture time. A. X-rays shows wedge-shaped in chest 12 and no vertebral fractures in waist 1. B. MRI $T_2$WI + FS shows old fracture in chest 12, fresh fracture in waist 1, but no deformation of waist 1 in the vertebral body. Kp surgery on the waist 1 patient, the patient's symptoms eased.

bone tissue itself does not contain protons, the bone marrow in the bone tissue contains a lot of fat and water protons, which can produce a strong signal, and the cancellous bone and cortical bone structure are often set off very clearly. Therefore, the changes in bone marrow MRI signal intensity can reflect changes in cancellous bone density and distribution structure [22, 23]. The changes in the density and distribution of cancellous bone mean that microfractures have occurred in the vertebral body. Clinically, the cancellous bone fracture line shown by MRI must rely on the marrow signal to show.

The fracture line of cancellous bone is caused by compression and twisting of trabecular bone. In other words, the density and distribution structure of cancellous bone in the vertebral body have changed. The MRI signal changes in the compression fracture of the cancellous bone fracture line are mostly clear and sharp, while MRI often shows unclear or irregular signals in the burst vertebral fracture.

However, not all vertebral cancellous bone fractures show fracture lines [24]. When cancellous bone is not compressed or twisted, the changes of cancellous bone distribution and density are not significant, and no fracture line is shown on MRI. Therefore, the diagnosis of vertebral cancellous bone fracture cannot be based solely on whether MRI fracture line appears. The changes in bone marrow signal in the vertebral body can more accurately determine whether there is the vertebral cancellous bone fracture. That is, the changes in MRI signal intensity in the vertebrae reflect the occurrence of fractures.

In the fresh fracture, hemorrhagic edema occurred in the vertebral body of the fracture, and the MRI signal intensity of the bone marrow was significantly increased (i.e, the fracture vertebrae showed lower $T_1$WI, higher $T_2$WI and significantly higher $T_2$WI+FS than the non-fractured vertebrae) when there is the vertebral body. However, the MRI signal can show normal signal (i.e. $T_1$WI, $T_2$WI, and $T_2$WI+FS are all the same as those in the non-fractured vertebral body), which means that the old fractured vertebral body has healed. Thus, the change of MRI signal intensity can reflect the fracture time [25, 26] (**Figure 2**).

For fresh fractures, the density and distribution structure of cancellous bone changes, indicating that the strength of the vertebral body is reduced. Even if there is no vertebral body deformation in the imaging, it can still cause clinical symptoms and should be treated according to the fracture. Therefore, the characteristics of changes in MRI signal intensity in the vertebral body can be used to guide Kp surgery before surgery (**Figure 2**).

For old fractures, if MRI signal still has a high signal after the lipid-reducing phase, it may indicate that the vertebral body still exists in the vertebral body or fracture in the subacute fracture end congestion. Bone absorption and the fracture line fuzzy indicate that the fracture is not completely healed. Thus, it should combine the clinical symptoms and signs in patients to comprehensively considerate the treatment method, a variety of treatment methods may be used to promote fracture healing. When there is no signal area on $T_1$WI and $T_2$WI of the MRI signal on the vertebral body, it indicates that the vertebral body fracture has completely deformed and is not suitable for kypho-

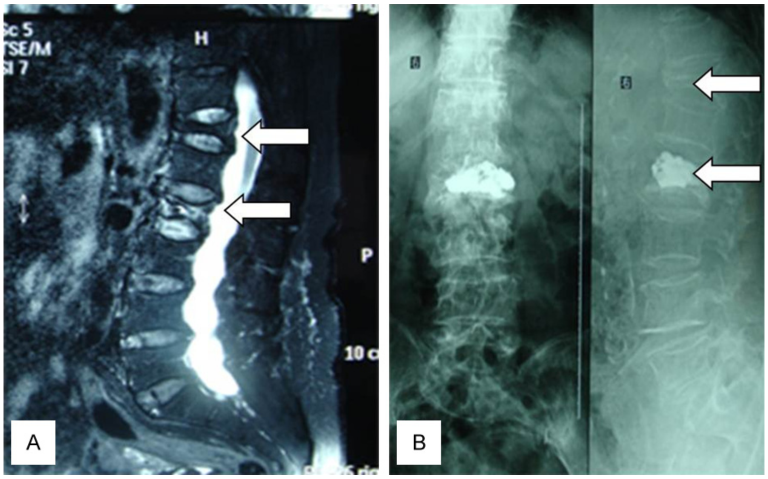


**Figure 3.** Old fracture healing after surgery. A. Newly fractured in lumbar 2 and old fractures in chest 12. B. Kyphectomy on the lumbar 2, no treatment on the chest 12.

plasty. There is still controversy about the complete healing of old fractures, because kyphoplasty is currently aimed at fresh fractures (**Figure 3**).

Therefore, clinically, MRI facilitates the early diagnosis of fractures, especially when some diagnosed fractured vertebrae by X-ray or CT examination without early detection of vertebral body deformity or fracture lines. In addition, it can help us identify whether it is a fresh fracture or an old fracture using MRI's unique "time limit", determine whether the fracture has healed based on signal changes, and thus help clinicians develop a treatment plan [14].

The healing style of osteoporotic vertebral cancellous bone fractures is different from that of cortical bone [9]. The fractures of posterior cancellous fractures of cancellous bone fractures are compressed or dissociated. There are two methods of healing, one is the direct repair via the hyperplasia of osteoblasts and capillary, and the other one for repairing trabecular bone is accumulating new bone in the fracture space. Therefore, there is no obvious bone formation like cortical bone in fracture healing of cancellous bone. It is especially difficult to understand the stage of healing using X-ray or CT and follow-up in clinical. However, the characteristics of MRI signal changes can sensitively reflect the secondary pathological changes of vertebral cancellous bone repair and reconstruction [27-29].

Kyphoplasty (Kp) differs from Vertebroplasty (Vp) in the fact that Vp is the pressure dispersion in the vertebral body through the cement, that is, the trabecular space along the cancellous bone to achieve filling, and then increase the strength of the vertebral body; Kp is to expand a certain space inside the vertebral body by hydraulic expansion, that is, to form a certain volume of cavity inside the vertebral body, and then fill this part of the cavity with bone cement. Kp brings two changes in the vertebral body [30, 31]. On the one hand, the cancellous bone in the original position is squeezed and filled into the space around the cavity, which is equivalent to the self-trabecular bone transplantation in the vertebral body. This process has changed the trabecular bone density in the space around the vertebral body and the distribution structure of the trabecular bone, and thus increases the trabecular bone density around the cavity. On the other hand, a trabecular bone fracture occurs in the space around the cavity, which means that the second fracture is generated in the vertebral body (**Figure 3**). Togawa et al. [32] had clinically performed postoperative autopsy on patients with osteoporotic vertebral body fractures that underwent Kp surgery. They found that the microarchitectural structure of the vertebral body resulted in trabecular bone breaks and rearrangements in the vertebral body due to the hydraulic expansion of the balloon, and alternative trabecular bone crawling appears, indicating that the fractures and rearrangements of the residual trabecular bone in fractures are microscopic fractures.

The fracture caused by Kp surgery also has the same basic healing process as our clinical fracture, which also requires a certain healing time. But it is also different from the healing of cortical fractures that we see in clinical. Clinically, the alignment of the fracture needs to be good in order to achieve a cortical fracture healing, and then it is necessary to provide a stable environment for the early fracture. We often need a certain internal fixation or external fixa-

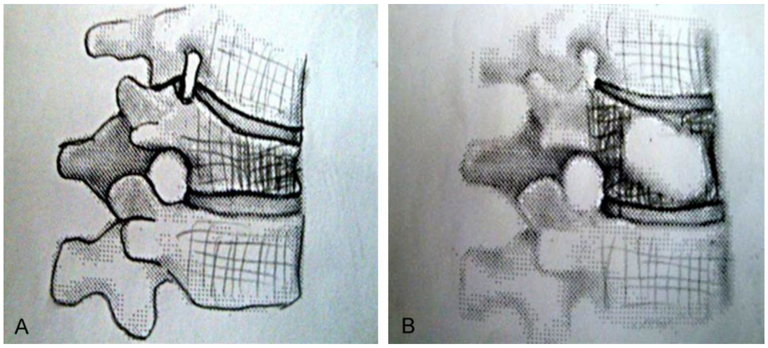


**Figure 4.** The vertebral body morphology and trabecular bone density and distribution before (A) and after (B) reset.

tion to ensure fracture healing. In the Kp operation of OVCF, a certain stable environment is also needed for the healing of trabecular bone fractures in the vertebral body. This stable environment is achieved by filling the entire vertebral body with a filler such as a bone cement after balloon expansion, thus the strength and stiffness of the vertebral body after fracture are restored or reached the strength or stiffness of the vertebral body before the fracture to achieve immediate fixation. This is not the same as our common practice of internal fixation and external fixation, but the effect is similar. In addition, from the view of fracture reduction, it is different from the fracture reduction requirements, such as anatomical reduction or functional reset criteria. This kind of trabecular bone fracture does not have the problem of anatomical and functional reduction (in fact, this kind of trabecular bone fracture has not been reset). The final fracture healing could be complete as long as the recovery of fracture strength provides a stable biomechanical environment and sufficient blood supply. From our observation of the MRI signal changes after fracture Kp, it could be seen that the bone marrow edema signal within the fracture is a long process, which represents that there is a repair and reconstruction process similar to new fracture occurrence and healing after the fracture and rearrangement of the trabecular bone postoperation. The whole process is accompanied with changes in the MRI signal in the vertebral body. This signal change exists over a period of time. From our observations, this type of intramedullary high signal change is still present within three months after surgery, but the signal intensity was significantly lower than that within 2 weeks after surgery. Subsequent changes in MRI signals within 3 months, 6 months, and 12 months reflected the healing process of trabecular bone fractures around the vertebral body that were absorbed, reconstructed, and autografted. In the non-surgical treatment of OVCF, the characteristics of changes in MRI signal at 3 months, 6 months, and 12 months after fracture were also observed with the similar changes indicating Kp treatment does not change the repair and reconstruction of vertebral cancellous bone. However, there is currently no conclusion whether the MRI signal changes in the vertebral body are completely the same between the Kp treatment and the non-surgical treatment due to the lack of prospectively randomized controlled studies.

Generally, the signal changes of the MRI signals in the vertebral body after Kp surgery disappear within 6 to 12 months after operation, and there is no significant difference of the signal changes compared with adjacent vertebral bodies without fracture (**Figure 4**). It indicates that after OVCF vertebral cancellous bone fracture, the reconstruction time is relatively long compared with the fracture healing time (**Figure 4**). Of course, the time listed in this article does not represent the exact time of OVCF healing, but merely reflects that it differs from the usual fracture healing time. Therefore, Kp surgery is not a traditional method for fracture reduction and fixation.

Kp surgery results in the simultaneous presence of cement and cancellous bone in the vertebral body, but is there an absorption and remodeling change in the interface between them? Many scholars have done in vitro and ex vivo experiments. The most direct evidence came in 2003, when Togawa et al. [32] performed a histological evaluation of the Kp vertebral body in patients undergoing corpectomy again after Kp surgery for 1 year. It was found that there was no bone formation at the interface of cancellous bone in the vertebral body, and the interface was mainly filled with a thin layer of fibrous tissue. In this study, the characteristics of MRI signal changes between the interface of cement and cancellous bone could not reflect the histological changes between the two interfaces. However, by observing the MRI signal changes, it was found that there was no obvious absorption, edema and reconstruction changes between the interface of bone cement and cancellous bone. Moreover, the MRI signal changes in vertebral body occur mainly in the bone cement surrounding cancellous expansion caused by cancellous bone region.

The cause of pain in osteoporotic vertebral fractures remains unclear. Some scholars believe that [33, 34] chemical factors may be one of the causes of pain, the speculated mechanism is that the intramedullary edema or hematoma is caused after fracture, then the high pressure leads to nerve compression and pain. It was found that MRI imaging of the vertebral body before surgery revealed bone marrow edema in the vertebral body, and MRI signals at 2 weeks, 3 months, 6 months, and 12 months after surgery still indicated edema in the vertebral body. However, the patient had no other preoperative symptoms such as pain, which suggests that the intramedullary edema is not a direct cause of local pain and other symptoms. Edema or hematoma reflects the pathophysiological changes in the vertebral body fracture and displacement. The real cause of the pain and other symptoms should be the following: on the one hand, it is an internal factor. The breakage of the trabecular bone in the vertebral body leads to a decrease in the strength and hardness of the vertebral body, eventually leading to biomechanical instability of the vertebral body, thereby stimulating the baroreceptor of the vertebral body end plate to cause pain. On the other hand, it is the external factors of the vertebral body. The strength of the vertebral body after fracture is reduced, resulting in increased stress loads on the posterior facet joints and adjacent vertebral bodies, and tension in the muscle ligaments results in secondary pain. Thus, the chemical factors may not be the main cause of pain. Kp surgery allows patients to quickly relieve pain, the key of Kp surgery can quickly restore the strength and stiffness of the vertebral body, then the vertebral body achieves a new stability, and the weight-bearing function of spine is restored quickly, while not reducing pain via burning nerve endings to necrosis in the vertebral body by the heat of cement.

## Conclusion

In this study, the characteristics of MRI signal changes before and after kyphoplasty were summarized. It is found that MRI signal changes are beneficial to improve the preoperative diagnosis rate and guide the design of the surgical plan. MRI signal changes postoperation reflect the reconstruction and final healing process of cancellous bone in the vertebral body, which is helpful for guiding postoperative rehabilitation. It also reflects the long process of fracture healing in the vertebral body. Kyphoplasty is a treatment method that spans the stage of fracture healing, allowing the spine to quickly recover its function and relieve the patient's symptoms. MRI, as an imaging examination method, also has some deficiencies, such as excessive signal sensitivity, long inspection time, and high cost. The present study does not advocate that all patients are routinely performed MRI examination, but wants to summarize the characteristics of MRI signal changes and its clinical significance analysis to facilitate clinical diagnosis and treatment. The number of postoperative nuclear magnetic resonances summarized in this article does not fully reflect the exact time for postoperative fracture healing but may provide some reference value for clinical treatment.

## Disclosure of conflict of interest

None.

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