Original Article

Correlations between preoperative diffusion tensor imaging and surgical outcome in patients with cervical spondylotic myelopathy

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Abstract: Objective: To investigate the correlations between preoperative diffusion tensor imaging (DTI), a Magnetic Resonance Imaging (MRI)-based technique and surgical outcome in patients with cervical spondylotic myelopathy (CSM). Methods: A retrospective study of 95 patients with CSM who received diagnosis and surgical treatment in our hospital was carried out. According to the recovery rate of the Japanese Orthopaedic Association (JOA) scale at the 1-year postoperative follow-up, the patients were divided into a good recovery group (JOA recovery rate ≥60%, n = 47) and a poor recovery group (JOA recovery rate <60%, n = 48). Patients in both groups underwent diffusion tensor imaging examination before surgery. The preoperative fractional anisotropy (FA) value, apparent diffusion coefficient (ADC) value, longitudinal dispersion (AD) rate, and lateral dispersion (VD) rate were compared between the two groups. Pearson correlation coefficient was used to analyze the correlation between the preoperative DTI quantization parameters (FA, ADC, AD, VD) and the postoperative JOA recovery rate. In addition, we compared the preoperative spinal cord compression ratio (CR), spinal cord cross-sectional area (TA), maximum spinal cord compression (MSCC), and maximum canal compromise (MCC) between the above two groups. The correlations between the four measurements and the postoperative JOA recovery rate were analyzed using Pearson correlation coefficient. Results: The preoperative FA value in the good recovery group was significantly higher than that in the poor recovery group, while the ADC value was significantly lower (both P<0.001). The good recovery group had lower preoperative AD and VD, but there was no statistical significance (both P>0.05). Pearson correlation analysis showed that the preoperative FA value was positively correlated with the JOA recovery rate (P<0.05), while the VD value had significantly negative correlation with the JOA recovery rate (P<0.05). The preoperative ADC and AD values were negatively correlated with JOA recovery rate, whereas there was no statistical significance (both P>0.05). The CR, TA, MSCC and MCC values measured before surgery in the good recovery group were significantly lower than those in the poor recovery group (all P<0.001); were negatively correlated with the JOA recovery rate (all P<0.05), while the correlation with TA was not statistically significant (P>0.05). Conclusion: DTI can evaluate the severity of the patient’s condition before surgery by analyzing the subtle structural changes in patients with CSM. At the same time, the preoperative FA, VD, CR, MSCC, and MCC values are all associated with the surgery efficacy, which paves the way for the next step of clinical treatment.

Keywords: Diffusion tensor imaging, cervical spondylotic myelopathy, Japanese orthopaedic association recovery rate, fractional anisotropy, correlation

Introduction

Cervical spondylotic myelopathy (CSM) whose clinical symptoms including numbness and weakness of the limbs, and sensory motor disorders, is the most serious subtype of cervical spondylolisthesis [1]. The incidence of CSM accounts for about 12% to 30% of cervical spondylolisthesis, with the peak age at onset being 50 years, of which the majority were from males [2]. At this stage, some scholars believe that developmental cervical cone stenosis and cervical degenerative changes are the main pathogenesis of CSM, but its etiology and pathogenesis remain unclear [3]. CSM generally develops slowly, and then gradually worsens. Most patients have mild symptoms at the beginning of the onset, but gradually suffer from paralysis of limbs as the condition worsens [4]. Therefore, once CSM is diagnosed, especially for patients with pro-
gressive symptoms who fails conservative treatments, in principle, surgical treatment should be performed as soon as possible. For those without surgical contraindications to relieve the spinal cord compression, control the progress of the disease, and reduce the difficulty of treatment [5, 6]. However, some patients miss the best treatment opportunity due to early mild manifestations or inconsistent clinical diagnosis of typical CSM [7]. Moreover, the patient’s spinal cord is irreversibly damaged in the later stages of the disease, which not only increases the difficulty of the operation but also affects the prognosis, so early diagnosis and treatment are extremely important [8]. Therefore, how to improve the early diagnosis rate, especially to predict the prognosis of patients based on the degree of spinal cord injury and functional level, is critical for choosing an appropriate treatment plan and improving the efficacy [9].

Magnetic Resonance Imaging (MRI) is an imaging method that is conducive to displaying soft tissues, including special items such as diffusion tensor imaging (DTI), and is considered to be one of the most effective diagnostic measures for CSM [10]. Conventional magnetic resonance imaging can display the position and shape of each segment of the cervical spine, as well as the degree of compression of the spinal cord. However, spinal cord compression caused by different reasons could not be specifically shown, and the reversibility and degree of damaged spinal cord lesions could not be directly reflected through images either [11]. Thus, it cannot be used to predict the prognosis of patients. The principle of DTI is related to the sensitivity of water molecules. Compared with conventional MRI, DTI can numerically quantify the lesion to observe its subtle structural changes [12]. With this feature, it is increasing widely used in clinical diagnosis of CSM. Vedantam et al. pointed out that the quantitative values of DTI have a significant correlation with the preoperative Japanese Orthopedic Association (JOA) scores, and it is inevitable related to the damaged spinal cord lesions of CSM patients [13]. JOA is a commonly used clinical evaluation system for the degree of spinal cord injury, which is regarded as the representative value of preoperative spinal cord injury [14]. However, there is a study which revealed that the JOA value of CSM patients can change significantly before and after treatment, so the preoperative JOA score cannot be used as an accurate indicator of the severity of spinal cord injury, which is controversial with the above research conclusions [15]. But the degree of change in the JOA score (i.e. JOA recovery rate) before and after surgery still reflect the therapeutic effect [16]. Therefore, this study set the JOA recovery rate as a research indicator reflecting the efficacy of CSM surgery, focusing on observing the correlation between the quantitative value of DTI and the JOA recovery rate, and exploring key indicators related to the postoperative prognosis of patients with CSM, which met the research objective while avoiding the above shortcomings.

Materials and methods

General data

This study was reviewed and approved by the ethics committee of our hospital (approval number: 2020055). A retrospective analysis of 95 patients with CSM who received diagnosis and surgical treatment in our hospital from March 2017 to May 2019 was carried out. According to the JOA recovery at the 1-year postoperative follow-up, they were divided into a good recovery group (JOA recovery rate ≥60%, n = 47) and a poor recovery group (JOA recovery rate <60%, n = 48). Patients in the both groups underwent DTI examination before surgery.

Inclusion criteria: (1) Patients met the diagnostic criteria of CSM formulated by the National Cervical Spondylosis Special Research Conference in 1994, and were confirmed by MRI [16]. (2) Patients were operated by the same group of doctors in our hospital. The surgical procedures included anterior cervical decompression and bone graft fusion with internal fixation (anterior approach), posterior cervical single-door laminoplasty (posterior approach) or a combination of the two. The postoperative reexamination was confirmed by MRI to fully decompress.

Exclusion criteria: (1) Patients had metal implants in the eyeball or body. (2) Patients had undergone cardiac or aneurysm surgery with implantable foreign matter. (3) Patients were accompanied with mental disorders and other diseases that would affect the results of the study.
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Methods

Before surgery and during follow-up, GE Signa HDxT 3.0 T magnetic resonance scanner (GE Medical Group, China) was used to perform conventional axial T2-weighted (TR/TE/IR, 9000/120/2100 ms) and sagittal T1-weighted (TR/TE, 600/15 ms), T2-weighted (TR/TE, 5200/140 ms) and cross-sectional T1-weighted (TR/TE, 2070/23 ms), and T2-weighted (TR/TE, 3000/113 ms). Eight-channel coils with 3-mm thickness, 1.0-mm spacing, field of view (FOV) = 240*240 mm, and matrix size of 512*512 were used. The most severely compressed cross-sectional plane was found on the MRI sagittal plane image. The spinal cord compression (CR) rate = smallest anteroposterior diameter of the spinal cord/largest transverse diameter of cord. At the same level, the drawing software illustrated one circle around the cross-section of the spinal cord, and then the cross-sectional area (TA) of the compressed segment of the cervical spinal cord was automatically calculated. The sagittal diameter of the spinal cord at the most severe part of the compression was set as a, the upper normal segment of cervical spinal cord sagittal diameter as b, and the lower normal segment cervical spinal cord sagittal diameter as c. On the T2-weighted sagittal image, the maximum spinal cord compression (MSCC) rate = (a/(b+c))*100%. On the T1-weighted sagittal image, the maximum canal compromise (MCC) rate = (a/(b+c))*100% [17, 18].

Philips Ingenia 3.0 T magnetic resonance scanner (Royal Philips, the Netherlands) was used to perform DTI examinations on all patients before surgery. SE-EPI sequence was adopted, and the diffuse gradient field took 36 directions. Parameters: b = 0/800 s/mm², TR 1677 ms, TE 83 ms, matrix size = 144*144, FOV = 220 mm*220 mm. The matching Siemens Sygno workstation and NEURO3D software were utilized to analyze and measure the post-processing of images and data measurement of each patient, and then we obtained axial preoperative FA, ADC, AD and VD values of the most severely compressed spine segment [19, 20].

Outcome measures

The preoperative DTI quantization parameters (FA, ADC, AD, VD) in two groups were compared. ADC = ln(S2-S1)/(b1-b2). The correlations between the four quantitative measurements and the postoperative JOA recovery rate were analyzed using Pearson correlation coefficient. Postoperative JOA recovery rate = ((JOA scores at 1-year postoperative follow-up - preoperative JOA scores)/(17 - preoperative JOA scores)) *100%. The JOA score has a full score of 14 points, of which upper- and lower-extremity function accounts for 4 points each; sensory in the upper- and lower-extremity, and somatosensory accounts for 2 points each; the bladder function accounts for 2 points. Lower scores represent a more serious nerve damage. Zero is defined as complete abnormality [21].

In addition, the preoperative spinal cord CR, spinal cord TA, MSCC, and MCC were compared between the two groups. The correlations between the four quantitative measurements and the postoperative JOA recovery rate were analyzed using Pearson correlation coefficient.

Statistical analysis

SPSS 21.0 software was used for data analysis. Measurement data was expressed as mean ± standard deviation (X ± sd). Independent t test was carried out for comparison between groups. Comparison of data before and after surgery within the group was represented by paired-sample t test. The rank sum test was utilized for rank variables, denoted by H. Count data were expressed by number or percentage (n/%), and compared with chi-square test, indicated as χ². Correlation analysis was performed by Pearson correlation coefficient. P<0.05 meant that the results were statistically different.

Results

Comparison of general data

The preoperative and postoperative JOA scores of patients in the good recovery group were significantly higher than those in the poor recovery group (both P<0.001). There were no significant differences in gender, age, average course of disease or other general data between the two groups (all P>0.05). See Table 1.

Comparison of typical MR images

The preoperative and postoperative MRI of the patients in the two groups clearly showed the
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**Table 1.** Comparison of general data (x ± sd)

<table>
<thead>
<tr>
<th>Item</th>
<th>Good recovery group (n = 47)</th>
<th>Poor recovery group (n = 48)</th>
<th>t/χ²/H</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender (male/female)</td>
<td>28/19</td>
<td>30/18</td>
<td>0.092</td>
<td>0.769</td>
</tr>
<tr>
<td>Age (year)</td>
<td>54.2±9.0</td>
<td>54.3±9.5</td>
<td>0.020</td>
<td>0.984</td>
</tr>
<tr>
<td>Course of disease (day)</td>
<td>6.96±1.14</td>
<td>7.01±1.07</td>
<td>0.221</td>
<td>0.826</td>
</tr>
<tr>
<td>JOA scale (scores)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before surgery</td>
<td>10.52±1.92</td>
<td>8.55±2.20</td>
<td>4.779</td>
<td>0.000</td>
</tr>
<tr>
<td>After surgery</td>
<td>14.37±2.15</td>
<td>9.65±2.42</td>
<td>10.028</td>
<td>0.000</td>
</tr>
<tr>
<td>Surgical approach (n, %)</td>
<td></td>
<td></td>
<td>0.437</td>
<td>0.804</td>
</tr>
<tr>
<td>Anterior</td>
<td>18 (38.30)</td>
<td>19 (39.58)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Posterior</td>
<td>22 (46.81)</td>
<td>24 (50.00)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anterior + posterior</td>
<td>7 (14.89)</td>
<td>5 (10.42)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time for surgery (h)</td>
<td>2.44±0.58</td>
<td>2.51±0.51</td>
<td>0.625</td>
<td>0.534</td>
</tr>
<tr>
<td>Cases for the most damaged segment (n, %)</td>
<td>9.64</td>
<td>7 (14.58)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C_3-4</td>
<td>5 (10.64)</td>
<td>7 (14.58)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C_4-5</td>
<td>17 (36.17)</td>
<td>18 (37.50)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C_5-6</td>
<td>19 (40.42)</td>
<td>17 (35.42)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C_6-7</td>
<td>6 (12.77)</td>
<td>6 (12.75)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: JOA: Japanese Orthopaedic Association.

position and shape of the most severely compressed cervical spine, whereas there was no significant difference between the groups (all P>0.05). See **Figure 1**.

**Comparison of preoperative DTI quantization parameters (FA, ADC, AD, VD)**

The preoperative FA value in the good recovery group was significantly higher than that in the poor recovery group, while the ADC value was significantly lower (both P<0.001). The good recovery group had lower preoperative AD and VD than the poor recovery group, whereas there was no statistical significance (both P>0.05). See **Table 2; Figures 2, 3**.

**Pearson correlation analysis of preoperative DTI quantization parameters and the postoperative JOA recovery rate**

Pearson correlation analysis showed that preoperative ADC and AD values of patients were negatively correlated with JOA recovery rate, but there was no statistical significance (both P>0.05). The preoperative FA value was positively correlated with the JOA recovery rate, while the VD value was negatively correlated with the JOA recovery rate (both P<0.05). See **Figure 4**.

**Comparison of preoperative CR, TA, MSCC and MCC values**

The CR, TA, MSCC and MCC values measured before surgery in the good recovery group were significantly lower than those in the poor recovery group (all P<0.001). See **Table 3**.

**Pearson correlation analysis of preoperative CR, TA, MSCC and MCC values and postoperative JOA recovery rate**

Pearson correlation analysis revealed that preoperative TA value was positively correlated with the JOA recovery rate, but the correlation was not statistically significant (P>0.05); while the preoperative CR, MSCC and MCC values were significantly and negatively correlated with the JOA recovery rate (all P<0.05). See **Figure 5**.

**Discussion**

DTI can reflect the changes in the microstructure of the diseased part through the quantitative numerical response of the micro-molecular changes, and differentiate the spinal cord injury of each of the patients examined. Additionally, it can give certain guidance to clinicians in the planning of the treatment to minimize the interference of subjective judgment caused by...
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Figure 1. Comparison of typical MRI of two groups before and after surgery. A-D: Sagittal preoperative and postoperative T2-weighted images, axial preoperative and postoperative T2-weighted images in the poor recovery group, respectively; E-H: Sagittal preoperative and postoperative T2-weighted images, axial preoperative and postoperative T2-weighted images in the good recovery group, respectively. MRI: magnetic resonance imaging.
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Hence, the clinical treatment plan is more in line with the actual situation of the patient, especially for patients with severe disease but not obvious symptoms and signs, which can greatly improve their prognosis [22, 23].

In this study, DTI, a MRI-based technique was adopted and the correlation between various parameters and the surgical efficacy of CSM patients was analyzed. The surgical outcome indicated the preoperative FA value was significantly higher in the good recovery group than in the poor recovery group, while the ADC value was significantly lower, which suggests that higher preoperative FA value revealed lower ADC value and better prognosis. The above conclusion is consistent with the findings of Rindler et al. that DTI had a significant relationship with the preoperative severity and postoperative outcome of patients with CSM after 310 days of follow-up [24]. The principle is under

<table>
<thead>
<tr>
<th>Group</th>
<th>FA</th>
<th>ADC</th>
<th>AD</th>
<th>VD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good recovery group (n = 47)</td>
<td>0.57±0.10</td>
<td>1.31±0.21</td>
<td>2.25±0.39</td>
<td>0.85±0.20</td>
</tr>
<tr>
<td>Poor recovery group (n = 48)</td>
<td>0.46±0.12</td>
<td>1.58±0.15</td>
<td>2.31±0.43</td>
<td>0.94±0.25</td>
</tr>
<tr>
<td>t/χ²</td>
<td>4.998</td>
<td>7.255</td>
<td>0.759</td>
<td>1.929</td>
</tr>
<tr>
<td>P</td>
<td>0.000</td>
<td>0.000</td>
<td>0.150</td>
<td>0.057</td>
</tr>
</tbody>
</table>

Note: DTI: diffusion tensor imaging; FA: fractional anisotropy; ADC: apparent diffusion coefficient; AD: longitudinal dispersion; VD: lateral dispersion.
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Figure 3. Quantitative parameters of preoperative DTI in the good recovery group. A-D: Preoperative FA, ADC, AD, and VD images in the good recovery group, respectively. DTI: diffusion tensor imaging; FA: fractional anisotropy; ADC: apparent diffusion coefficient; AD: longitudinal dispersion; VD: lateral dispersion.

Figure 4. Pearson correlation analysis between the preoperative DTI quantitative values and the postoperative JOA recovery rate. A: Pearson correlation analysis between preoperative FA and postoperative JOA recovery rate; B: Pearson correlation analysis between preoperative ADC and postoperative JOA recovery rate; C: Pearson correlation analysis between preoperative AD and postoperative JOA recovery rate; D: Pearson correlation analysis between preoperative VD and postoperative JOA recovery rate. DTI: diffusion tensor imaging; FA: fractional anisotropy; ADC: apparent diffusion coefficient; AD: longitudinal dispersion; VD: lateral dispersion; JOA: Japanese Orthopaedic Association.

long-term compression of the injured cervical spinal cord,
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Table 3. Comparison of preoperative CR, TA, MSCC and MCC values (x ± sd)

<table>
<thead>
<tr>
<th>Group</th>
<th>CR (%)</th>
<th>TA (cm²)</th>
<th>MSCC (%)</th>
<th>MCC (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good recovery group (n = 47)</td>
<td>27.00±4.02</td>
<td>0.46±0.11</td>
<td>31.07±4.24</td>
<td>30.27±4.10</td>
</tr>
<tr>
<td>Poor recovery group (n = 48)</td>
<td>39.27±5.21</td>
<td>0.60±0.13</td>
<td>43.21±5.23</td>
<td>42.99±5.14</td>
</tr>
<tr>
<td>t/χ²</td>
<td>12.825</td>
<td>5.463</td>
<td>12.416</td>
<td>13.312</td>
</tr>
<tr>
<td>P</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Note: CR: compression ratio; TA: cross-sectional area; MSCC: maximum spinal cord compression; MCC: maximum canal compromise.

The nerve cells within the spinal cord gradually atrophy and the cytoplasm decreases. The changes in the intracellular mechanism lead to disturbances in the intracellular and extracellular balance, which in turn results in extracellular edema, gaps enlargement, and acceleration of extracellular free water activity [25]. The FA value represents the proportion of the anisotropic component of the water molecules in the measurement area in the entire dispersion tensor, larger value stands for better integrity of the nerve fiber bundles, and thus better prognosis [26]. The ADC value mainly depends on the mobility of water molecules inside and outside the cells. The greater degree of diffusion of water molecules represents the greater ADC value. This means that the spinal cord in the measured area is insufficiently perfused, the local cells are subjected to ischemia and hypoxia, and have caused certain damage to the cells. On the contrary, the damage to the lesion is less [27].

At the same time, from the Pearson correlation analysis results, we found that the preoperative FA value had positive correlation with the JOA recovery rate, while the VD had significantly negative correlation. It was revealed that the changes of the lesions before and after surgery were obviously related to the preoperative FA and VD values, but have nothing to do with the preoperative ADC and AD values. This may occur because the ADC and AD values are easily affected by the change of free water in the patient’s spinal cord. Therefore, the value will change at any time during the patient’s movement or the treatment process, leading to interference factors with the surgical efficacy, so there is no correlation between the two and the JOA recovery rate. The FA value reflected by it
will not change in a short period of time after surgery. Under the same surgical conditions, the postoperative nerve fiber integrity of patients with severe damage is still lower than that of patients with less damage, and their prognosis is generally worse than that of patients with mild damage. There are few external factors that interfere with the change of FA value, and the quantitative value is stable, so it is positively correlated with the JOA recovery rate, which can indirectly indicate the prognosis [28]. Theoretically, the VD value has the same theory as the AD value. Perhaps due to the limitation of the number of cases in this study, the random error was large, and the results obtained cannot represent the overall condition [29].

In this study, The CR, TA, MSCC and MCC values measured before surgery in the good recovery group were significantly lower than those in the poor recovery group. Pearson correlation analysis revealed that the preoperative CR, MSCC and MCC values were significantly negatively correlated with the JOA recovery rate, while preoperative TA value was positively correlated with the JOA recovery rate, but there was no statistical significance. This indicated a correlation between CR, MSCC, MCC values and the prognosis of patients with CSM. The larger values indicated worse prognosis, and patients with better prognosis may have a smaller TA value, but the two were not related, which is consistent with the research results of Gibson [30]. MSCC and CR represent the degree of compression of the injured spinal cord. The heavier the compression, the smaller the sagittal diameter of the spinal cord and the larger the value. MCC is on behalf of the percentage of invasion in the sagittal plane of the compressed part in the entire spinal canal. The larger the percentage of invasion, the larger the value, which indirectly indicates more severe damage. At the same time, the heavier the compression is, the more severe the injury is, then under the same treatment conditions, the patients have a longer recovery time and a lower JOA recovery rate. Therefore, these three are negatively correlated with the JOA recovery rate [31]. However, although the TA value reflects the cross-sectional area of the measured spinal cord compression plane, it can be affected by many other uncontrollable variables such as height, weight, and gender. Therefore, the preoperative TA value cannot reflect the accuracy of the measured early spinal cord lesions. There is no correlation with JOA recovery rate [32].

In the past, the relationship between the postoperative DTI and JOA recovery rate or the relationship between preoperative DTI and preoperative or postoperative JOA value was used to study the correlation between DTI and the prognosis of CSM patients. But the effects of postoperative DTI are inevitably affected by surgery and stress response, and the evaluation time after surgery cannot be used as a basis for formulating a surgical plan; the JOA value will automatically change with the spinal cord injury time, which affects the reliability of the experimental results. Therefore, we chose the preoperative DTI and JOA recovery rate as the research point, which not only conforms to the research theme, but also avoids the above shortcomings, and can be used for preoperative evaluation and treatment plan formulation. Besides, with the in-depth analysis of the relationship between the preoperative examination results of CSM patients and the prognosis of the operation, through the accumulation of many experimental experiences and different research angles, the accuracy and reliability of the relevant research are gradually improved. By this way, clinicians are guided to predict and evaluate the prognosis of each patient before surgery, so as to facilitate the formulation of reasonable treatment plans and improve the living standards of patients to a certain extent.

However, this study still has some limitations, such as the small sample size, short follow-up time, contingency of experimental results, and error caused by the individual factors, which need further research.

In summary, diffusion tensor imaging analyzes the subtle structural changes in patients with CSM, and can evaluate the severity of the patient’s condition before surgery. Meanwhile, the preoperative FA, VD, CR, MSCC, and MCC values are all associated with the efficacy of surgery, which paves the way for the next step of clinical treatment.

**Disclosure of conflict of interest**

None.
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