### Signal intensity histogram features extraction

To reduce the influence of individuals, a modified method was used in calculating the difference between the two peaks in IVD signal intensity histogram **(Fig. 3f)** after being normalized according to the peak signal intensity of cerebrospinal fluid in the spinal canal **(Fig. 3d, e)**. The formula for calculating the signal intensity difference ($∆SI$) between two peaks as following:

$∆SI^{i}=\frac{SI\_{2}^{i}-SI\_{1}^{i}}{SI\_{CSF}}×255$ (1)

Among them, $SI\_{1}^{i}$ and $SI\_{2}^{i}$ respectively represent the signal intensity values corresponding to the first and second peaks of the histogram of the intervertebral disc, $i$ represents the position of the $i$th intervertebral disc. $SI\_{CSF}$ represents the signal intensity corresponding to the peak of the histogram of the cerebrospinal fluid area, and 255 is an amplification factor.

### Vertebral Body Height

According to the channels of the segmented vertebral body, the Shi-Tomasi corner detection method was used to accurately point the four corner vertices (superior-anterior ($L\_{sa}^{i}$), superior-posterior ($L\_{sp}^{i}$), inferior-anterior ($L\_{ia}^{i}$), and inferior-posterior ($L\_{ip}^{i}$)) of the vertebral body **(Fig. 3h)**. The Euclidean distance between two midpoints ( $L\_{ma}^{i}$ of $L\_{sa}^{i}$ and $L\_{ia}^{i}$, $L\_{mp}^{i}$ of $L\_{sp}^{i}$ and $L\_{ip}^{i}$) is defined as the vertebral body diameter **(Fig. 3g).** The vertebral body diameter calculation as following:

$VD^{i}=\sqrt{\sum\_{j=1}^{2}\left(L\_{ma}^{i}\_{j}-L\_{mp}^{i}\_{j}\right)^{2}}$ (2)

Where, $i$ denotes the $ith$ vertebrae, in the range from 1 to 5, $j$ denotes the midpoint coordinate dimension, value of 1,2.

The area of the vertebral body was calculated with the sum of all the pixel values of the vertebral body mask channel, and then the vertebral body height was obtained by dividing by the diameter of the vertebral body. The vertebral body height calculation formula as following:

$VH^{i}=\frac{1}{VD^{i}}\sum\_{x=1}^{h}\sum\_{y=1}^{w}P\_{xy}$ (3)

Among them, $h$ and $w$ respectively represent the height and width of the picture, $P\_{xy}$ represents the pixel value when the height coordinate is $x$ and the width coordinate is $y$, and the value of $P\_{xy}$ is 0 or 1.

### Intervertebral Disc Height

In the field of IVD height calculation, previous study showed that using area-based quantitative measurement method was than using point-based method, in which result with excellent reliability showed that IVD height was equal to 60% or 80% of IVD diameter in saggital view [1]. Therefore, in this study, 80% of the lumbar disc diameter was used to calculate the lumbar disc height.

After the feature location points being obtained, the area of the lumbar IVD was calculated with the sum of all the pixel values between the two line segments **(Fig. 3i)**, while the height of the lumbar intervertebral disc was obtained by dividing by the diameter of the lumbar intervertebral disc. The IVD height calculation formula as following:

$DH^{i}=\frac{1}{μDD^{i}}\sum\_{x=min⁡X\_{D}}^{max⁡X\_{D}}\sum\_{y=min⁡Y\_{D}}^{max⁡Y\_{D}}P\_{xy}$ (4)

Among them, $μ$ represents the percentage of the center area of the entire lumbar intervertebral disc, taken as 80%, $DD^{i}$ represents the diameter of the $i$th lumbar intervertebral disc, and $X\_{D}$ and $Y\_{D}$ represent the width and height coordinate sets of the four characteristic location points respectively: $\{x\_{D\_{1a}^{i}},x\_{D\_{2a}^{i}},x\_{D\_{1p}^{i}},x\_{D\_{2p}^{i}}\}$、$\{y\_{D\_{1a}^{i}},y\_{D\_{2a}^{i}},y\_{D\_{1p}^{i}},y\_{D\_{2p}^{i}}\}$.

### Disc Height Index

Intervertebral disc height index (DHI) helps to reduce individual difference from the overall size of the spine. After marking the angle of the vertebral body and the midpoint of the endplate, the measurement line was drawn according to the marked point, and the distance measurement is carried out[2], whose calculation formula is as following:

$DHI^{i}=\frac{2×DH^{i}}{VH^{i}+VH^{i+1}}$ (5)

Among them, $DH^{i}$ represents the height of the $i$th lumbar intervertebral disc, and $VH^{i}$ and $VH^{i+1}$ respectively represent the height of the $i$th and the ($i+1)$th vertebral body.

### Disc Height to Diameter Ratio

Disc height to diameter ratio (HDR) is proposed to simultaneously characterize the height and shape of the intervertebral disc, which is considered to be the most accurate and repeatable[3]. In this study, average IVD height was calculated using the area-based method. The calculation formula is as following:

$HDR^{i}=\frac{DH^{i}}{\left‖D\_{al}^{i}D\_{pr}^{i}\right‖^{i}}$ (6)

Where $\left‖D\_{al}^{i}D\_{pr}^{i}\right‖^{i}$ represents the maximum diameter of the $i$th lumbar intervertebral disc.

# References

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