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EVALUATION OF MORPHOLOGICAL CHARACTERISTICS FOR DETECTING CERVICAL SPINE HERNIATION: A COMPREHENSIVE STUDY

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Abstract

Medical image processing is essential in many medical research and clinical practice fields since it greatly helps with early and accurate disease identification and diagnosis. Morphology is the process of obtaining images that aid in describing a region's boundaries, form, etc. Morphology is a collection of techniques that can be used to post-processing stage output or pre-processing input data utilized in the image segmentation stage. The purpose of morphological procedures is to remove structural flaws from the image. A class of image processing techniques called morphology analyses images using specified structural components, which are also referred to as kernels. By applying this structural feature to an input image, morphological approaches yield an identically sized output image. During the morphological processing, a value is assigned to every pixel in the output image based on a comparison with its neighbouring pixels in the input image. Differentiating between the distinct herniation phases is made possible by the morphological traits. Different herniation phases can be identified with the help of morphological structural components. Structural components are crucial to improve or obtain insights from medical imaging during morphological processes such as erosion and dilation. Morphological techniques play an important role in understanding the different stages of herniation. An organ or tissue protruding abnormally through its normally contained wall is referred to as a herniation. The structuring elements of morphological techniques are effectively carried out in various herniation stages to provide insights into the underlying pathology and direct therapy strategies.

Keywords: *Morphology, Structuring Element, Dilation, Erosion.*

I. INTRODUCTION

The study of an object's morphology focuses on its structure and form. A key component of image processing is mathematical morphology, which allows one to carefully alter an image's geometric content without compromising the stability of its essential geometric characteristics. In morphological processes, a structural element and a binary image are the two parameters. The structuring element is positioned throughout the image in every feasible area, with its exact position determined by the area surrounding each pixel. A small matrix called the structure element (SE) which is used to analyze the image under study. Each SE needs to have an origin provided to be able to be positioned at a certain point or pixel: For example, a 2-D image specified on an 8-connected grid is displayed in a centered 3×3 window. The elementary isotropic SE of an image is defined as a point and its neighbors, with the origin, used as the focus point. When a SE appears at point x, it indicates that its origin corresponds with x. In reality, for the SE to match the processed image patterns, it must be resized and altered in shape. Set-theoretic image processing techniques are offered by mathematical morphology. There is a small overlap between image segmentation and morphology in the paper [1]. Morphology encompasses techniques that can be applied to either post-process the image output or do post-processing on the segmentation input data.

The relationship between cervical disc herniation morphology and the clinical outcomes of posterior percutaneous full-endoscopic cervical discectomy in patients with cervical spondylotic radiculopathy is described in Liu et al.'s study [2]. It was found that following PPECD, the recovery of CSR patients is highly influenced by the preoperative morphology of CDH.

In paper [3], Heard et.al., examined the herniation morphology, affect patient-reported outcomes and surgical results following microdiscectomy in adults from 2014 to 2021. All the patients improved following surgery, however, three months later, the patients with more posteriorly expanding disc herniations reported a much better outcome despite their preoperative physical performance being worse. The depth of the disc herniation did not associate with improvements in the Mental Component Summary (MCS), Oswestry Disability Index (ODI), or Visual Analog Scale (VAS) for back and leg pain at three and twelve months after surgery. An image is represented in morphological processing as the union of level-shifted and translated structural elements [4]. The research conducted by Modic et al. [5] to evaluate the clinical use of spine magnetic resonance imaging (MRI) involved seventy-two patients. Myelography, high-resolution computed tomography, and conventional radiography were compared with MRI utilizing various pulse sequences. Pathologic diseases evaluated included rheumatoid arthritis, canal stenosis, herniated disks, neurofibromas, trauma, Chiari malformation, syringomyelia, and arteriovenous malformation. Thirty-five normal people participated in the study. With three distinct variations of the pulse sequence, the spin-echo method seems quite promising. The optimal spatial resolution and signal-to-noise ratio are achieved with a short echo time (TE). While raising TE and TR simultaneously causes the cerebrospinal fluid's signal intensity to be selectively amplified, prolonging TE enhances the ability to distinguish between various tissues according to the strength of their signals. Extended TE and TR sequences are necessary because CSF (cerebrospinal fluid), a degenerative disk, and cortical bone can all exhibit similar signal intensities with extra pulse sequences.

The versatility of analyzing the spine during a single examination is substantially increased by using several pulse-sequence approaches and multidimensional imaging with MRI. In order to solve the problem of injuries in lateral cervical imaging being unnoticed because of human mistakes, Masudur Rahman Al-Arif [6] outlined the completely automated vertebral column segmentation framework for X-ray images proposed in the publication. The cervical vertebrae in images obtained from X-rays are automatically segmented by the system using deep learning techniques such as fully convolutional neural networks, probabilistic spatial regression networks, and shape-aware segmentation networks. This process eliminates the need for human participation. With a form inaccuracy of 1.69 mm and a Dice similarity coefficient of 0.84, this method shows promise for precise vertebrae segmentation. The fully automated cervical vertebral segmentation framework for X-ray images may be extended to segmentation processes for magnetic resonance imaging. Deep learning techniques can then be utilized to further enhance the categorization.

Iqbal et al., stated the usefulness of image-enhancing techniques on retrieved texture features for prostate cancer detection. According to results and discussions, this paper highlights the potential impact on clinical practice and patient outcomes. It also addresses any challenges encountered during the research process and suggests avenues for further investigation and improvement. In conclusion, the paper underscores the importance of integrating image enhancement techniques with machine learning approaches for enhancing prostate cancer detection. It summarizes the main research findings and emphasizes the significance of early diagnosis in improving treatment outcomes for patients with prostate cancer. The conclusion also discusses future directions for research in this area, including potential advancements in technology and methodologies that could further enhance diagnostic accuracy.

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Sitte et.al., [8] aims to investigate the specific alterations that occur in the intervertebral disc following trauma, focusing on the relationship between fracture type and degeneration grade. Through a longitudinal analysis, changes in disc morphology were assessed at various time points post-trauma. The results revealed distinct patterns of response based on the type of fracture and the degree of pre-existing degeneration. Fracture type significantly influenced the extent and nature of morphological changes observed, with certain types of fractures leading to more pronounced alterations compared to others. Additionally, the degeneration grade at the time of trauma played a crucial role in determining the subsequent evolution of disc morphology. Higher degeneration grades were associated with accelerated degenerative changes post-trauma, highlighting the importance of considering pre-existing conditions when evaluating disc response to injury. According to Pierre-Jerome et al. [9], assessment of the spine and spinal cord is frequently done using magnetic resonance imaging (MRI). This article discusses broad indications, prospects, restrictions, typical anatomy, and standard and sophisticated imaging modalities when it comes to spine MRIs.

According to Modic [10], magnetic resonance imaging has assessed the foramen magnum and spine. It has demonstrated not only that it can show the normal spinal anatomy but also a range of pathologic conditions, and it can be done in an outpatient setting safely and noninvasively.

Hesamian et al. propose a critical assessment of popular methods that segment medical images using deep learning techniques [11]. The primary issues surrounding deep learning-based methods for medical picture segmentation were the main topic of this paper. According to Hwa et al. [12], local morphological contrast enhancement and the edge-detected canny operator are used to X-ray images. It illustrates the efficient classification of edge X-ray images with high accuracy, true positive, and false positive rates. Faleh H. Mahmood et.al.,[13] state that by utilizing three samples of CT scan images from lung cancer patients, correlation, contrast, energy, and homogeneity were determined for four statistical characteristics of texture. This study indicates that the best quality for distinguishing across textures is contrast. Tumor tissue has energy and homogeneity properties that are consistently higher than those of healthy tissue.

Gupta et al.'s review work [14] goes into great detail about image edge detection techniques. The primary use of edge detection in image processing is to locate edges and prominent objects in images. The authors provide an in-depth evaluation of a variety of edge detection strategies, including both conventional and modern approaches. They talk about model-based approaches like the Canny edge detector and well-known gradient-based techniques like Sobel, Prewitt, and Robert's operators. Megha Kadam et al., [15] has been recognized as an approach with promise for improving brain disorder diagnosis and understanding. In particular, deep learning models have shown a remarkable aptitude for interpreting and extracting important information from intricate medical imaging data. Artificial Neural Networks (ANNs) can learn to classify images into several categories, such as typical brain scans or particular clinical conditions, by training them on large datasets of labeled MRI brain images.

The vertebral discs segmentation approach was first described by Ruiqiond Shil et al., [16]. The spinal cord is located using the Hough Transform, and the discs are detected and identified using a self-adaptive window. The algorithm's accuracy and efficiency are demonstrated by the experimental findings on clinical spine MR images. Kapur et al., [17] introduced entropy-based methods, where entropy is utilized for thresholding. Entropy, a measure of uncertainty or unpredictability, is used in this novel approach of automatic gray level image thresholding to choose the appropriate threshold value for image segmentation. The first stage in the entropy-based thresholding technique is to create the gray level image's histogram, that reveals the frequency distribution of pixel intensities.

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A deep valley between two distinct peaks, each of which represents the background or an object, in the ideal image histogram. The area is where the threshold is situated. However, threshold selection is challenging in such cases because unimodal and bimodal images cannot differentiate the pixels as two peaks [18]. It introduces a novel approach to thresholding gray level images. Using an ultra-fuzzy measure in conjunction with spatial correlation features, this method enhances thresholding accuracy and efficiency. In summary, this research offers a significant understanding of the complex interactions among trauma, fracture type, degeneration grade, and anatomical alterations in the human cervical intervertebral disc. In this paper, various types of structuring elements are examined in Section II. Section III provides an exhaustive review of the suggested methods for morphological feature extraction. Section IV shows the results that were acquired using simulation tools. Section V concludes with a conclusion.

II. OVERVIEW OF STRUCTURING ELEMENTS

Mathematical morphology based on set theory compares the image under study to a known geometric unit known as a structuring element. [19]. In medical image processing, structural components are crucial to morphological processes. These operations are crucial for tasks like medical image segmentation, feature extraction, and noise reduction. Two primary categories of structural elements are employed: non-flat elements like arbitrary and ball, and flat elements like disk, line, and rectangle. Structure elements fall into two categories: flat and non-flat. A flat structuring element is a binary-valued neighborhood, either two or multidimensional, where the correct pixels are included in the morphological operation and the false pixels are eliminated. Flat Structuring Elements: Throughout their shape, flat structuring elements preserve a constant value [20]. Because they are easy to use and effective, they are frequently employed in morphological operations. Flat structural components, such as disks, lines, and rectangles, are applied to images in the context of medical image processing to perform operations like dilation, erosion, opening, and closing. The flat structuring element may be used to both binary and grayscale images. The strel function can be used to construct flat structural elements. Grayscale and binary images can both benefit from the use of flat structural components.

A flat structuring element's shape can be either linear for line finding or diamond-shaped for particular applications, depending on the required processing requirements. The structuring element defines the neighborhood that is used to process each pixel in the image. The structuring element's dimensions and form must correspond to the items in the input image that are being processed. In image processing, erosion and dilation are vital operations. They are essential for improving, extracting features, and minimizing noise in images as they modify objects in images [21]. These methods use a minimal binary structure to construct pixel regions on binary images, where each pixel is either black or white. During morphological processes, flat structural parts may break down into smaller pieces to improve performance. Through the division of more complex operations into smaller ones, this strategy can increase computer efficiency. The program for morphological processes is written using the MATLAB simulation tools.

1) Mathematical Modelling

A flat structuring element is a crucial component of morphological operations that offers binary neighborhood definitions with unique origin identification and customizable shapes for efficient image processing applications. The diamond, octagon, arbitrary, rectangle, square, and line are examples of flat structuring elements. Non-flat structuring elements have different values at different points in their structure. They feature more asymmetrical patterns or structures in images, despite being more complicated than flat structuring elements. The utilization of non-flat structural components is limited to grayscale images.

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Non-flat structuring elements have different values at different points in their structure. Their patterns or structures in images are more asymmetrical, despite their complexity being higher than that of flat structuring elements. The non-flat structuring elements are used only with grayscale images. A non-flat structuring element includes an additive offset for each pixel in the neighborhood. The offset strel function can be used to construct non-flat structural elements. These elements can have real value offsets in the neighborhood, they are only appropriate for processing grayscale images.

An offset strel object's property provides insight on a non-flat element's structure. A non-flat structuring element is related to a finite real value that can be employed to examine the morphological technique. These variables are used to modify the grayscale image's functionality and can change. Non-flat structuring elements are made expressly to work with grayscale images, where pixel intensity changes are important for image processing applications [22].

The offset strel function, which lets users specify the neighborhood's form and the offsets that correspond to each pixel, is usually used to generate non-flat structural elements. Compared to flat structuring elements, non-flat structuring elements are more flexible when offsets are included, which makes them appropriate for more intricate morphological procedures on grayscale images. Non-flat structuring elements, like balls or arbitrary forms, can be used in medical image processing for more complex feature extraction or analysis tasks. Flat structural elements are more straightforward and effective, yet non-flat parts are more flexible in expressing intricate patterns.

III PROPOSED WORK

The gold standard for identifying a cervical spine herniation is magnetic resonance imaging (MRI), which is capable of producing exact images of soft tissues including nerve roots, the vertebral column, and the discs between the vertebrae. Disk bulge, nerve root compression, and signal abnormalities can all be detected on an MRI.

Magnetic Resonance Imaging (MRI) is a primary tool used to visualize the cervical spine and identify herniated discs. Unlike X-rays or CT scans, Intervertebral discs, spinal nerves, and the spinal cord can all be examined in excellent resolution on an MRI. Because of this feature, MRI is especially useful for identifying diseases like disc herniation. Herniated discs can be treated with injections, physical therapy, medication, rest, or, in extreme situations, surgery to release pressure on the afflicted nerves.

The standard MRI protocol for assessing cervical disc herniation typically includes T1-weighted and T2-weighted sequences. T2-weighted images are especially useful because they highlight fluid-filled structures, making it easier to identify herniated disc material that may be pressing on nearby nerves or the spinal cord.

Radiologists analyze MRI scans for signs of disc herniation into four stages namely disc degeneration, disc prolapse, disk extrusion and disk sequestration. Disc degeneration is the cervical spine's initial herniation stage. The disc's aging-related chemical alterations lead to the nucleus pulposus' degradation during the first stage. If there is no herniation at this point, the disc is beginning to lose moisture and is becoming less resilient to the strain that comes with movement. Disc prolapse is the second stage of herniation. During a disc prolapse, the nucleus remains enclosed within the annulus, but only because it is kept inside by the outermost fibers. Prolapse is characterized by a change in the location or shape of the disc, a little lump or distension that may begin to swarm the spinal nerves or spinal line.

Disc extrusion is the cervical spine's third stage of herniation. Plate expulsion is the process by which the sensitive substance containing the core separates from the circle structure while remaining connected to it. This suggests that the tissue of the annulus fibrosis is in touch with the core pulposus. The annular fibers break, creating a hole that allows the soft material to pass through. The cervical spine's fourth stage of herniation is called disc sequestration. Parts of the annulus and core appropriately reach the exterior of the plate because of the sequestered circle. The four stages of herniated images are utilized in edge detection techniques to improve image quality and bring out finer image details. In order to recognize and extract boundaries between objects and their backgrounds in digital images, one crucial method for processing images is edge detection. The Canny edge detection operator is the most successful among the several edge detection operators. It follows a multistage algorithm that applies several filters to detect edges more accurately and robustly than other methods.

IV. SIMULATION STUDY AND RESULTS

In this experiment, morphological operations are carried out on edge-detected canny images. Simple modifications to binary or grayscale images are called morphological procedures. Here, an image of the canny edge is processed using the basic morphological processes of erosion and dilatation to reveal the edges. The use of simulation tools in MATLAB can aid in the analysis and visualization of this condition through morphological techniques. Using MATLAB for simulating cervical disk herniation through morphological expansion provides valuable insights into spinal health conditions. First, determine the structural element related to morphological processes.

1) Dilation

The symbol for image A that has been dilated by structuring element B is A$\oplus$ B. The dilation of A by B, $A \oplus B$, is described as,

$$A \oplus B = \{x | (\hat{B})_x \cap A \neq \emptyset\} \qquad (1)$$

Let $\hat{B}$ represents the reflection of B with respect to its origin, and let $(B)_x$ represent the translation of B by x. and shown in Eq.1. The dilation operation is the collection of all distances x from the origin at which set B overlaps with set A by at least one nonzero element. Dilation involves determining whether a pixel is considered foreground or background based on its surrounding eight pixels.

2) Erosion

Let A and B be sets in Z^x, x > 0. The erosion of a set A by B is represented by (A Θ B). Let $(B)_x$ denote the translation of B by x. The operator's main effect on a binary image is the erosion of the foreground pixel area boundaries. Erosion operation is shown in Eq.2 and can be represented as,

$$A \ominus B = \{x | (B)_x \subseteq A\} \qquad (2)$$

Therefore, holes within foreground pixel areas get larger while front pixel areas themselves become smaller.The structural element is needed to investigate the implications of their size and shape used during morphological operations. Before morphological changes are made, the images are resized to 100 × 100 to reduce processing complexity. The four stages of herniated discs - degeneration, prolapse, extrusion, and sequestration - can be identified using gray level images and the edge detected Canny operator. These stages are depicted in Fig.1.

To find the starting point of a structuring element in gray images, the formula (Eq.3) is used.

$$\text{origin} = \text{floor}((\text{size}(\text{nhood})+1)/2) \qquad (3)$$

where neighborhood denotes the area that defines the structural element. The neighborhood matrix's size is computed using size(nhood). floor() rounds down to the nearest integer.

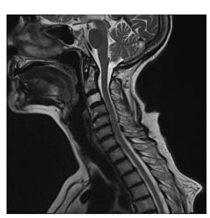
For every edge-detected herniation image, erosion and dilation procedures are applied, with differing sizes and structural features.

The Sobel method is credited as being the first edge detection method [23]. The four stages of canny edge detection are hysteresis, gradient calculation, non-maximal suppression, and noise reduction [24].

In Fig. 2, the gray level and its edge detected canny image is displayed. Different structuring elements applied with herniated images are shown in Fig.3. The Extrusion stage is represented by a gray image that has been processed using edge detection techniques, specifically the Canny algorithm. Each canny edge detected herniation image yields distinct morphological images, which are as follows: [(disk,1), (disk,2), (line (2,45º), line,9,0°), (rectangle, [1 2]), (rectangle, [2 1]), (octagon,3), (octagon,6), (square,2), (square,5)] are shown in Fig.2.

The disk structuring element can be convenient when identifying curved or smooth edges in the image. It is feasible to obtain different levels of edge detection sensitivity by modifying the disk's size. Identification of linear characteristics in an image is the main objective of edge detection using a line structuring element. It is applied to the image using convolution, which highlights edges that correspond to the line's direction. Images with straight edges and contours can be effectively highlighted with this method. When applying a rectangle structuring element for edge detection, the image is convolved with this shape to highlight edges that coincide with vertical or horizontal lines.

Different parts of edge information can be retrieved from the image by varying the rectangle's dimensions, giving flexibility in identifying different edges. In edge detection applications, rectangular structuring elements are often employed when dealing with larger objects or irregularly shaped features where circular or linear structuring elements may not capture all relevant information.

Herniated Stage Images	**Gray scale (100×100 pixels) Image**	**Canny Image**
Degene-ration		
Prolapse		

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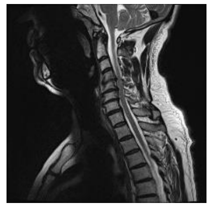
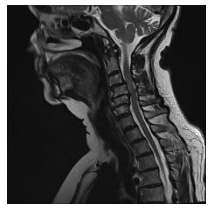
Extrusion		
Seques-tration		

Fig.1 Different stages of herniated images with its gray level images and its edge-detected canny images.

The octagon structuring element is an eight-sided polygon that closely resembles an ellipse. It is constructed by combining simpler shapes like rectangles and diamonds in a specific configuration. The octagon shape provides a good approximation of an ellipse, it is computationally more efficient to work with simpler shapes like rectangles and diamonds. By decomposing the octagon into these basic shapes, morphological operations can be performed more quickly.

The square structuring element has a square shape, with all sides being equal in length. This shape allows for probing and analysing images based on their spatial orientation and features that align with a square pattern. The dimensions of the square structuring element define its size; typically, this can be determined as a n by n matrix, where n is an odd integer that ensures a pixel in the center. The size influences the scale at which image objects or features are differentiated during morphological operations. In the context of image processing, a structuring element with a constant gray level inside its domain is called a flat structuring element. These components work especially well for processes like gray value closing, in which an image is subjected to erosion and dilation processes using the structural element. Flat structuring elements offer several advantages and have significant future scope in image processing applications.

	Gray Image	**Canny Image**
Sample Image		

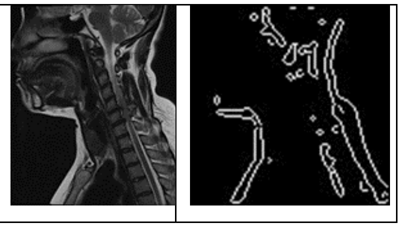


Fig 2. Gray image and Canny image

Flat structuring elements can be further optimized for advanced morphological operations in image processing, such as feature extraction, noise reduction, and object segmentation. Their efficiency can lead to improved results in these areas. With the speed and simplicity of flat structuring elements, real-time image processing applications can benefit significantly.

V. CONCLUSION AND FUTURE SCOPE

Specific morphological characteristics were identified as significant predictors of cervical spine herniation. The study emphasizes the correlation between morphological changes observed through imaging and clinical symptoms reported by patients. Symptoms such as radiculopathy or myelopathy often align with specific morphological findings, reinforcing the need for a thorough assessment. Areas like surveillance, medical imaging, and autonomous systems can leverage these elements for quick and reliable analysis. Finally, flat structuring elements hold immense promise for the future of image processing due to their efficiency, simplicity, consistency, and adaptability.

Structuring Element	**Images**	
	Size 1	Size 2
Disk		
	Line 2,45°	Line 9,0°
Line		
	Rect [1 2]	Rect [2 1]

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Rectangle		
Octagon	Size 3	Size 6
		
Square	Size 2	Size 5
		

Fig 3. Different structuring elements applied with Herniated images

Out of all structuring elements, the rectangle structuring element provides a more efficient way of displaying images as it contains more detail within the image. When using a rectangle structuring element in image processing, the resulting output tends to be more detailed and visually informative compared to other types of structuring elements. This is due to the rectangular shape's ability to capture finer details and nuances present in the image, resulting in substances that is presented with more accuracy and clarity.

Finally, the use of a rectangle structuring element enhances the overall quality of the image representation by preserving intricate features and patterns that might be lost or distorted when employing other types of structuring elements.

Future computational image processing and machine vision studies on rectangle structural elements will examine sophisticated algorithms and methods to improve the efficiency of morphological processes like dilation and erosion. Researchers are focusing on developing more efficient methods for utilizing rectangle structuring elements to improve object detection, image segmentation, and pattern recognition tasks. The current investigation intends to evaluate the morphological and structural aspects of the cervical spine that may indicate the existence of herniated discs, thereby enhancing diagnostic accuracy and treatment planning.

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