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IMPACT DYNAMICS OF DAMAGED AND REPAIRED LUMBAR DISCS: A BIOMECHANICAL INSIGHT

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Abstract

Back pain is among the most prevalent health issues in industrialized societies, incurring significant direct and indirect costs. Spinal intervertebral discs serve as cushions and shock absorbers between vertebrae, and their degeneration increases the risk of rupture and herniation, potentially causing localized or radiating pain. This study investigates the biomechanical response of damaged and repaired lumbar discs under impact loading conditions. Various loading scenarios are considered, including static, semi-static, dynamic, and complex impact loads. The findings indicate that increasing the impact duration leads to a reduction in the maximum stress within the damaged disc. However, the decreasing slope of the stress-time curves suggests a reduced sensitivity of the maximum stress to further

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increases in impact duration. Moreover, when the impact is applied at an angle (45 degrees inward, outward, or lateral) relative to the spinal axis, the resulting maximum stress in the repaired disc does not exhibit significant variation.

Key words: Lumbar disc-impact energy transfer-biomechanics-ANSYS- Back pain

Introduction

Back pain is one of the most common problems in industrial societies, which has many direct and indirect costs. Nearly 80% of people over the age of 30 experience back pain at different periods of their lives [1]. According to the statistics of the World Health Organization (WHO), back pain is one of the most important causes of individual disabilities, which is directly related to the quality of life of people as well as their efficiency in industrial environments [2]. In fact, back pain is known as the second chronic disease that requires a doctor's visit, and it is also the most common cause of spine surgery [3]. The destroyed intervertebral disc is one of the most important causes of back pain, which often leads to surgery [4]. Figure 1 depicts the geometry of the disk. Between each vertebra, the spinal discs serve as a cushion and shock absorber. Each disc has a jelly-filled doughnut appearance. Degenerative disc disease raises the risk of disc rupture and protrusion, which can cause localized or shooting pain. Disc protrusion and compression of lower back nerves may cause sciatica pain. The body's cartilage changes with ageing in terms of its protein and water composition. Weak, fragile, and thinning cartilage is the outcome of this transformation. Discs and joints have cartilage as part of their structure, thus over time, these parts begin to wear out and degrade. Degenerative disc disease, often known as degenerative disc disease, is the gradual degeneration of the disc between the vertebrae. Facet joint degenerative disease, also known as spinal bone arthrosis, is characterized by bone alterations in the neighboring joint and wear on the facet cartilage. Degenerative disc disease can result from spine injuries. In actuality, 13 degenerative disc disease is a painful condition that develops when one or more spinal discs are damaged or broken. This condition can also cause numbness, weakness, and discomfort in the legs in addition to back pain. Although the word "disease" appears at the start of the name "degenerative disc," disc degeneration is not a disease but rather an aging-related normal process in the body. Since the discs between the vertebrae serve as shock absorbers, the spine can naturally bend and rotate. These discs eventually deteriorate and are no longer as effective at defending the spine's vertebrae as they once were. Regardless of the kind of discs, risk factors, or processes behind the injury, destruction of intervertebral discs (IVDs) is the leading contributor to disability worldwide and is directly associated to excruciating lower back pain (LBP). is the

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globe Nearly one-third of adults worldwide are affected by degenerated disc disease (DDD), which poses several difficulties for the patient in terms of disability and social and economic burden. The prevalence of this condition has increased along with the growing elderly population. The state of healthy discs is affected by a number of factors, including age, nutritional issues, a history of mechanical loading, environmental and hereditary factors, and other factors. These factors all contribute to the degeneration of these discs (DD). The impact of mechanical stresses on DD is generally acknowledged. Recent research has examined the impact of effective treatment approaches in light of the development of medical engineering sciences and the growth of research in the fields of tissue engineering and regenerative medicine. These are initially explored from several histological and biomechanical aspects in this kind of research. They require animal models that can effectively imitate the mechanism of disc degeneration by intentionally applying the disc degeneration principle to the animal model in order to simulate the disc degeneration process [5],[6]. Therefore, it is very appealing to understand the biomechanical mechanism of artificial ways of disc destruction. On the other hand, impact loading has been studied in recent years as one model for replicating the shattered disc [7],[8].

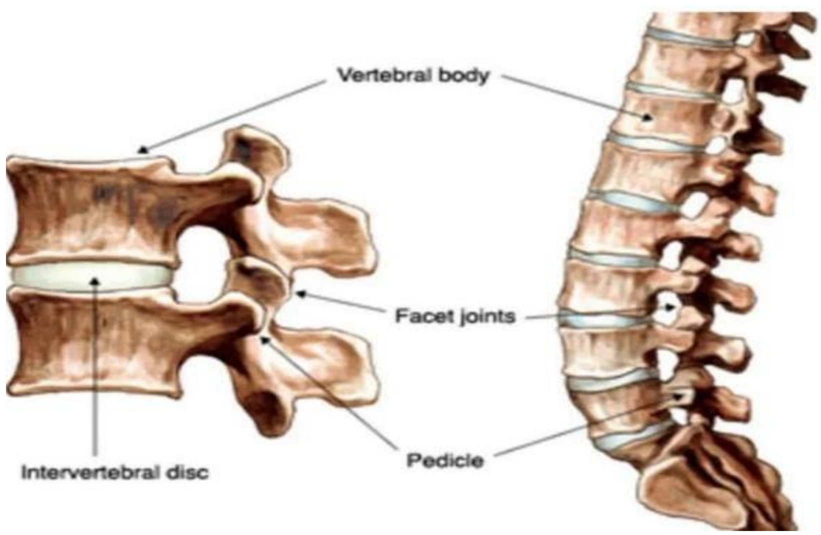

Fig.1 A view of the human spinal disc

In this work, the novelty via two experimental and numerical methods that can be employed to conduct stress analyses on spinal discs because of the geometrical complexities they have. Therefore, a low-cost and precise technique of analyzing these discs using numerical methods can be very helpful in this field. The finite element approach has emerged as a dependable technique for carrying out such studies in recent years as a result of the development of FE software and the rise in accuracy of this software. Since there hasn't been much research done on the application of this technology for the analysis of repaired discs, it has the potential to further the field's existing understanding.

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- Examined the biomechanical behavior of lumbar intervertebral discs in both injured and surgically repaired states when subjected to impact loading conditions.
- Investigated the influence of mechanical stresses on the degeneration of spinal discs across the lumbar, thoracic, and cervical regions.
- Built upon findings from theoretical, experimental, and computational studies that address disc degeneration and structural failure.
- Considered a wide spectrum of loading conditions, including:

I. Static and semi-static loads
II. Dynamic impact loads
III. Complex multi-directional forces

2. Background

Lee et al[9] conducted a study aimed at predicting changes in biomechanical parameters under different impact rates, including intradiscal pressure, dynamic stiffness, stresses in the endplate region, and spinal shock absorption mechanisms. Analytical investigations were used to examine the connection between loading speed and vertebral body fracture. A finite element model with 3D motion segment L3-L4 was used to simulate stress absorption phenomena. Results showed that fractures are more likely to occur under shorter shock duration situations, and the core pressure remains unaffected by the impact force. The study concluded that the impact duration plays a role in inducing spinal trauma. As depicted in Figure 2. Fagan et al [10]. performed a finite element analysis is a widely used method in various sectors, including research, to improve diagnostics, examine complex systems, and test innovative designs. It has been used to better understand the spine and its components, demonstrating its biomechanical operation and behavior in various states. Idealization of spine models can help isolate cause-and-effect relationships and reduce the uncertainty of empirical studies. This work reviews the evolution of finite element analysis in spine modelling, highlighting its benefits in clinical investigations and the potential for creating patient-specific models for pre- and intraoperative planning and assessment. ito et al [11]. Conducted a study in 2005, determined the peak dynamic elongation of annular disc tissue and disc shear strain during a frontal model simulation of the entire human cervical spine. Results showed that frontal impact results in greater annular tissue strain and disc shear stress than physiological limits at the C2-C3 intervertebral level. Rear impacts cause disc injury at lower impact accelerations, potentially leading to chronic symptoms like head and neck discomfort.

Noailly, et al conducted [12]A new form of composite device with a structure resembling the natural lumbar intervertebral disc was modelled in a 2005 and its mechanical interaction with a portion of the L3-L5 lumbar spine was investigated using finite element analysis ,The aim was to determine how the prosthesis affected the biomechanical alterations brought on by the L3-L4 lumbar spine fragment model after the implant had taken the place of the natural L4-L5 intervertebral disc. The prevalence of back pain in human civilizations is a major impetus for research into intervertebral disc prosthesis. The difficulties following spinal fusion surgery demonstrated the importance of the mechanical characteristics of the new components and how they interact with the 37 remainder of the spine. In the previously created physiological model of the L3-L5 lumbar spine segment, this prosthesis took the place of the L4-L5 intervertebral disc. Simulated loads in compression, bending, extension, and axial rotation were compared

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with the physiological model for two different forms of vertebra-implant interaction. According to the findings, the models with disc replacement are significantly more rigid than the physiological model. The implant behaves like a natural intervertebral disc in full contact with neighbouring vertebrae and follows the motion segment's biomechanics. Although no impact stresses were predicted in nearby vertebrae, trabecular bone remodelling is anticipated. They stated that this study offers the opportunity to forecast the static mechanical behaviour of a novel device in the structure of the lumbar spine using numerical methods, which appears to be very beneficial for preclinical research. Schroeder et al [13]highlights the mechanical impact of intervertebral discs on the spine. They studied the interaction of osmotic, viscous, and elastic forces under axial compressive load using a fibril-reinforced poroviscoelastic swelling model. The study found that loading discs reduce height and protrude the outer ring, with osmotic forces causing larger tensile ring stresses. The estimated stress profiles accurately captured experimentally observed stress profiles. Li and Wang[14] developed a 3D geometric model of the lumbar and intervertebral discs using spinal CT and MRI data. They created a 3D finite element model of an L1-L2 segment, incorporating physiological states and loads. This approach offers more accurate results than geometric parameter data, making it a potential technique for clinical diagnosis and treatment. Kiani et al.[15] studied the behavior of spinal sagittal rossoli (SMPs) as intervertebral discs (IVDs) under pure bending pressure using analytical and computational techniques. They found that SMPs with preserved frozen volume fraction are better representations of a typical lumbar disc and can sustain damage-free minimum angle variations for bending loads and pure bending strain. Wang et al.'s study examined the biomechanical reaction of four lumbar sagittal rossoli to degeneration of various IVD segments using 3D finite element models. They found that lumbar anteflexion increased with decreasing NP and AFM strength, while lumbar type 2 exhibited the most lumbar anteflexion and posterior pelvic rotation. Lintz et al.[16]. studied the impact of diabetes hyperglycemia on young intracranial discs (IVDs) in mice. They found that diabetic discs had higher glycosaminoglycan and total collagen content, increased deformation resistance, and stiffer boundaries. These changes negatively affected function, suggesting that diabetes may predispose developing discs to degenerative disc disease by altering extracellular matrix deposition patterns and fibre development. Liu et al[17] Intervertebral disc degeneration (IVD) is a common condition linked to aging and back discomfort. The avascular tissue within the IVD makes it difficult for indigenous cells to survive and function. Mesenchymal stem cells (MSCs) have been suggested as a potential stem cell resource for IVD regeneration. Recently, endogenous IVD progenitor cells have been discovered in the IVD, demonstrating their self-repair capacity. However, it is unknown how IVD progenitor cells react to microenvironmental elements and how they may differ from MSCs in some aspects. This work provides a summary of microenvironmental variables in IVD and analyzes available studies on IVD progenitor cells and MSCs' reactions to these agents. Biswas et al. [18] study examined the flexibility, stability, stress conditions, implanted bone, and loading settings of lumbar spine implants. They created a finite element model of the complete lumbar spine using a two-level artificial disc replacement and stem screw and rod fusion. The study found that total range of motion (ROM) reduced for bilevel pedicle screw fixation and increased for the artificial disc replacement model. The study also found that ROM increased for left-to-right lateral bending and flexion-extension in neighboring segments after disc replacement. Raham et al. [19] conducted a 2022 study on the biomechanical impact of a C5-C6 section on the human lower cervical spine. They created an accurate 3D entire finite element model of the C5-C6 region and built three degenerate models, including mild, moderate, and severe degeneration. The

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study found that the range of motion of the degenerated and normal segments diminishes as the C5-C6 segment degenerates over time. Facet joint forces increase in both degenerated and normal segments, and intradiscal pressure decreases while increasing in normal segments. The study suggests that an abnormal rise in facet joint force in deteriorated models could accelerate degeneration in healthy sections. Gao and Fan's [20] examined the impact of material properties on the dynamic response of the human lumbar spine to vertical vibration. They conducted sensitivity investigations on annular ground substance (AGS), annular fibres (AF), and nucleus pulposus (NP) in the disc. Transient dynamic analysis was performed on the model with raw material properties under a vertical sinusoidal vibration load. The results showed that the AGS property influenced the axial displacement of vertebrae and the von Mises stress in AGS, while the AF property influenced disc protrusion. NP specificity had minimal impact on response metrics. The study's findings can help in choosing the right material parameters for the intervertebral disc in the finite element model of the lumbar spine.

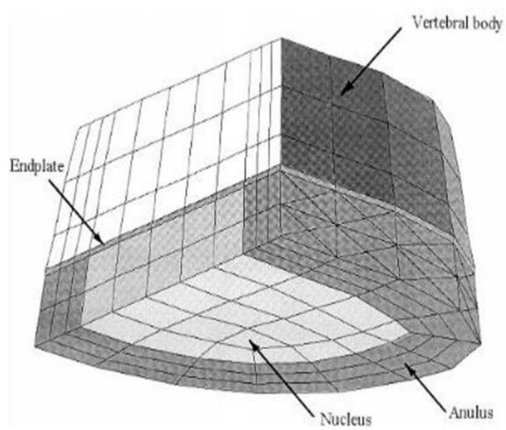

Fig.2. Finite element model used

3. Methodology

Recent research has examined the impact of effective treatment approaches in light of the development of medical engineering sciences and the growth of research in the fields of tissue engineering and regenerative medicine. These are initially explored from several histological and biomechanical aspects in this kind of research. Animal models that intentionally apply the disc degeneration principle to the animal model in order to accurately reproduce the disc degeneration mechanism are necessary to simulate the disc degeneration process [21]. Therefore, it is very appealing to understand the biomechanical mechanism of artificial ways of disc destruction. However, some simulation models of the damaged disc have been studied in recent years. Among these, shock (fatigue) loading is one that comes to mind [22]. This kind of dynamic loading involves applying load before abruptly stopping it. "Impact loads" are the loads applied in these situations. When two items collide or when a falling object strikes a structure, impact loads are produced. However, the objective of this study is to determine how damaged and

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repaired lumbar discs respond biomechanically to impact loading. The following equations [23] can be used to calculate the strain rate, strain, and stress under impact loading.

$$\varepsilon^{\cdot}(t)= \frac{c}{LS}(\varepsilon i - \varepsilon r - \varepsilon t)$$

$$\varepsilon^{\cdot}(t)= \frac{c}{IS}(\varepsilon i - \varepsilon r - \varepsilon t)dt$$

$$\sigma(t)\frac{A}{2AS}\frac{c}{IS}(\varepsilon i - \varepsilon r - \varepsilon t)dt$$

And the impact force is obtained from the following relationship:

$$P(t)=E_b A\left(\frac{\varepsilon i(T)-\varepsilon r(t)-\varepsilon t(t)}{2}\right)$$

where c is the longitudinal wave speed, ls is the length of the sample, Eb is the elastic modulus of the material, and A is the cross-sectional area of the disk. Then, as in the static method, the stress trend at the center of the disk is obtained

where c is the longitudinal wave speed, ls is the length of the sample, Eb is the elastic modulus of the material, and A is the cross-sectional area of the disk. Then, as in the static method, the stress trend at the center of the disk is obtained

$$\sigma(t)\frac{2P(t)}{\pi Al}$$

where D is the diameter of the sample and L is the thickness of the sample.

The geometry of the problem in this works the disk designed in SolidWorks software is shown in 3 while after designing the disk and transferring it to Ansys software, and discretizing it, it will be shown in Figure 4. After extracting the material properties, updated FE simulations of the specimen under These models are used to calculate the axial stress and intradisc pore pressure in response to a sequence of impact loads during 10 different durations (1-10 milliseconds). Impact loads are produced in the form of triangular waves, which are applied to the person's body as a result of a heavy object falling from a height, and a preload of 400 Newtons is used to simulate the body's weight impact loading will be performed.

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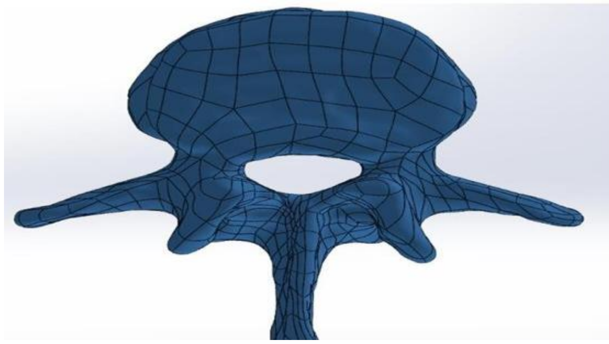

Fig.3-Disk designed in SolidWorks software

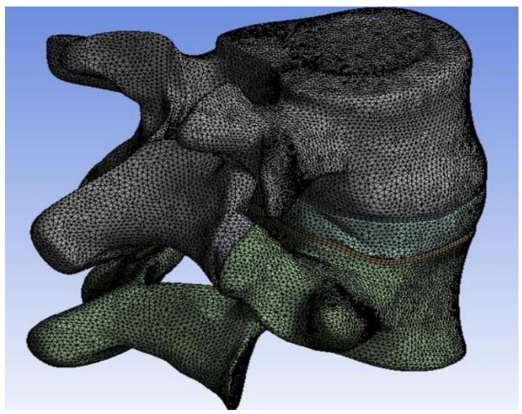

Fig4. 3D view of discretized disc

4. Outcomes and discussion

We provide the impact response analysis results for the lumbar disc vertebra with the characteristics. The mesh convergence procedure is used to determine the solution's independence from other variables. The mesh is displayed first, and then the suitable element is chosen for examination.

The study discusses the accuracy of the simulation results and compares them to earlier research to assess their validity. The data are given as contours and graphs, with interpretation and analysis.

mesh convergence Due to the existence of many complexities in the structure of the bones adjacent to the examined disc, Ensys software considers only tetrahedral elements acceptable for discretization of the bone and disc complex. In order to find the independence of the solution from the grid, an analysis is performed under the condition that a vertical force of 1000 Newtons is applied to the upper bone of the

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disc in a period of 10 milliseconds and the lower edge of the lower bone of the disc is considered as a supporting support. accept the schematic shape of the tetrahedral elements used to discretize the geometry of the problem is shown in Figure 5. The diagram of the maximum deformation according to the dimensions of the elements used for the tetrahedral element is shown in figure 6.

Fig.5. Schematic form of tetrahedral element

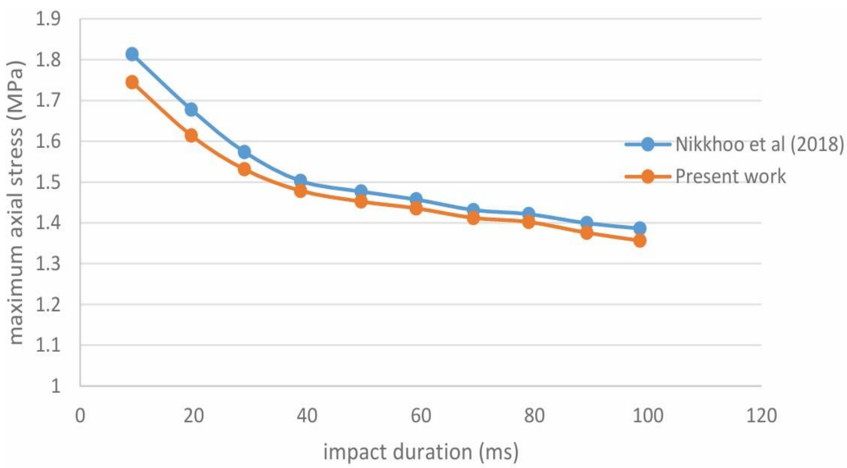

Fig.6.Maximum deformation changes relative to element dimension

As it can be seen from the above figure, when using tetrahedral elements, after the dimensions of the elements reach the range of 5 mm, the behavior of the graph is fixed and the calculated maximum deformation converges to 0.14 mm. According to the mentioned contents, for the further analysis, tetrahedral elements with dimensions of 5 mm and less will be used, but it should be noted that the large reduction in the dimensions of the elements also causes a decrease in the speed of calculations by the software and in the result of increasing the duration is analyzed.

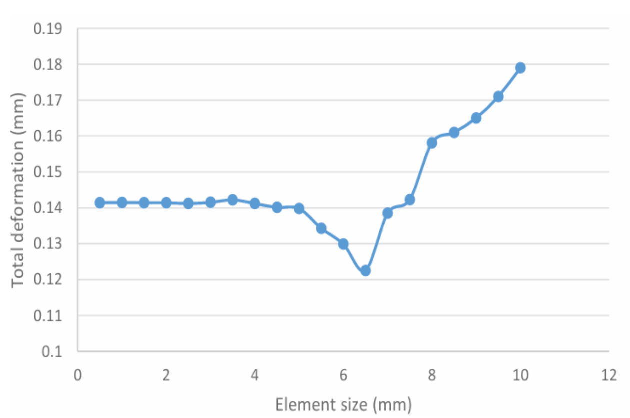

Fig.7 Comparison of the results obtained in this research with reference results

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In order to ensure the accuracy of the results obtained in each research, it is necessary to compare some of

the results obtained in that research with the results obtained in the previous research. In this regard, the deformation obtained in the sandwich panel under the boundary conditions provided by Nikkho et al. (2018) [24] under the settings made in this research has been compared with the reference in Figure 4 It can be seen in Figure 6 that the biggest difference between the results obtained in this research and the results of reference is about 5%, which is due to the type of elements and discretization conditions and software version. and solver updates, this amount of difference seems acceptable. According to the verification of the obtained results, it is possible to present them and discuss them with certainty of the accuracy of the results.

4.1 Stress distribution in the damaged disk

If a part of the disc wall is destroyed and reaches the pulp area inside the disc, the stress distribution at different impact angles is displayed in this section.

The stress distribution in a damaged disc is analyzed at different impact angles.

In Figure (8- a) the calculated von Mises stress is lower in the upper and lower regions of the destroyed part due to their lack of support. The maximum stress occurs in the damaged part, which is due to the loss of the integrated structure and the creation of stress concentration in the disc. This maximum tension for a 10-millisecond impact time is equal to 5.6 MPa.

In Figure (8-b) the stress distribution is shown for a blow to the outside of the body at a 45-degree angle for 10 milliseconds. The tension created in the upper and lower areas of the destruction place decreases, while more stress is created in the inner and outer edges of the disk than in its central areas. The maximum stress is 120 times greater than the case of vertical impact, with a value equal to 10 MPa.

In Figure (8-c) the stress distribution in the damaged disc due to an impact for 10 milliseconds with an angle of 45 degrees towards the inside of the body shows that the maximum stress is created in its inner edge, with a significant decrease compared to the case of an outward impact. This indicates that blows inflicted on the disc inside the body do not have much effect on the place of destruction created in the disc.

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Figure (8-d) illustrates the stress distribution on a damaged disc when the spine is subjected to lateral impact. The tension on the upper and lower surfaces, left and right sides, exceeds the inner and outer edges. The maximum stress is highest at the point of destruction, indicating that lateral blows to the spine are more dangerous for damaged discs.

4.2 Distribution of deformation in the damaged disc

This section examines the deformation patterns in a damaged disc after impacts from different directions.

For vertical impacts, the highest deformation occurs at the upper part of the damaged area, with more deformation on the upper surface than the lower, which decreases as one moves down (as shown in Figure 9.a)

When the impact is blows to the outside of the body, the maximum deformation appears at the outer edge of the disc, while the middle of the lower plate shows minimal deformation. This scenario results in significantly greater deformation compared to vertical impacts. (as shown in Figure 9.b)

In cases where the impact is blow to the inside of the body, maximum deformation is observed at both the inner and outer edges, with the least deformation still at the middle of the lower plate. The overall deformation here is more than during vertical impacts but less than with outward impacts. (as shown in Figure 9.c)

For lateral impacts, the highest deformation again occurs at the upper section of the disc, also affecting the middle part of the lower plate, indicating that lateral impacts cause significant deformation in the damaged area. (as shown in Figure 9.d) Stress distribution in the repaired disc

4.3. Stress distribution in the repaired dis

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In fgure.10 -a) illustrates the stress distribution contour of a repaired disc after a vertical impact to the spine. The maximum stress is at the outer edge, while the minimum is at the inner edge. The maximum stress is reduced by about 5 times compared to the damaged disc. The stress is distributed equally on the upper and lower surfaces of the disc,10- b) The stress distribution contour for impact at a 45-degree angle to the outside of the body shows that stress is uniformly distributed on the upper surface of the disc, with inner and outer edges being more stressed on the lower surface than the middle areas. The maximum stress created in the disk is about 5 times the maximum stress in the previous state, and this stress is applied on the inner edge of the upper surface of the disk. And 10-c) illustrates the von Mises stress distribution in a repaired disc when the spine is subjected to a 45-degree impact. The maximum stress is created in the inner part of the disc, distributed in both the upper and lower surfaces. This stress is almost equal to the stress created in the previous state and its maximum value is also created at the inner edge of the disc. The stress on the upper surface is minimal, while stress in the inner and outer areas occupies the largest amount on the lower surface. Figure 10-d illustrates the stress distribution of a disc subjected to a 45-degree lateral impact. The stress on the surface of the disc is highest on the side of the lateral force applied, while on the lower surface, both sides' stress is uniformly distributed. As the stress approaches the middle areas of the bottom plate, it approaches its minimum value. Comparing these four cases, it is evident that impacts with an angle to the disc's axis cause more stress than vertical impacts.

4.4. Deformation in the repaired disc

In figure.11. depicts the stress distribution of a disc when subjected to a 45-degree lateral impact The stress on the side of the lateral force is highest on the upper surface, while on the lower surface, both sides are uniformly distributed. As the stress approaches the middle areas of the bottom plate, it approaches its minimum value. Comparing these four cases, it is evident that impacts with an angle to the disc's axis cause more stress than vertical impacts.

On other hand, this section presents the analysis of the repaired disc under impacts at different angles, examining the deformation distribution created and the repaired disc. The

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maximum deformation is created in the outer area of the upper surface of the disc, with greater deformation in the lower surface. The minimum deformation is found in the central regions of the lower plate. as shown in Figure 11.a)

Figure 11.b) Illustration. For a 45° outward impact on the repaired disc, the greatest deformation occurs at its outer edge, with minimal deformation in the middle area of the lower plate. However, the maximum amount of deformation created in this state is much more than in the previous state.

While Figure 11. c) shows that for an impact at an angle of 45 degrees towards the inside of the body, the maximum deformation occurs on both the inner and outer sides located on its upper surface. The minimum deformation is also created in the middle area of the bottom plate, but the maximum amount of deformation created in this case is much less than in the case of an impact to the outside of the body. And Figure.11-d) displays the deformation distribution in a repaired disc under lateral impact. The maximum deformation occurs at the lateral edge of the upper surface and in the direction of the impact, with a lower amount than previous cases. Minimal deformation is also created on the lower surface and middle areas of the disc.

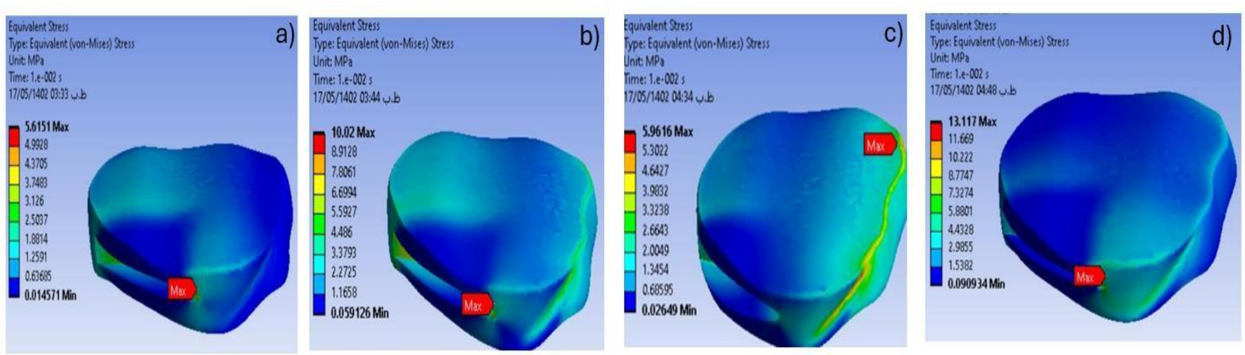

Fig.8. Stress distribution in the damaged disk

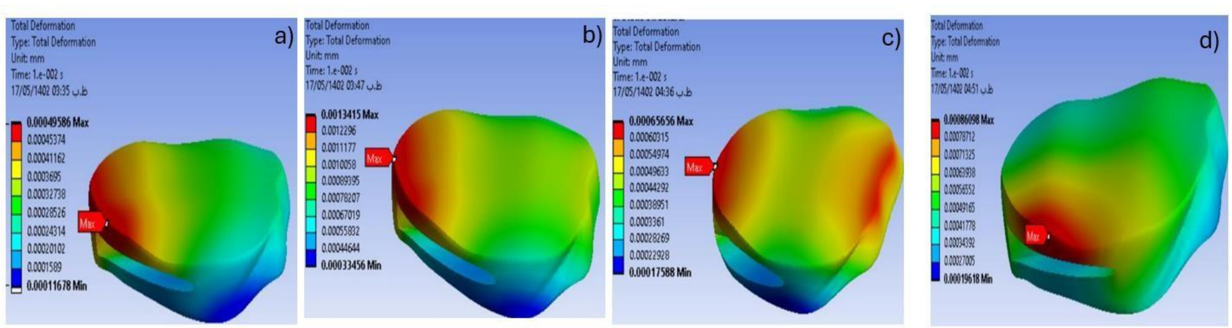

Fig.9. Distribution of deformation in the damaged disc

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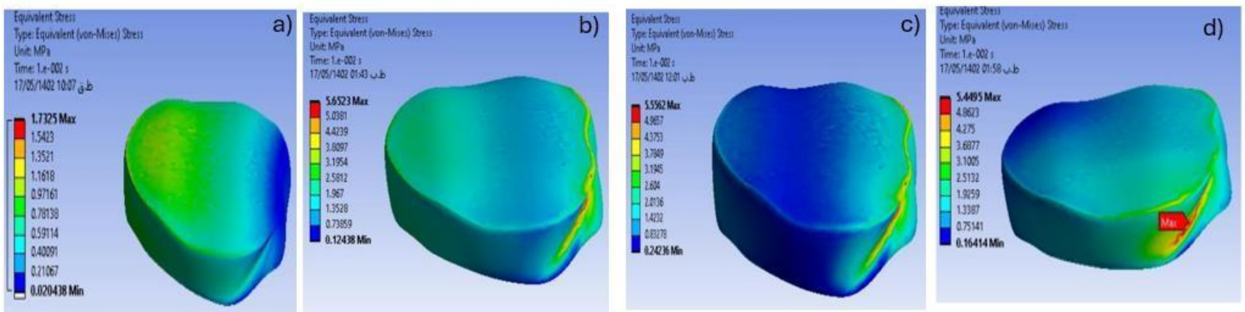

F.10. Stress distribution in the repaired dis

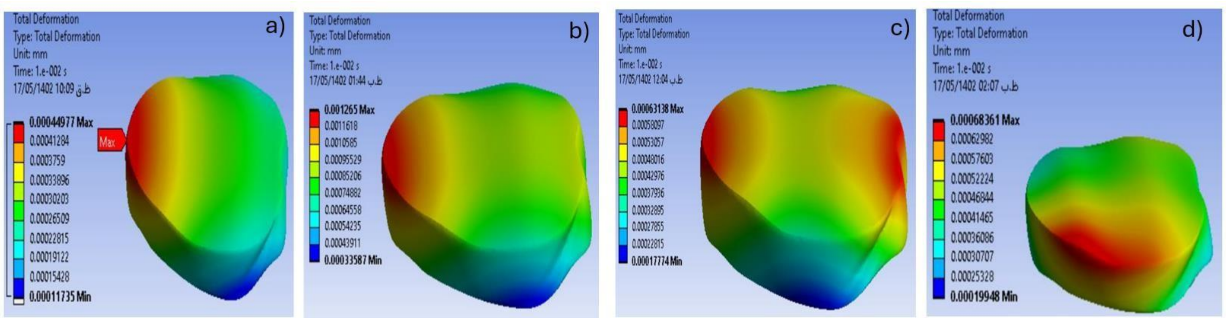

Fig.11. Deformation in the repaired disc**4.5The final analysis of work**In this part of this

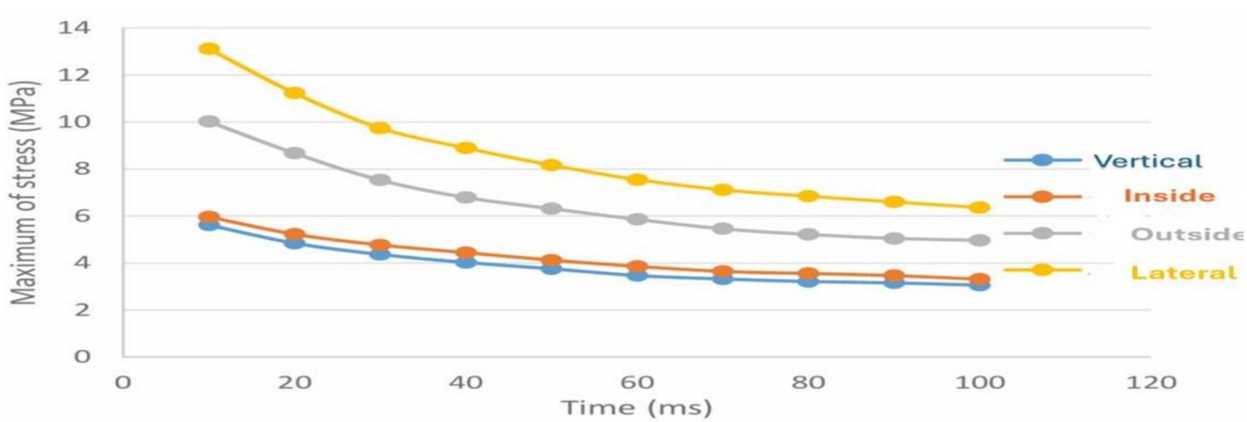

Fig.12. Stress changes withX respect to time in the degraded disc

research, the effect of time on the maximum stress created in the damaged and repaired disc is investigated. Figure 12 shows the changes in the maximum stress created in the damaged disc with respect to time. In this figure, it can be seen that as the impact time increases, the maximum stress created in the damaged disc decreases. But the slope of the graphs decreases with the increase of the impact time, which indicates that the maximum stress loses its sensitivity to time

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with the increase of the impact time. It is also clear that in the two cases of vertical impact and impact to the inside of the body, the maximum stresses created were lower than the other two cases and the slope of these two graphs is also lower than the other two graphs, which shows the lower sensitivity of these two cases. It increases the time of the blow, and Figure 13. shows the changes in the maximum stress created in the repaired disc with respect to time. Which if the impact is angled (45 degrees inwards, outwards or laterally) to the spine, there will not be much difference in the maximum stress created in the repaired disc. became. But if the spine is hit vertically, the maximum stress on the repaired disc will be reduced by about a fifth. However, by comparing the graphs shown in Figures (10&11) it can be seen that the maximum stress created in the repaired disc is significantly lower than the maximum stress created in the damaged disc in all cases.

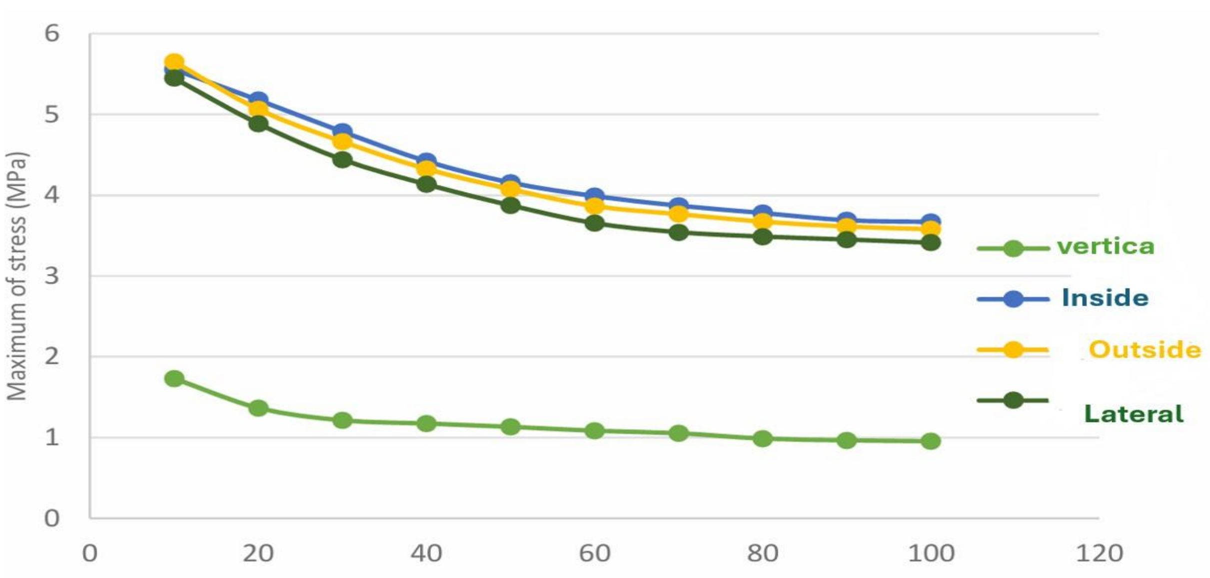

Fig13 Stress changes with respect to time in the repaired disc

Conclusion

The study reveals that increasing the impact duration reduces the maximum stress in damaged lumbar discs, but this effect diminishes with time. Vertically applied impacts significantly reduce stress in repaired discs—by up to fivefold compared to damaged ones. Stress distribution varies based on the impact angle: vertical, inward, outward, or lateral. Maximum stress in damaged discs typically occurs at the injury site due to structural discontinuity, while in repaired discs it localizes at

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outer or inner edges depending on the impact direction. Deformation patterns also differ, with outer or lateral surfaces of repaired discs experiencing the most deformation. Overall, repaired discs show more favorable biomechanical responses to impact than damaged discs.

References

[1] Zheng, Yalin, M. S. Nixon, and R. Allen. "Lumbar spine visualisation based on kinematic analysis from videofluoroscopic imaging." Medical engineering & physics 25, no. 3 (2003): 171-179.

[2] Freeman, B., J. Kuliwaba, M. Zarrinkalam, C. Jones, C. Shu, C. Colloca, James Melrose et al. "Allogeneic mesenchymal stem cells improve indices of lumbar intervertebral disc degeneration without site specificity of injection in an ovine model." Osteoarthritis and Cartilage 23 (2015): A81.

[3] Marras, William S., Steven A. Lavender, Sue E. Leurgans, Fadi A. Fathallah, Sue A. Ferguson, W. Gary Allread, and Sudhakar L. Rajulu. "Biomechanical risk factors for occupationally related low back disorders." Ergonomics 38, no. 2 (1995): 377-410.

[4] Roberts, Sally, Janis Menage, Sarit Sivan, and Jill PG Urban. "Bovine explant model of degeneration of the intervertebral disc." BMC musculoskeletal disorders 9 (2008): 1-6.

[5] Hsu, Yu-Chun, Ya-Wen Kuo, Ya-Ching Chang, Mohammad Nikkhoo, and Jaw Lin Wang. "Rheological and dynamic integrity of simulated degenerated disc and consequences after cross-linker augmentation." Spine 38, no. 23 (2013): E1446 E1453.

[6]Zhang, B., Li, T. C., Wang, X., Zhu, R., Du, C. F., & Xie, Y. (2025). The Effect of Disc Degeneration on the Biomechanical Response of the Lumbar Spine under Vibration Loading Condition. *Journal of Medical and Biological Engineering*, *45*(1), 22-33.]

[7] Zhang, C., Song, Y., Zhang, Q., Teo, E. C., & Liu, W. (2024). Biomechanical study of symmetric bending and lifting behavior in weightlifter with lumbar L4-L5 disc herniation and physiological straightening using finite element simulation. *Bioengineering*, *11*(8), 825.

[8] Kuo, Ya-Wen, and Jaw-Lin Wang. "Rheology of Intervertebral Disc: An: Ex Vivo: Study on the Effect of Loading History, Loading Magnitude, Fatigue Loading, and Disc Degeneration." Spine 35, no. 16 (2010): E743-E752.

[9] Lee, Choon-Ki, Young Eun Kim, Choon-Sung Lee, Young-Mi Hong, Jun Mo Jung, and Vijay K. Goel. "Impact response of the intervertebral disc in a finite element model." Spine 25, no. 19 (2000): 2431-2439.

[10] Fagan, M. J., S. Julian, and A. M. Mohsen. "Finite element analysis in spine research." Proceedings of the institution of mechanical engineers, part h: journal of engineering in medicine 216, no. 5 (2002): 281-298.

Received: August 11 ,2025

ISSN: 1311-1728 (printed version); ISSN: 1314-8060 (on-line version)

[11] Ito, S., Paul C. Ivancic, A. M. Pearson, Y. Tominaga, S. E. Gimenez, W. Rubin, and Manohar M. Panjabi. "Cervical intervertebral disc injury during simulated frontal impact." European Spine Journal 14 (2005): 356-365.

[12] Noailly, Jérôme, Damien Lacroix, and Josep A. Planell. "Finite element study of a novel intervertebral disc substitute." Spine 30, no. 20 (2005): 2257 2264.

[13] Schroeder, Yvonne, Wouter Wilson, Jacques M. Huyghe, and Frank PT Baaijens. "Osmoviscoelastic finite element model of the intervertebral disc." European spine journal 15 (2006): 361-371.

[14] Li, Haiyun, and Zheng Wang. "Intervertebral disc biomechanical analysis using the finite element modeling based on medical images." Computerized Medical Imaging and Graphics 30, no. 6-7 (2006): 363-370.

[15] Kiyani, Saeed, Fathollah Taheri-Behrooz, and Amir Asadi. "Analytical and numerical study of shape memory polymers as intervertebral discs under pure bending." Polymer Testing 120 (2023): 107943.

[16] Lintz, Marianne, Remy E. Walk, Simon Y. Tang, and Lawrence J. Bonassar. "The degenerative impact of hyperglycemia on the structure and mechanics of developing murine intervertebral discs." JOR spine 5, no. 1 (2022): e1191

[17] Lyu, Feng-Juan. "Impact of microenvironmental changes during degeneration on intervertebral disc progenitor cells: A comparison with mesenchymal stem cells." Bioengineering 9, no. 4 (2022): 148.

[18] Biswas, Jayanta Kumar, Anindya Malas, Sourav Majumdar, and Masud Rana. "A comparative finite element analysis of artificial intervertebral disc replacement and pedicle screw fixation of the lumbar spine." Computer Methods in Biomechanics and Biomedical Engineering 25, no. 16 (2022): 1812-1820.

[19] Rahman, Waseem Ur, Wei Jiang, Fulin Zhao, Zhijun Li, Guohua Wang, and Guanghui Yang. "Biomechanical effect of C5-C6 intervertebral disc degeneration on the human lower cervical spine (C3-C7): a finite element study." Computer Methods in Biomechanics and Biomedical Engineering (2022): 1-15.

[20] Guo, Li-Xin, and Wei Fan. "Impact of material properties of intervertebral disc on dynamic response of the human lumbar spine to vertical vibration: a finite element sensitivity study." Medical & biological engineering & computing 57 (2019): 221-229.

[21] Y.C.Hsu, Y.W.Kuo, Y.-C.Chang, M. Nikkhoo, J.-L Wang, “Rheological and dynamic integrity of simulated degenerated disc and consequences after cross-linker augmentation”,Spine,38(23), pp. E1446-1453, 2013

[22] Y.W. Kuo, J.L. Wang, “Rheology of intervertebral disc: an ex vivo study on the effect of loading history, loading magnitude, fatigue loading, and disc degeneration”, pine (Phila Pa 1976), 35(16), pp. E743-752, 2010

Received: August 11 ,2025

Volume 38 No. 8s, 2025

ISSN: 1311-1728 (printed version); ISSN: 1314-8060 (on-line version)

[23] Wu, R. J., Li, H. B., & Wang, D. P. (2021). Full-field deformation measurements from Brazilian disc tests on anisotropic phyllite under impact loads. International Journal of Impact Engineering, 149, 103790

[24] Nikkhoo, Mohammad, Jaw-Lin Wang, Mohamad Parnianpour, Marwan El-Rich, and Kinda Khalaf. "Biomechanical response of intact, degenerated and repaired intervertebral discs under impact loading–Ex-vivo and In-Silico investigation." Journal of biomechanics 70 (2018): 26-32.

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