Mechanical influences in disc degeneration and prolapse: medico-legal relevance

This short contribution aims to explain how intervertebral disc 'degeneration' differs from normal ageing, and to suggest how mechanical loading and constitutional factors interact to cause disc degeneration and prolapse. We suggest that disagreement on these matters in medico-legal practice often arises from a misunderstanding of the nature of 'soft-tissue injuries'.

INTERVERTEBRAL DISC AGEING, DEGENERATION AND PROLAPSE

Intervertebral discs

These pads of fibrocartilage are the largest avascular structures in the body. Their low cell density ensures that they have limited ability to adapt, or heal following injury.

Ageing

After skeletal maturity, disc cell density does not normally change, but an increasing number of cells become senescent, and the rate of matrix turn-over (repair) falls.[1] There is steady fragmentation and loss of the proteoglycan molecules which bind water into the tissue, and consequently, ageing discs become dehydrated.[2] Reduced turn-over also leads to increased cross-linking of the matrix collagens, making the tissue stiffer and more easily damaged. Small circumferential splits occur between lamellae in the annulus, and the nucleus contains fibrous regions separated by softer tissue.[3] Cross-linking between collagen and sugars gives rise to the yellow-brown colour which characterises most old cartilage. These changes occur first, and to a greater extent, in the nucleus.[4] Functional changes with age include a gradual decrease in the hydrostatic pressure in the nucleus, increased load-bearing by the annulus, slightly increased radial bulging, and reduced ranges of intervertebral movement.[5] Generally, however, old discs still function much like young discs, and there is no invasion of blood vessels or nerves.

Degeneration

Approximately half of all old human lumbar discs become 'degenerated',[6] especially those at L4-S1. It is conventional to recognise four or five 'grades' of degeneration from anatomical images or MRI scans.[3,7,8] Essentially, grading is an exercise in pattern recognition, and unfortunately, some of the 'features' used to describe the grades occur in all old discs, as described above. However, severe grades of disc degeneration are characterised by gross structural changes such as endplate defects, radial fissures and rim-tears in the annulus, herniation of nucleus pulposus (especially through the posterior annulus), and general collapse of the annulus, both into the nucleus and also radially outwards. These structural changes lead to a marked (sometimes complete) loss of nucleus pressure, high stress concentrations in the annulus (especially the posterior annulus), marked bulging of the outer annulus leading to vertebral body osteophytes, and a major shift in load-bearing from the disc to the adjacent neural arch.[5] Disc cell biology becomes abnormal, with increased cell signalling and release of matrix-degrading enzymes.[2] As described below, these biological changes probably arise from the abnormal matrix stresses created by structural disruption. Defects in the endplate and outer annulus allow blood vessels and nerves to grow into the disc.[9] Recent population studies show that degenerated and herniated discs are often (but not always) painful.[10,11]

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Two disc degeneration phenotypes?

Variable associations between disc degeneration, pain and risk factors suggest that only certain features of disc degeneration are painful, and others are not.[12] Disc degeneration is evidently not a single condition. Recently, it was proposed that two disc degeneration 'phenotypes' can usefully be distinguished: 'endplate-driven' degeneration arising from primary defects in the endplate, and 'annulus-driven' degeneration arising from annulus fissures.[13] The former is common in the upper lumbar and thoracic spine, and the latter is common at L4-S1. According to this scheme, disc herniation should be viewed as an advanced form of annulus-driven degeneration.

MECHANICAL INFLUENCES IN DISC DEGENERATION AND PROLAPSE

Structural disruption can be caused by injury, and 'fatigue'

Experiments on cadaveric spines and animal tissues have shown that all of the structural features of disc degeneration can be created in the laboratory by controlled mechanical loading.[5] Endplate fracture (and vertical disc herniation) is caused by excessive compressive loading down the long axis of the spine. Endplate fracture causes an immediate decompression of the adjacent nucleus, and high stress concentration on the adjacent annulus, and subsequent cyclic loading then causes the annulus to collapse into the nucleus.[14] These effects are greatest in the upper lumbar and thoracic spine, and least at L4-S1,[15] explaining the distribution of endplate-driven degeneration. If compressive loading is combined with bending, as it is during manual handling,[16] then the site of injury is often the annulus on the side of the disc that is stretched by the bending. A radial fissure forms, from the inside out and often adjacent to a vertebral endplate, and this can allow radial migration of nucleus pulposus.[14,17] Similar endplate and annulus injuries can be caused by less severe but repetitive loading[18] as microdamage spreads through the affected tissue to cause 'fatigue failure'.

Biological consequences of injury

An intact intervertebral disc, even an old one, exhibits an even distribution of compressive stress within it.[19] However, the very high and very low stresses found in different regions of disrupted discs[14] severely inhibit disc cell metabolism,[20] and very high stresses also stimulate the release of matrix-degrading enzymes.[21] Not surprisingly, injured discs always degenerate, and this has been demonstrated on various animal models[22,23] as well as in 'found' experiments in humans.[24,25] At a local level, the creation of fissures within a disc leads to focal swelling (because collagen restraint is reduced) and then to proteoglycan loss from the swollen tissue. These changes ensure that annulus fissures are chemically and mechanically conducive to the ingrowth of blood vessels and nerves.[26] Not surprisingly, blood vessels, nerves and inflammatory cells invade physically disrupted regions of discs,[27] and are particularly evident in herniated discs, where their presence appears to be unrelated to pre-existing disease.[28]

Physical disruption also influences disc biology by breaking down barriers. Endplate fracture allows free communication between vertebral body bone marrow and the disc nucleus. Herniating disc tissue can also pull some of the hyaline cartilage endplate away from subchondral bone,[29] leaving a very porous barrier.[30] Two-way movements across this barrier probably explain why degenerated and herniated discs are associated with inflammatory changes, and infection.[31]

Tissue weakness: genes and ageing

Genetic inheritance explains approximately 30% of the variance in disc degeneration in the lower lumbar spine, and 50% of variance in the upper lumbar spine.[32] The difference is probably explained by greater mechanical influences at L4-S1. Heritability can rise as high as 70% in middle-aged women,[33] who are less likely to be 'discordant' for mechanical loading. There is no 'disc degeneration gene': rather, many gene variants exert small influences on matrix strength and metabolism. Evidently, genes and environmental influences are both important in disc degeneration. Age-related increases in disc degeneration[10,34] are probably attributable to the matrix becoming weaker and more vulnerable to injury.

SOFT-TISSUE 'INJURIES'

An injury is damage to a living tissue. Typically the cause is mechanical, and a laboratory-created mechanical injury can be identified by the tissue manifesting a permanently reduced resistance to load. Injury begins at the 'elastic limit', when non-reversible deformation starts, and this is probably the point at which an injury becomes painful.[35] When 'brittle' tissues such as bone are deformed beyond their elastic limit, there is a sudden marked increase in deformation accompanied by the release of stored-up energy, and brittle fracture usually is accompanied by visual and audible signs. However, in 'tough' fibrous and cartilaginous tissues, injury begins with a gradual 'yielding' as collagen fibres slide imperceptibly past each other; generally there is no visual or audible clues, and the 'injury' must be identified from subtle changes in a force-deformation graph.[36]

In living people, soft-tissue injuries must be inferred from patients' symptoms, perhaps with the help of MRI, but often there is no objective confirmation that an injury has occurred. This can be contrasted with bone fracture, which can almost always be identified from radiographs. We suggest that this disparity in the ability to detect hard- and soft-tissue injuries is important, because it often leads to the latter being overlooked, or not considered seriously. It is true that some well-vascularised soft tissues such as muscle heal quickly, and are not as serious as bone fractures. But injuries to intervertebral discs, cartilage and tendon are often more serious than bone fractures, because their low healing potential often results in progressive and painful degenerative conditions.[37]

It can be confusing if the word 'injury' is used synonymously with 'trauma'. The latter implies very high loading, often associated with violent collisions and falls. But injury simply requires the mechanical loading to exceed tissue strength. If the tissue has been severely weakened by the combined influences of an unfavourable genetic inheritance, ageing and prior 'fatigue' loading, then it can be injured during the activities of everyday living. It is widely acknowledged that 'metabolic'

weakening of bones can lead to osteoporotic vertebral fracture during an activity as mild as opening a window[38] and this understanding should be applied to soft tissues also.

MEDICO-LEGAL IMPLICATIONS

Uncertainty over the nature of disc degeneration and prolapse

According to the above account, some discs are so weakened by genetic inheritance and ageing that they can be injured during the activities of everyday living, and 'degeneration' essentially consists of the disc's frustrated attempts to heal itself despite low cell density and continued mechanical loading. This concept of disc degeneration was first expounded in what has become the most-frequently cited paper on the subject.[37] However, there is still no scientific consensus, with some scientists placing more emphasis on the role of disc nutrition, genetic inheritance, or abnormal cell signalling. Disc herniation is better understood than disc degeneration in general, and there is no doubt that it can be a mechanical injury; but there is still disagreement over the importance of prior age-related degenerative changes.

Mechanical 'advancement' or 'acceleration' of disc degeneration

In the medico-legal arena, it is sometimes proposed that an injury or work practice has accelerated disc degeneration, so that pain and disability arise several years earlier than if 'nature had taken its normal course'. This concept is not quite compatible with the disease process outlined above. Many tissues appear to age faster in some individuals because of genetic influences on metabolism: for example, altered hormone levels can accelerate collagen cross-linking in cartilage, or accelerate the loss of mineral density in bones. However, excessive mechanical loading does not influence the musculoskeletal system by accelerating these metabolic ageing effects. Rather, it diverts the disc from its normal 'ageing' pathway to a separate 'degeneration' pathway, which involves structural disruption, grossly altered biomechanics and tissue metabolism, and which allows re-vascularisation and re-innervation. It is the diverging 'degeneration' pathway, rather than the ageing pathway, that leads to pain and disability.

Liability

The above argument would appear to place all of the blame for discogenic back pain on to mechanical loading, which diverts the disc on to a degeneration pathway. However, this is not the case. Even trivial mechanical loading can disrupt a very weak disc, and tissue weakening depends on genetic inheritance and ageing. If discogenic pain arises in the absence of any substantial mechanical provocation, then the pain can mostly be blamed on ageing and genetic inheritance for weakening the disc, and predisposing it to injury and degeneration. On the other hand, if there is a substantial mechanical provocation, then discogenic pain can mostly be blamed on the injury or work practice which precipitated the disc injury and degeneration. Liability should be apportioned according to the perceived relative importance of these predisposing and precipitating causes. Relative importance should be judged on a scale from 0 to 100%, because genetic susceptibility and age-related weakening are both continuous variables, so the affected disc cannot simply be judged either 'normal' or 'diseased'.

What has been established beyond reasonable doubt?

Despite this uncertainty, spine science has advanced considerably during the last ten years, and the following statements would be difficult to refute on the basis of current evidence.

- Injuries to the annulus fibrosus or vertebral body endplate can cause human intervertebral discs to degenerate.
- Excessive mechanical loading can cause human discs to herniate, even if they appear 'normal' for their age. Middle-aged discs at lower lumbar levels are most vulnerable.
- Many such herniations are injuries, but few are traumatic.
- Most degenerative changes in surgically-removed disc herniations are consistent with them occurring after herniation.
- Experts should not claim that any herniated disc must have been degenerated before it herniated, unless there is independent evidence of this prior degeneration. (Insisting that it must have been degenerated because it herniated is a circular argument.)

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