CHAPTER 2

THE ORIGIN OF LOW BACK PAIN

The International Association for the Study of Pain (IASP) has defined pain as “an unpleasant sensory and emotional experience associated with actual or potential tissue damage”.50 This rather broad description implicates both sensory and emotional factors to be involved in the pain experience. The sensory part refers to the signal system of nociception, activated when adequate stimuli provoke free nerve endings to transmit signals to the spinal cord or brain stem to finally become aware in the brain. The emotional part is a complex signal system with cognitive, emotional, and behavioral components and occurring subsequent to nociceptive stimulation.23 Actual and potential tissue damage refers to the fact that pain can occur in the absence of tissue damage and therefore is not invariably linked-up with a damaging stimulus. In assessing the problem, Loeser48 subdivides four modalities:

Nociception: potentially tissue-damaging thermal, chemical, electrical or mechanical energy impinging upon specialized nerve endings that in turn activate A-delta and C fibers.

Pain: nociceptive input to the nervous system and its awareness.

Suffering: negative affective response generated in higher nervous centers by pain and other situations: loss of loved objects, stress, anxiety, etc.

Pain behaviour: all forms of behaviour generated by the individual commonly understood to reflect the presence of nociception, including speech, facial expression, posture, seeking health care attention, taking medications, refusing to work.

When an attending physician is confronted with a patient suffering from low back pain a combination of anatomical, physiological, and psychosocial factors underlies the patient’s pain experience. To what extent each of these components attribute to the pain experience must be evaluated in the individual with regard to diagnosis making and treatment of choice. In patients with a predominant physical source of the low back pain, additional medical investigations and physical treatment are appropriate. In depressed patients with apparent psychosocial difficulties, psychotherapeutic and social intervention is rather indicated. In the latter category, excessive medical and surgical treatments will be irrelevant and are potentially hazardous.

In order to understand the very nature of low back pain, various neuroanatomical mechanisms of the lumbar pain will be discussed in 2.1. Low back pain as a result of spinal degeneration will be discussed in 2.2.
2.1 NEUROANATOMICAL CONSIDERATIONS IN LOW BACK PAIN

2.1.1 Innervated structures

In principle, any structure in the lumbar spine that possesses a nerve supply can become a source of pain when affected by pain-producing tissue damage. Therefore the possible sources of pain can be determined by reviewing the innervated structures and the lesions that might affect them. Several authors, including Bogduk, Edgar, Groen, and Hirsch, have described the innervation of the vertebral column and its associated structures. Innervated structures of the lumbar spine are the vertebral venous plexuses and the dura mater, the zygapophysial joints, the ligaments of the vertebral arches, the back muscles and their fascia, the vertebral bodies and their covering periosteum, the vertebral laminae, the longitudinal ligaments and the discs (see figure 2.1). Possible pain mechanisms are shown in figure 2.2.

![Figure 2.1](image)

**Figure 2.1** Schematic drawing of the innervation of the upper lumbar spine according to Groen. (printed with permission)
Bogduk\textsuperscript{7} has reviewed the various lesions of the lumbar spine that might be responsible for low back pain. Of the innervated structures of the lumbar spine, the venous plexuses are not thought to play a role in the onset of acute low back pain. The dura mater may undoubtly be a source of acute low back pain when irritated by pus (meningitis), blood (subarachnoid hemorrhage) or reactive exudates (disc herniation). No lesions of the ligamentum flavum, the interspinous, the supraspinous or the iliolumbar ligaments are likely to cause low back pain. Like every muscle in the body, any of the individual back muscles could become a source of pain following excessive exertion or sudden unexpected stretch. These selflimiting conditions possibly explain a large proportion of the selflimiting acute back pain cases.

Well known sources of low back pain are fractures, infections or expanding lesions of the vertebral bodies and other bony elements of the lumbar spine. Subchondral fractures and fractures of the articular-processes may also affect the lumbar zygapophyseal joints in such a way that they become a source of pain. Theoretically, the zygapophyseal joint may also become painful following trauma, when damaged meniscoid structures act as loose bodies within the joint, or become trapped in the subcapsular pockets of the joints. Then,
the innervated meniscoid structures are painful themselves or elicit pain by stretching the joint capsule.

According to Bogduk and Jull, this zygapophyseal meniscus entrapment theory is also applicable to the relatively common clinical syndrome of “acute locked back”. In this condition the patient, having bent forward, is unable to straighten because of severe focal pain on attempted extension. Until now its cause remains speculative. We firmly believe, however, that a more valid explanation of the “acute locked back”, “Hexenschuss” or “witch’s blow” is damage to the intervertebral disc. Physical stress related strains of the anulus fibrosus are one of the most potent, yet overlooked, sources of acute low back pain. The anular strains can be peripherally (rim lesions), circumferentially (concentric) or radially. Since the anulus fibrosus is densely innervated it is not surprising that these ruptures are painful. Secondary to painful movement muscle spasms may occur resulting in an “acute locked back”. Tears may be produced in the anulus following twisting or flexion-rotation injuries or as a result of excessive compression. The possibility of developing these tears is increased when the vertebra is flexed and when the disc is submitted to lateral stress. The collagen fibers will then become subjected to microtrauma, a process often seen in disc degeneration (see 2.2 spinal degeneration and low back pain). It is interestingly that torsion injury inflicts lesions in the anulus fibrosus while the nucleus pulposus virtually remains unaffected.

2.1.2 The pain pathway

The free nerve endings of the innervated structures, also called nociceptors (Latin nocere = to injure), respond selectively to damaging stimuli. An action potential is then generated which passes along the pain fibers into the dorsal horn of the spinal cord where it synapses for the first time. The second order neuron conducts the action potential across the spinal cord and synapses in the white matter of the anterolateral spinothalamic tract to the thalamus. Other ascending pain pathways are the spinoreticular tract, spinomesencephalic tract, spinocervical tract, and the dorsal column. The third order neuron sends the message to the somatosensory cortex of the brain. In addition to the ascending tracts there are also descending inhibitory circuits in the spinal cord and local excitatory and inhibitory circuits in the dorsal horn.

Nociceptors

In humans, pain is mediated by the several different nociceptors:

1. **Mechanical nociceptors**, which are activated only by strong mechanical stimulation and most effectively by, sharp objects. A pinprick or pinch causes a brisk response while no response is evoked when a blunt probe is pressed firmly into the skin.

2. **Thermal nociceptors** which respond when the receptive field is heated to temperatures greater than 45 °C, the heat pain threshold in humans.

3. **Polymodal nociceptors** which respond equally to all kinds of high-intensity noxious stimuli; mechanical, electrical, heat and chemical.
The noxious stimulus activates the nociceptor by depolarizing the membrane of the sensory ending, but the exact mechanisms by which the diverse stimuli depolarize the nerve endings and trigger an action potential are not known. The nociceptors can be activated and sensitized by agents resulting from tissue damage such as potassium, serotonin, bradykinin, histamine, prostaglandins, and leukotrienes. The sensation of pain may be enhanced, also called hyperalgesia, and this may involve a lowering of the threshold of the nociceptors or an increase in the magnitude of the pain evoked by suprathreshold stimuli. The nociceptors themselves can also release peptides, such as substance P, thus sensitizing the nerve endings.

Nerve fibers
The nerve fibers responsible for pain sensation are the A-delta (Aδ) and C fibers. The Aδ fibers are thinly myelinated and conduct at about 5-30 m/s. Activation of these fibers causes a sharp, pricking pain. The free nerve endings include thermal and mechanical nociceptors. The small diameter, unmyelinated C fibers conduct a sickening burning sensation following fast pain at 0.5-2 m/s. The Aδ and C fibers are not solely pain fibers, but are also involved in sensing temperature, pressure, and crude touch. The free nerve endings include the polymodal nociceptors.

The synapses of nociceptive fibers with dorsal horn neurons
The cell bodies of the Aδ and C fibers are located within the dorsal root ganglion. The myelinated Aδ fibers predominantly terminate on projection neurons in the most superficial layer (lamina I) of the dorsal horn, also known as the marginal zone; some fibers project more deeply (figure 2.3). The substantia gelatinosa (lamina II) contains the terminals of the unmyelinated, polymodal nociceptive C fibers. By means of stalk cell interneurons in lamina II the unmyelinated C fibers may contact the projection neurons in lamina I.
Figure 2.3 Synapses of nociceptive fibers in dorsal horn of myelum (laminae according to Rexed\textsuperscript{59}).

In the dorsal horn, chemical transmitters transmit the nociceptive signals. The A\textgreek{delta} and C fibers release transmitters which can evoke fast and slow postsynaptic potentials in the superficial dorsal horn neurons. Neuropeptides that can be produced by the afferent neurons include substance P, somatostatin, cholecystokinin-like substance, vasoactive intestinal polypeptide, calcitonin gene-related peptide, gastrin-releasing peptide, dynorphin, enkephalin, and galanin.\textsuperscript{42,66}

Of all these transmitters substance P has been studied most extensively. In 1931, Von Euler and Gaddum\textsuperscript{20} discovered the polypeptide substance P (SP). Identification of its structure by Leeman et al.\textsuperscript{18} facilitated important progress in SP research. SP an eleven-amino acid neuropeptide produced within the dorsal root ganglion in cell bodies of primary afferent neurons and that is delivered to the central and peripheral parts of the neurons by axonal transport.\textsuperscript{66} At the peripheral nerve ending SP causes vasodilatation, plasma extravasation, and release of histamine from mast cells (figure 2.4).

Thus, when tissue damage occurs, substances like bradykinin and prostaglandins are released which in turn activate the nociceptors. Activation of the nociceptors results in release of neuropeptides, such as SP, producing histamine release, vasodilatation and plasma extravasation. Histamine excites the nociceptors directly and the vascular changes result in edema causing further liberation of bradykinin.\textsuperscript{57}

SP released in the first synapse evokes a slow excitatory postsynaptic potential (EPSP) in dorsal horn cells. It must be noted that the role of SP as a pain transmitter is only one of many physiological roles of SP.\textsuperscript{55} Furthermore, SP is present in only 10-20\% of primary afferent fibers. The C- and A\textgreek{delta} fibers use various excitatory and possibly inhibitory transmitters. Discovery of these transmitters and their antagonists may open up new possibilities for the development of new non-narcotic analgesics.
Figure 2.4 Activation and sensitization of nociceptors, transduction along the pain fibers and their termination on projection neurons in the dorsal horn of the spinal cord.66

**Pain perception**
There are five major ascending pathways that carry the nociceptive information from the projection neurons of the dorsal horn to the brain: the spinothalamic tract, the spino reticular tract, the spinomesencephalic tract, the spinocervical tract, and the dorsal column of the spinal cord. The spinothalamic tract is the most prominent ascending pathway originating from the neurons in laminae I, IV and V of the dorsal horn and terminating in the thalamus. The information is then sent to the post-central gyrus of the brain where the pain is localized and interpreted. The frontal and temporal lobes provide Affective and memory components.

**Central mechanisms that modulate pain**
The spinal cord also contains descending pathways arising from several structures in the brain (hypothalamus, periaqueductal grey matter of the midbrain, locus ceruleus, ventromedial, and ventrolateral medulla) which can inhibit the nociceptive projection neurons of the dorsal horn by releasing neurotransmitters that act both pre- and post-synaptically.61 A second way to inhibit nociceptive transmission is by endogenous opioid peptides (enkephalins, endorphins, dynorphins) whose receptors are located at key points in the pain modulating system.

**2.2 SPINAL DEGENERATION AND LOW BACK PAIN**
Spinal degeneration is a normal part of the aging process but unfortunately it may be the cause of low back symptoms as well. Degenerative changes affect all structures of the motion segment, including the intervertebral discs, facet joints, and ligaments.24 The
spinal degeneration process is initiated in the intervertebral disc resulting in secondary changes in the facet joints and ligaments because of load shifts from the disc to these structures (see figure 2.5). This concept is supported by many studies on disc degeneration. Only in exceptional cases facet degeneration can occur without preceeding signs of disc degeneration. In addition it has been reported that facet joint pathology may accelerate the degenerative process of the disc.

The progress of spinal degeneration can be divided into three phases as suggested by Kirkaldy-Willis. In stage I (dysfunction), changes in biochemical composition, physiology, and biomechanics of the motion segment may result in clinical symptoms. When these changes result in increased mobility at the affected level and cause symptomatic instability it is called phase II (instability). In phase III (stabilization), the motion segment will stabilize because of biochemical alterations and spinal osteophyte formation. In this last phase symptoms may subside or symptoms of spinal stenosis may occur due to osteophyte formation and facet hypertrophy. The biochemical, physiological, and biomechanical changes in the three phases of spinal degeneration are apparently equal in both the normal aging process and in the symptomatic degenerative lesions. With the exception of severe, multiple degenerative disease, there is no correlation between the degenerative process shown on radiographs and the incidence or severity of low back pain. It is not understood why these changes generally do not correlate with the patient’s symptoms. For a better insight in the relation between degeneration of the lumbar spine and low back pain, the degenerative changes of different elements of the motion segment will be discussed below.

Figure 2.5 Consecutive steps of degeneration of the motion segment.

Degenerative changes of the intervertebral disc
Fundamental changes occur in the intervertebral discs during degeneration and aging. Biochemical changes in the nucleus pulposus include decrease in the proteoglycan concentration\(^4,30,36\) and water content\(^39\), and an increase in collagen\(^39\) and collagen-proteoglycan binding.\(^1\) In early adult life, the proteoglycans make up about 65% of the dry weight of the nucleus but this decreases to about 30% at the age of 60.\(^4\) The proteoglycans also become smaller, lighter in molecular weight, and their composition changes.\(^21\) The water content of the nucleus changes from about 88% at birth to about 65-70% at the age of 75.\(^30\) The collagen content and the collagen binding of the nucleus pulposus increases and the fibril diameter of the collagen increase as well.\(^3,53\) The collagen type II of the nucleus starts to resemble the type I collagen of the anulus fibrosus. In the anulus fibrosus, the collagen content also increases\(^15\) but the average fibril diameter decreases.\(^37\) The concentration of the elastic fibers in the anulus decreases from 13% at age 26 to 8% at age 62.\(^44\)

With aging related degeneration, the intervertebral disc becomes progressively dry, stiff, and less resilient. It also becomes more difficult to distinguish the nucleus pulposus from the transitional zone since its specific features disappear with age. In the elderly, the disc appears as a solid plate of fibrocartilaginous tissue surrounded by the anulus fibrosus.\(^6,21,37,58\) Since aging of the intervertebral disc and disc degeneration are continuous processes attempts have been made to develop grading systems for the study of disc degeneration based on disc morphology, discographic-features and magnetic resonance (MR) appearance.

When the nucleus becomes more fibrous and drier its ability to exert fluid pressure and to transmit weight weakens (see Ch 1: Clinical anatomy of the lumbar spine).\(^46,68\) There will be less radial pressure being build up in the anulus fibrosus and the anulus will be subjected to greater vertical loads. The collagen lamellae also may become more fibrillated and in combination with the mechanical overload of the anulus it may give rise to cracks and fissures.\(^40\) These lesions are believed to be the first step in the process of degeneration of the motion segment. The concomitant pain may in part be related to the chemical environment within the degenerated disc and the sensitized state of its anular and perhaps even nuclear nociceptors (see Ch 3).\(^66\)

**Degenerative changes of the facet joints**

The degenerative changes of the facet joints are similar to osteoarthritis in other synovial joints.\(^24\) Biochemically, quantitative and structural changes occur in the cartilage proteoglycan and collagen.\(^13,41,69,70\) In continuation of structural degeneration of cartilage focal and diffuse erosions may occur with full thickness loss of cartilage as a result. In addition erosive changes of the cartilage may induce proliferation and increase of its matrix synthesis. The resulting osteochondrophytes produce sclerosis of subchondral bone and subchondral bone cyst formation. The degeneration process of the facet joints also includes biomechanical, inflammatory and immunological factors.\(^28\)

Pain from an arthrotic facet joint may be provoked by free nociceptive nerve endings and mechanoreceptors abundantly present in the facet capsules.\(^8\) They can be activated by inflammatory and immune responses or by mechanical factors.\(^66\) Furthermore, in facet degeneration, a well known cause of pain radiating in one or both legs is compression of nerve roots in the lateral recess of the spinal canal due to hypertrofied joints or synovial cysts.
Degenerative changes of the ligaments
With increasing age ligamentous changes occur including disorganization of ligament fibrillar and cellular alignment, selective increase of collagen degradation over formation, and proteoglycan decrease associated with loss of water. Pain symptoms may result from their contribution in spinal stenosis.

Degenerative changes of the vertebral bodies and end-plates
With aging, the vertebral end-plate, originally part of the growth plate of the vertebral body, becomes thinner, its growth zone decreases and will contain less proliferating cells, and ossification will take place at the peripheral areas. At the age of about twenty, the subchondral bone plate is formed which separates the vertebral end-plate from the vertebral body. Because of the subchondral bone formation and because of further ossification with aging and degeneration, the nutrition of the avascular disc progressively decreases which causes biochemical changes in the disc.

The trabeculae in the vertebral body change in size and pattern with aging and degeneration, resulting in decreased vertebral body strength and density. Characteristic is the loss of horizontal trabeculae, particularly in the central part of the vertebral body. With the loss of vertebral body trabeculae, less of the compressive load is borne by the trabecular bone and much more by the cortical bone. Consequently, the vertebral body becomes less resistant to deformation and injury. The end-plates may, partly due to lacking support of the underlying bone, develop microfractures which can accelerate the degenerative process and contribute to the occurrence of low back pain. Fractures of the end-plate may extend to a degree that allows nuclear material to extrude into the vertebral body, a phenomenon known as Schmorl’s nodes. These end-plate infractions occur with equal frequency in patients with and without a history of low back pain so the importance of Schmorl’s nodes in the cascade of factors causing low back pain remains unsolved.

2.3 SUMMARY
Low back pain is a complex entity of nociception, pain conduction, pain perception, and pain modulation greatly affected by emotional factors. Any innervated structure of the lumbar motion segment is a potential source of pain. Generally recognized sources are the zygapophyseal joints, the para-vertebral muscles, the dura mater, the anterior and posterior longitudinal ligaments, and the intervertebral discs. Pain arising from these musculoskeletal structures of the lumbar spine is described as “typical” low back pain. Pain arising from disorders of the spinal nerves and spinal nerve roots is called “radicular pain” or “sciatica”.
A variety of lesions can cause low back pain, but of particular interest is low back pain as a result of spinal degeneration. Spinal degeneration is a sequence of biochemical, biomechanical, and physiological changes, starting in the intervertebral disc and finally affecting all structures of the motion segment. Spinal degeneration affects everyone since it is a normal part of the aging process. Interestingly, some people will develop low back pain symptoms as a result of the degeneration process and some do not. So far, it has been hard to differentiate between symptomatic spinal degeneration and normal physiologic aging events, but some insight in the underlying mechanisms has been gained yet.
REFERENCES
