DISCOGENIC LOW BACK PAIN

LUMBAR SPONDYLODESIS REVISITED

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DISCOGENIC LOW BACK PAIN

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Contents

PREFACE AND AIM OF THIS STUDY

Although low back pain has been reported since many centuries, this complex entity of pathophysiological, biomechanical, psychological and social factors, in fact, can be considered as a post- World War II phenomenon in Western society. The total number of people reported suffering from low back pain has increased exponentially since 1945. Currently, the inability to work as a result of low back pain appears to be socially accepted and the costs of unemployment compensation are rising to incredible extents. In The Netherlands, in 1991, the total costs involved were estimated at 1.7% of the Gross National Product[1]. The majority of payments are attributed to people suffering from chronic disabling low back pain.

Over the years, many studies, both basic and clinical, have been conducted aiming at understanding the pathophysiological mechanisms underlying chronic disabling low back pain. Several factors appear to be involved to some extent but an over-all satisfying pathogenic theory has not been presented yet. The lack of understanding about the importance of each factor involved and moreover their mutual interaction renders the development of a scientifically based therapeutic regimen futile. On a "try and error" base a wide variety of treatment modalities both non-invasive and invasive is (still) being applied to affected people. Although mostly without satisfying result, the persistence of this variety of treatments further underlines this conclusion.

By means of literature-, experimental-, and clinical studies we try to add to better insights in the mechanisms leading to severely disabling chronic low back pain and its current and future (surgical) management. The major part of this study including the patient analysis and treatment, and the lab investigations on disc innervation have been performed at the Leiden University Medical Center, Department of Neurosurgery.

The aim of this study is to:

1. Review what is currently known about low back pain and its relevant anatomical structures (Ch 1 and Ch 2).

2. Study the degenerated intervertebral disc: are there arguments to consider it as a source of chronic low back pain (CH 3)?

3. Evaluate a combination of particular criteria in order to select patients with discogenic chronic low back pain for surgical treatment (Ch 5).

4. Evaluate the method of interbody lumbar spinal fusion in these patients with presumed discogenic chronic disabling low back pain (Ch 4 and Ch 5) and evaluate the long-term clinical results (Ch 6).

5. Improve the radiological evaluation of lumbar spinal fusion results (Ch 7).

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CHAPTER 1

GENERAL INTRODUCTION

Back pain and sciatica have plagued mankind for many thousands of years. The earliest description of sciatica is in an Egyptian manuscript, dated about 2.500 B.C..[30] In this case report a patient is presented with low back and leg pain, exacerbating with leg raising. The cause of the back and leg pain was attributed to vertebral strain and treatment was by (bed) rest. Later on in history, it was Hippocrates who introduced the term "sciatica", but it were ancient Roman authors, like Soranus and Caelius Aurelianus, who defined sciatica and introduced the terms "psoadica" and "ischiadicus dolor" for pain in the psoas and ischia regions.[30]

Although Aurelianus and Soranus clearly described different types of back pain, no contributions were made with regard to the anatomy of the lower back and to the pathogenesis of low back pain.[30] It was not until human dissections were performed by Vesalius in the 16th century[61] before an anatomical basis for the etiology of low back pain was suggested. In the 18th and 19th century, many authors like Cotugno, Von Luschka, Lasègue, Oppenheim, Babinski, Virchow and Kocher[19,30] attributed to the understanding of back pain. A reasonable and scientific explanation of one source of low back pain in combination with leg pain did emerge in 1934 with the publication of the classic paper by Mixter and Barr.[35] These investigators, for the first time, assigned prolapse of the intervertebral disc as the etiologic factor of - especially the sciatic part of - the symptoms. Nineteen patients with a prolaps of the intervertebral disc who underwent surgery were discussed. The operation existed of laminectomy followed by transdural removal of the herniated disc. Mixter himself was convinced that this type of surgery increased the change of instability of the spine and therefore he recommended additional spinal fusion.

Steinler[50] first highlighted a relation between low back pain and degeneration of the intervertebral disc in the late forties. The impact of disc degeneration on the spinal motion segment and its role in causing low back pain has been studied extensively ever since (see Ch 3).

Although many factors presumed to be involved in causing low back pain have been studied thoroughly, it is remarkable that in most patients with low back pain seen nowadays, no actual cause can be held responsible. Some factors that are thought to either induce or potentially affect low back pain are shown in figure 1.1.

1.1 CLASSIFICATIONS OF LOW BACK PAIN

Getting the diagnosis does not only enable the attending physician to inform the patient about prognosis and treatment modalities, but it is also the first step for the patient in dealing with low back pain. Unfortunately, in contrast to a lot of well defined diseases like appendicitis, myocardial infarction or gonarthrosis, back pain is only a symptom; a personal and subjective experience usually without any objective signs.[59] Therefore, we have to rely on the individual verbal report and behavior in the appraisal of the severity of

low back pain. Only in less than 15% of all the people suffering from low back pain, an accurate cause-related diagnosis can be made.

Differentiation based on the duration of symptoms

Transient low back pain. Almost everyone is likely to experience transient twinges in the lower back area once in a while in his or her life. The passing awareness of discomfort, or perhaps sharper sensations, related to the back is brief and typical. Because of the universality of such symptoms, transient low back pain is the largest group of back pain. However, it is unlikely that this complaint is presented to a doctor, so it tends to be neglected in the consideration of this problem.

Acute low back pain. This is the type of back pain that most people are likely to think of, although this class is exceeded by the transient experiences in terms of magnitude. The key distinction between acute and transient low back pain is the duration of the symptoms. Acute back pain refers to symptoms present for sufficient time to compel most sufferers to take note of them. This category embraces a very considerable range of variation, extending from some hours up to three months.

Chronic low back pain. The smallest, but by far the most difficult to treat/handle, type of pain is the pain experienced by the group of chronic low back pain sufferers. In the literature, patients who suffer for periods in excess of three to six months are included. The critical distinction between acute and chronic low back pain is therefore largely a function of duration; people who experience low back pain for over 3-6 months are considered chronic low back pain sufferers.

The differentiation between transient, acute, and chronic low back pain is solely based on the duration of symptoms and says nothing about the onset or severity of the complaints. The onset of complaints may be dramatic, as with the “Hexenschuss” or witch’s blow, or it may be gradual, while the severity of suffering may extend from the mild too severe. The symptoms may be confined to the lumbar region (=lumbago) or they may radiate to other areas (e.g. to the lower limb = sciatica).

Clinical classification of low back disorders

A strict pathophysiological classification associated with low back pain is presented in table 1.1. Essential in making a diagnosis are objective clinical criteria, obtained through thorough history taking, physical examination and further evaluation (radiographs).

Although it is very difficult to make cause-related diagnosis in the group of back pain sufferers, an important role appears to be attributed to the intervertebral disc. The disc may be either a direct source of the pain (“painful” disc), or indirectly by exerting pressure on a nerve root (“herniated” disc). Furthermore disc degeneration causes decrease of the interbody height, which may induce wearing and tearing of any innervated constituent element of the motion segment, i.e. facet joints, ligaments, bone and muscles. Other diseases like Bechterew, Paget’s disease, Scheuermann’s disease, osteoporosis, primary- and secondary spinal tumors, rheumatoid arthritis, scoliosis, infections of the vertebral column, spondylolisthesis, and spondylolysis only make up a small portion of the low back pain symptoms.

Figure 1.1 Factors that may induce and/or maintain low back pain.

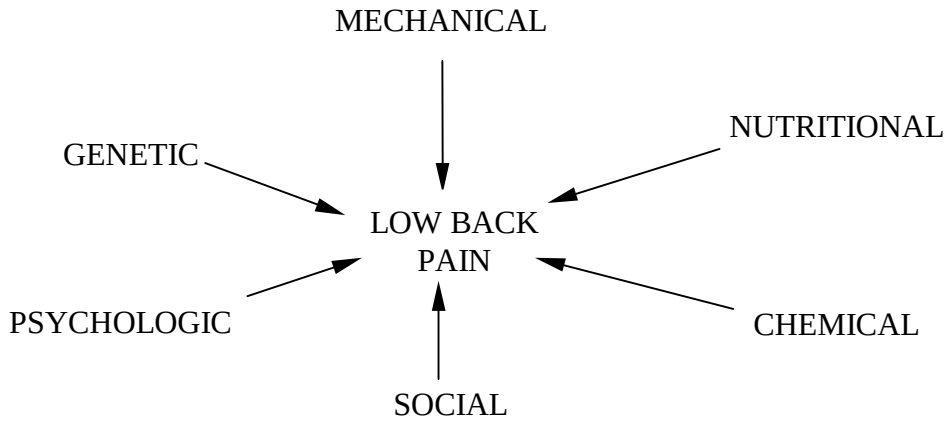


Table 1.1 Pathophysiological classification: causes of low back pain.

Classification	
Vertebral and paravertebral causes	
Degenerative disc disease	disc prolaps, anular tears
Degenerative joint disease	disc space narrowing, spinal stenosis, facet abnormalities, segmental instability
Arachnoiditis	postsurgical, postradiographic contrast study
Musculoskeletal disorders	strain, sprain, spasm
Neoplasm	metastatic, primary spinal tumors
Infectious	discitis, epidural empyema, vertebral osteomyelitis, spondylitis tuberculosa (Pott's disease)
Rheumatic conditions	ankylosing spondylitis, Reiter's syndrome
Traumatic	vertebral fracture
Idiopathic	
Referred causes	
Vascular origin	abdominal aortic aneurysm, arterial occlusive disease
Biliary origin	obstructed bile ducts, distended gall bladder
Gastrointestinal	visceral perforation
Uterine origin	ovarian carcinoma, endometrial carcinoma
Renal origin	renal carcinoma, kidney stones, ureteral stones, pyelonephritis, bladder carcinoma

The Quebec study classification

In 1987, a group of experts on low back pain agreed on a classification of disorders of the lower spine[3,5,49], useful in clinical decision making, establishing a prognosis, evaluating the quality of care, and in guiding scientific research. The study was funded by the Institute for Worker's Health and Safety of Quebec and is therefore also known as the Quebec classification for disorders of the lumbar spine (see table 1.2). The classification is based on three assumptions: 1) the majority of patients with low back pain do not have verifiable structural abnormalities; 2) the majority of low back pain symptoms are self-limiting in a relatively short period of time; 3) the most valuable information for classification is the patient's description of pain localization: in the lower back alone, in the lower back and the upper buttocks or thigh, or in the lower back and radiating to below the knee.

In the Quebec classification, emphasis is laid on objective documentation of the back pain symptoms, and, only when necessary, on possible causes of the pain. Possible sources of pain in category 1, 2, and 3 are, for example, injuries to soft tissues, the facet joints or the intervertebral disc. Lumbar disc herniation, specific nerve root lesions, and cauda equina syndrome due to (massive) lumbar disc prolaps are classified in categories 4 and 6. Category 5 includes acute spinal trauma and segmental instability, category 7 all forms of spinal stenosis. Issues related to spinal surgery and "chronic pain syndrome" are grouped in 8, 9, and 10. Other causes of low back pain like spondylolisthesis, primary and secondary tumors, and inflammatory lesions are in category 11.

Table 1.2 The Quebec classification for disorders of the lumbar spine.[49]

	Classification	Duration of symptoms from onset	Working status at time of evaluation
1	Pain without radiation		
2	Pain + radiation to extremity, proximally	a (< 7 days) b (7 days -7 weeks) c (7 weeks - 6 months)	W (working) I (idle)
3	Pain + radiation to extremity, distally		
4	Pain + radiation to upper/lower limb + neurologic signs		
5	Presumptive compression of a spinal nerve root on a simple roentgenogram (i.e., spinal instability or fracture)		
6	Compression of a spinal nerve root confirmed by: - modern imaging techniques (computerized axial tomography, CT-myelography, magnetic resonance imaging) - ancillary diagnostic techniques (e.g., conventional caudography electromyography, epidural venography)		
7	Spinal stenosis		
8	Postsurgical status, 1-6 months after intervention		
9	Postsurgical status, > 6 months after intervention 9.1 asymptomatic 9.2 symptomatic		
10	Chronic pain syndrome		W (working)

How to classify low back pain

A major factor in the problem of making a diagnosis in back pain sufferers is the discongruence between findings on physical examination, radiographs, and histopathological studies. So, instead of categorizing by strict pathophysiological criteria it is often more useful to classify low back pain by non-specific findings, like the duration of symptoms and working status, because these parameters are strongly related to the eventual treatment outcome and socio-economic costs of low back pain.[36] Only when objective documentation is certain, classification by strict medical criteria can be attempted.

1.2 EPIDEMIOLOGY OF LOW BACK PAIN

In understanding low back pain, epidemiology offers insights in the magnitude of the problem, the natural history of low back pain and in individual and external risk factors associated with low back pain.[1] Unfortunately, a major problem in the epidemiology of low back pain is the lack of a generally accepted diagnostic classification, (see above 1.1). Some authors even argue that the epidemiology of back conditions should be restricted to sciatica and disc herniations, because they are easier and more uniformly defined and classified.[25]

The magnitude of low back pain: prevalence and incidence

The *prevalence* of back pain is defined as the number of people who have complaints at a particular time in a given population irrespective of whether back pain was present before the survey was started or not. Prevalence depends on the incidence and duration of the symptoms. The *point prevalence* of back pain means back pain at the time the question is asked, whereas, for example, a 1-month prevalence means back pain occurring during the past month. *Incidence*, on the other hand, is a measure of the number of people without back pain who develop such pain (new cases) over a defined period e.g. the “ten-year-incidence” or the “lifetime incidence” of low back pain. Incidence depends only on the rate at which the symptoms occur. The determination of prevalence has the advantage that it can be obtained from a single survey, while incidence often requires following a population free of symptoms over a period of time.

Valkenburg and Haanen[58] performed a well-known study concerning the incidence and prevalence of low back pain in the Netherlands between 1975 and 1978 in Zoetermeer (table 1.3). Their study was based on a population of 3091 men and 3493 women 20 years of age and older. Evaluation was by questionnaires and standard physical examination. In people over 45 years of age, additional radiographs were made. Of all the people studied the lifetime incidence of low back pain was 51 % in males and 58 % in females. The point prevalence of low back pain was 22 % and 30 % respectively, both increasing with age up to 55 and 65 respectively, and decreasing thereafter. Thirthy percent had suffered from low back pain for more than three months. In 85% recurrences occured. Disc prolapse, defined by clinical signs and symptoms, was found in 1.9% of the men and in 2.2 % of the women. Compared to other countries the lifetime incidence of low back pain is rather low and the point-prevalence is rather high (table 1.4).

Data on the prevalence and incidence of low back pain are retrieved from insurance and hospital resources and from prospective and retrospective clinical

studies.[9,23,32,33,34,40,58,62] From these data the impact of low back pain on a specific population can be estimated. The outcome, however, must be interpreted with caution for several reasons[1]: 1) since a global definition of back pain is lacking in/exclusion criteria vary; 2) differences in the consequences of low back pain largely reflect individual (working conditions) and social differences (worker's compensation programs); 3) back pain is often intermittent resulting in false-positive as well as false-negative back pain observations in cross-sectional studies; 4) under-reporting often takes place in questionnaire data, illustrated by Svenson and Anderson[52,53] who showed that of the men who said they had never had back pain, one fourth in fact had been off work with that diagnosis.

Table 1.3 Lifetime incidence and point prevalence of low back pain in the Netherlands, related to age and sex (EPOZ 1975-1978). (Based on data from Valkenburg and Haanen[58])

	% according to age group							
	20	25	35	45	55	65	75	total %
Men (number in sample)	292	662	778	674	398	201	86	3091
Lifetime incidence*	51.7	50.6	53.8	53.0	53.8	41.8	32.6	51.3
Point prevalence**	19.5	20.7	23.5	23.0	26.6	17.0	15.2	22.2
Women (number in sample)	298	764	833	684	415	305	194	3493
Lifetime incidence*	46.0	56.1	61.1	64.9	60.0	52.7	46.4	57.8
Point prevalence**	23.6	26.0	31.4	32.6	34.4	33.4	28.4	30.2

* Lifetime incidence defined as: low back pain ever
** Point prevalence defined as: low back pain now

Table 1.4 Prevalence and lifetime incidence of low back pain in different countries.

Lifetime	Prevalence (%)		Study group				
incidence (%)	Point	1-month	N	Age	Sex	Country	References
62.6	12.0	-	449	30-60	M	Denmark	Biering-Sörensen[6]
61.4	15.2	-	479	30-60	F		
60.0	-	-	1193	25-59	M	Sweden	Hult[27]
48.8	-	-	692	15-72	F		Hirsch et al[26]
61	-	31	716	40-47	M		Svensson et al[53]
67	-	35	1640	38-64	F		
51.4	22.2	-	3091	20+	M	The Nether-	Valkenburg/Haanen[58]
57.8	30.2	-	3493	20+	F	lands	
-	18.0	-	1135	18-64	M	United States	Nagi et al[39]
					F		
69.9	-	-	1221	28-55	M		Frymoyer et al[16]

Impairment and disability

Back pain is an impairment, which can give rise to functional limitations, disability or even to a handicap. The World Health Organization (WHO) has defined impairment as "any loss or abnormality of psychological, physiological, or anatomical structure or function" (1980). Body injury may result in impairment. Disability is defined as "any restriction or lack of the ability to perform an activity in the manner or within the range considered normal resulting from an "impairment". The definition for a handicap is "a disadvantage for a given individual, resulting from an impairment or a disability, that limits or prevents the fulfillment overall that is normal (depending on age, sex, and social and cultural factors) for that individual (WHO 1980). The concept of disability includes the presence of illness, reduced capacity to function, actual reduction in functioning, and handicap. The relation between impairment and disability rates is not necessarily linear, as pointed out by Haber[24] (see table 1.5). For example, although the impairment rate for heart trouble is less than half the impairment rates for arthritis and rheumatism, the disability rates for the conditions are similar. Reports on back and spine impairments are high, but the disability rates are less impressive and less than one tenth of the impaired are severely disabled and handicapped. This has probably to do with the fact that many people will experience low back pain in their lives, usually of short duration followed by a brief interval of restricted activity. Only a small percentage will have persisting low back pain leading to health care consumption, inability to work, and eventually to a disability status.[13] Haber[24] also pointed out that selective factors in the distribution of the disorder in the population (age, work, and educational level) could influence the disabling potential of the impairment.

Table 1.5 Morbidity and disability from selected conditions in Great Britain (rates per 1.000 persons).[24]

	Impairment	Disability	
Condition		All grades	Severe
arthritis and rheumatism	79	21	7
back and spine impairments	52	18	4
heart trouble	29	20	7
high blood pressure	47	9	4

In 1992, Nachemson[37] reported on the international incidence of disabling low back pain. Table 1.6 is partially based on his data. Nachemson emphasizes the influence of insurance factors on the disability of low back pain. The patient, believing that the back pain is work-related, will seek remuneration. This process will take quite some time, and, meanwhile, the patient will adapt to the sick role resulting in pain behavior.

Table 1.6 International comparison of the yearly incidence of disabling low back pain, based on data from Nachemson.[37]

Country	Inhabitants (millions)	% sicklisted with back diagnosis*	Average days of absence**
USA	240	2	9
Canada	23	2	20
Great Britain	55	2	30
West Germany	61	4	10
The Netherlands	14	4	25
Sweden			
1980	8	3	25
1983	8	5	30
1987	8.5	8	40

* % of workforce sicklisted with back diagnosis per year;
** average number of days of back pain-related absence per patient per year.

Social-economic consequences

In the United States, low back pain is the most expensive health care problem in the 20-50 year old age group and the most common cause of disability in the population less than 45 years old.[15,24] The major costs of back pain are associated with people suffering chronic disabling low back pain. Approximately 5.2 million persons are disabled by low back pain, 50 % of them permanently.[22,46] The total estimated costs attributed to low back pain in the United States are between $16-$50 billion and at least 85 % of these costs is related to recurrent or chronic disability (1986).[2,17,48,51] Low back pain is, when compared with other health conditions, also costly in terms of earning losses, productivity losses, and debility costs.[10]

Van Tulder et al.[57] estimated the costs of back pain to society in The Netherlands to be 1.7 % of the gross national product (GNP) in 1991. The total direct medical costs were estimated at $367.6 million and the total indirect costs (result from productivity losses) for the entire labor force at $4.6 billion.

The natural history of disabling low back pain

After an acute episode of idiopathic low back pain, data reflecting functional return reveal an excellent prognosis (see figure 1.2).[37] Within four weeks from the onset of the low back symptoms, 50 % of the patients will return to work and after six weeks 90% is working again. Little can be done, in way of treatment, to alter this course. Only 5 % of the low back pain sufferers will be disabled for over three months, 2-3% for over six months and about 1% will experience disabling low back pain for over a year. Some factors are known to complicate the natural course and include sciatica, certain radiographic findings, and a variety of social, psychological, and economic conditions.[63] In a prospective cohort study on low back pain in the Netherlands by Van den Hoogen et al.[61] (1997), similar results are reported. However, 10% of the patients still experience back pain after one year.

Attacks of low back pain recur rather frequently but they may not be so severe as the first attack. Normally, recurrences are less common during the third year than during the

first two. This perhaps demonstrates a tendency of low back pain to last for a couple of years but then to subside.[56]

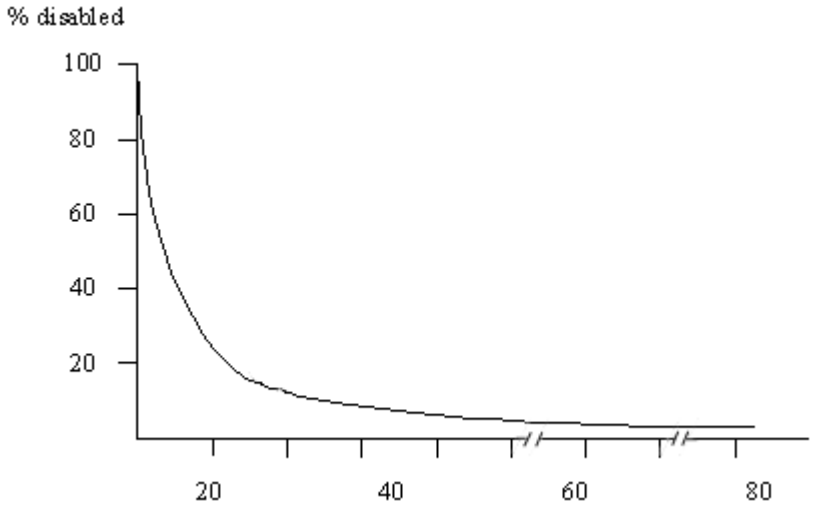


Figure 1.2 Timecourse of disabling low back pain.[3]

Risk factors

Age
A study by Biering-Sörensen[6] indicates an increasing risk of low back pain with age until the fifth decade of life. Thereafter, the relative risk decreases in men but not in women. In the study by Valkenburg and Haanen[58], a similar course can be seen in men but a decrease in the prevalence of low back pain can not be noticed in women until after the age of 65 (see table 1.3 again). A study by Svensson[54] also shows an increasing risk of low back pain until the age of 64 in women. A hypothesis for the later decrease in the prevalence in women is that the high prevalence of osteoporosis in women after the menopause makes them more susceptible for low back pain. The risk of disc herniation at the L4-L5 and L5-S1 levels also increases until the fifth decade, followed by a decrease.[47] The relative risk of disk herniation at the L2-L3 and L3-L4 levels is greater in people over 50 years old.[47]

Sex
Cross-sectional studies show little or no differences in the relative risk of low back pain between the sexes until the fifth decade of life.[16] Thereafter the risk is greater in women (osteoporosis, see *Age*).[6,47,54,58] However, for uncertain reasons, the disability risk of low back symptoms and the risk of hospitalization for disc herniation are greater in men than in women.[24,29] Socioeconomic factors rather than biologic differences appear to be responsible for this phenomenon.

Pregnancy
Low back pain is also common during pregnancy[3] and the relative risk ratio is approximately 3 to 1 in multiparous versus nulliparous.[14]

Hereditary factors

Until now, there is some evidence that low back pain has a genetic component.[15] Some researches[12,31,60] found a significant increase in the prevalence of disc herniation in the first-degree relatives of patients with disc herniation. A case-control study by Simmons[45] shows a familial predisposition for degenerative disc disease. Furthermore, in a recent study of Annunen et al.[4] examining the COL9A2-gene, which codes for one of the polypeptide chains of collagen IX, an allele of this gene was identified that is associated with intervertebral disc disease. The intervertebral disc contains small amounts of collagen IX. This collagen is thought to serve as a bridge between collagens and noncollagenous proteins in discs. The analysis identified a putative disease causing sequence variation in an allele of COL9A2 that converts a codon for glutamine to one for tryptophan. The tryptophan allele was correlated with the disease fenotype and found in the families studied with low back pain. A genetic antecedent is also present in specific but rare conditions associated with low back pain like congenital spondylolisthesis, Scheuermann's disease and achondroplasia.

Body weight/height/physical fitness
Some studies indicate that body weight and height are related to the prevalence and incidence of low back pain while others do not find such a correlation.[12,42] Lots of attention has been paid to physical fitness and sports in relation to low back pain and it is thought that low back pain is more common in the physically unfit.[15,17,29,54]

Smoking
The relation between smoking and low back pain has been described by several investigators[8,17,55] and many explanations have been postulated such as: 1) coughing from smoking increases the internal abdominal pressure and the intradiscal pressure and thus strains the spine[38]; 2) nicotine reduces vertebral body blood flow, disc nutrition will be reduced promoting disc degeneration[17]; 3) smoking may be associated with anxiety and depression, which exacerbate or prolong back pain.[11]

Occupation
Next to certain movements and actions related to work (bending, twisting, vibration, heavy lifting[15]), the psychosocial factors of work are also important in relation with low back pain.[7] Job satisfaction might be as important as the physical burden of labor itself in being free from low back pain. These psychosocial factors even become more important in the development of chronic low back pain.[18] However, it is not quite sure if the observed psychosocial difficulties either caused or resulted from the disability.

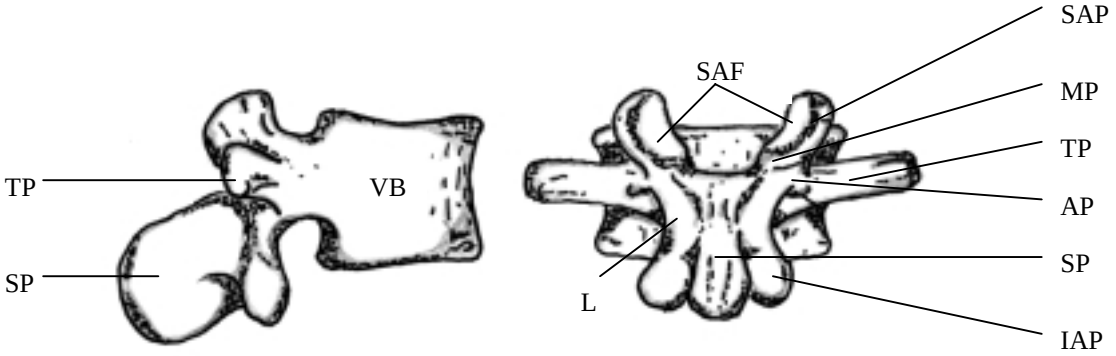
Concluding remarks
National statistics from the different European countries and from the United States indicate a (point) prevalence of low back pain in the 15-35% range. Although the natural history of low back pain shows an excellent recovery within weeks, approximately 1% of the low back pain patient will become chronically disabled. The socioeconomic consequences of this group of chronic disabled low back pain patients are enormous in terms of earning losses, productivity losses, and debility costs. Important risk factors for prolonged low back pain disability are psychological and psychosocial factors including work dissatisfaction.

1.3 CLINICAL ANATOMY OF THE LUMBAR SPINE

The spine can be considered as a multi-curved column, perfectly designed for its main functions: distribution of body forces, provision of flexibility for motion, and protection of the spinal cord.[20] The vertebral column consists of 33 vertebrae, of which, in the adult, nine are fused together to form the sacrum and coccyx. The sacrum is integrated into the pelvis in such a way that, normally, only little motion can occur in the sacro-iliacal joints (SI-joints). The 24 mobile vertebrae can be divided into 5 lumbar vertebrae, 12 thoracic vertebrae and 7 cervical vertebrae, joined together by intervertebral joints, intervertebral discs, and ligaments. The different structures of the spinal column each serve specific functions but, with respect to a single vertebral level, they all act together in a functional and anatomical unit called the "motion segment". The term, originally called "motor segment", was introduced by Junghanns[28,44] who suggested that, in order to understand and study the motion of the lumbosacral spine, all articular tissue, spinal muscles, and segmental contents of the vertebral canal and intervertebral foramen had to be combined in a single functional unit.[41] In the following, the different structures, their functions, and the functional motion segment of the lumbar region will be discussed.

The lumbar vertebrae

The lumbar vertebra can be divided into three functional parts: 1) the vertebral body; 2) the pedicles; 3) the posterior elements. The different parts have unique functions but they act together in the integrated function of the whole vertebra (figure 1.3).



AP – accessory process
IAP – inferior articular process
L – lamina
MP – maxillary process
P – pedicle
SAF – superior articular facet
SAP – superior articular process
SP – spinous process
TP – transverse process
RA – ring apophysis
VB – vertebral body

Figure 1.3 The lumbar vertebra.

The vertebral body

The vertebral body is a large block of bone, perfectly designed for its - longitudinally applied - weight-bearing purpose. Its internal structure consists of a cancellous cavity with vertical and transverse trabeculae surrounded by a layer of cortical bone. The main advantages of having the trabecular internal structure over a solid bone block is the lesser weight of the vertebra, the ability of sustaining static as well as dynamic loads, and the possibility of being well supplied by the arteries and veins running through the trabecular cavity. The trabecular cavity of the vertebral body filled with blood appears as a sponge and is therefore also known as spongiosa. Although the weight-bearing capacity of the vertebral bodies is enormous, the vertebral bodies can not resist sliding and twisting movement of the lumbar spine.

The pedicles

The pedicles function as a bridge between the vertebral body and the posterior elements. They transmit both tension and bending forces acting on the posterior elements of the vertebra to the vertebral body.

The posterior elements

The posterior elements of the vertebra consist of the articular processes, the spinous processes, and the laminae. The posterior elements are submitted to various forces acting on the vertebra. The inferior and superior articular processes, for example, resist forward sliding and twisting of the vertebral bodies. The spinous, transverse, accessory and mamillary processes are muscles-attachments and are therefore submitted to muscular forces acting on the vertebra. The laminae conduct forces from the spinous and articular processes to the vertebral body resulting in movement and providing stability. A specific part of the laminae at the junction of the vertically oriented lamina and the horizontally projecting pedicle, the pars interarticularis, is subjected to forces transmitted by the lamina into the pedicle. The laminae have, in addition to the conduction of forces, a protective function of the neural contents of the vertebral canal.

Intervertebral joints

Between two consecutive lumbar vertebrae, there are three joints: a joint between the vertebral bodies, and two joints between the articular processes (zygapophyseal joints or facet joints). Part of the interbody joint is the intervertebral disc, a layer of strong, deformable, soft tissue allowing load transfer and movement of the vertebrae in all directions. The structural and functional properties of the intervertebral disc will be discussed in detail below. The zygapophyseal joints are typical synovial joints, covered by articular cartilage, synovium, and enclosed by a fibrous capsule. The zygapophysial joints prevent forward displacement and rotary dislocation of the vertebrae. The extent to which a zygapophyseal joint can prevent movement strongly depends on the shape and position of the articular processes.

The intervertebral disc

The lumbar intervertebral discs consist of a central nucleus pulposus surrounded by an anulus fibrosus. A third component of the disc is the vertebral end-plate, which covers the top and bottom of the disc. The central fibers of the inner two-third of the anulus fibrosus attach directly to the cartilaginous end-plates and the peripheral fibers insert along the bony vertebral body margin (ring apophysis) as the so-called Sharpey's fibers (figure 1.4).

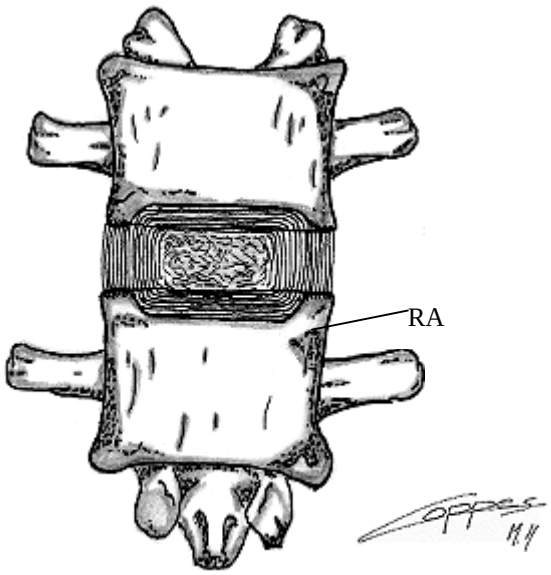


Figure 1.4 Detailed structure of the vertebral end-plate.
The collagen fibres of the inner two-thirds of the anulus fibrosus sweep around into the vertebral end-plate, forming its fibrocartilaginous component. The peripheral fibres of the anulus are anchored into the bone of the ring apophysis (RA).

The nucleus pulposus is an acellular meshwork of proteoglycan units, aggregates, and collagen fibers collectively called the nucleus matrix. The proteoglycans make up 65% of the dry weight of the nucleus, the collagen (predominantly type II) 15-20%. The proteoglycan units are formed by many glycosaminoglycans linked to a core protein. These proteoglycans contain water, the main component of the nucleus pulposus. The high water content of the nucleus pulposus (70-90%) is essential for maintaining its principle function: sustaining and transmitting weight. When the intervertebral disc is compressed, the pressure in the nucleus pulposus will increase resulting in deformation of the nucleus pulposus. The pressure is then exerted radially onto the anulus fibrosus. Subsequently, the tension in the anulus fibrosus will rise and this will prevent further radial expansion of the nucleus pulposus.

Water is also the main component of the anulus fibrosus (60-70%) but collagen (mainly type I) makes up 50-60% of the dry weight and only 20% of the dry anulus is proteoglycan. This high concentration of collagen thickens the anulus. Another difference between the nucleus and the anulus is the high concentration of elastic fibers in the anulus (10% of the dry weight). These elastic fibers are arranged circularly, obliquely and

vertically in the lamellae of the anulus and are predominantly located towards the attachment sites of the anulus on the vertebral end-plate. Because the collagen fibers of the anulus are elastic they can stretch and thereby retain energy. This energy can be exerted back onto the nucleus pulposus and restore its deformation.
The vertebral end-plates are also composed of water, proteoglycans, and collagen. The relative concentrations of the components in the end-plate are similar to that in the disc: high water and proteoglycan concentrations in the part of the end-plate adjacent to the nucleus; high water and high collagen concentrations in parts of the end-plate in contact with the anulus. Small molecules can therefore freely diffuse from the vertebral sinusoids to the avascular disc elements, important for nutritional needs. Once the tension in the annulus has increased after compression of the intervertebral disc, nuclear pressure is exerted on the end-plates by the anulus as well as by the nucleus. This pressure eventually transmits the load from one vertebra to the next.

Ligaments of the lumbar spine
In general, ligaments provide much of the joint-stability and limitation to the range of motion. The ligaments of the lumbar spine may be divided in those connecting:
1) the bodies of the vertebrae;
2) the laminae;
3) the spinous processes;
4) the articular processes;
5) the 5^{th} lumbar vertebra to the sacrum and ilium;
Finally, so called false ligaments are present.
Ligaments connecting the bodies of the vertebrae
The ligaments that interconnect the vertebral bodies are the *anterior longitudinal ligament* and the *posterior longitudinal ligament*. The two ligaments are strongly related with the *anuli fibrosi* of the intervertebral discs. During extension, the anterior longitudinal ligament resists anterior separation of the vertebrae, while the posterior longitudinal ligament prevents posterior separation during flexion. The anulus fibrosus resists distraction, bending, sliding, and twisting of the intervertebral joint during all kinds of motion.

Ligaments connecting the laminae
The *ligamentum flavum* is a short, thick ligament interposed between the laminae of two consecutive vertebrae. The ligaments consist of yellow elastic tissue and are therefore often called the yellow ligament. Its unique elastic properties are thought to be necessary for returning the flexed lumbar spine into the extended position and for preserving the upright posture.

Ligaments connecting the spinous processes
The interspinous ligaments connect two spinous processes. They limit forward bending by preventing supraphysiological separation of the two spinous processes. The supraspinous ligament interconnects the apices of the spinous processes. The supraspinous ligament is closely blended with the aponeurosis of the back muscles.

Ligaments connecting the articular processes
The capsular ligaments form the capsules of the zygapophysial joints (see *intervertebral joints*). They function as ligaments by preventing excessive motion of these joints.

The lumbo-sacral and ilio-lumbar ligaments

The *lumbo-sacral ligament* is short, thick, and triangular and connects the lower and front part of the transverse process of the fifth lumbar vertebra to the lateral part of the base of the sacrum. The *ilio-lumbar ligament* binds the transverse process of the fifth lumbar to the ilium. The ilio-lumbar ligament consists of five parts: anterior, superior, posterior, inferior, and vertical.

False ligaments

The lumbar spine contains some ligaments that can not be considered as "real" ligaments for several reasons such as structure and origin.[7] They include the *intertransverse ligaments*, the *transforaminal ligaments*, and the *mamillo-accessory ligament* (figure 1.5). The intertransverse ligaments are sheets of connective tissue connecting the upper border of one transverse process to the lower border of the transverse process above. They lack distinct borders, and the fibers are not densely packed nor are they oriented as fibers of true ligaments. The transforaminal ligaments are collagen fibers traversing the outer end of the intervertebral foramen, present in about 47% of the population.[21] They do not connect two bones and their structure resembles bands of fascia rather than ligament. The mamillo-accessory ligament connects the tip of the ipsilateral mamillary and accessory processes of each lumbar vertebra and its structure appears more like a tendon than a ligament.

ICL - inferior corporotransverse ligament
ITL - inferior transforaminal ligament
MAL - mamillo accessory ligament
MTL - middle transforaminal ligament
SCL - superior corporotransverse ligament
STL - superior transforaminal ligament

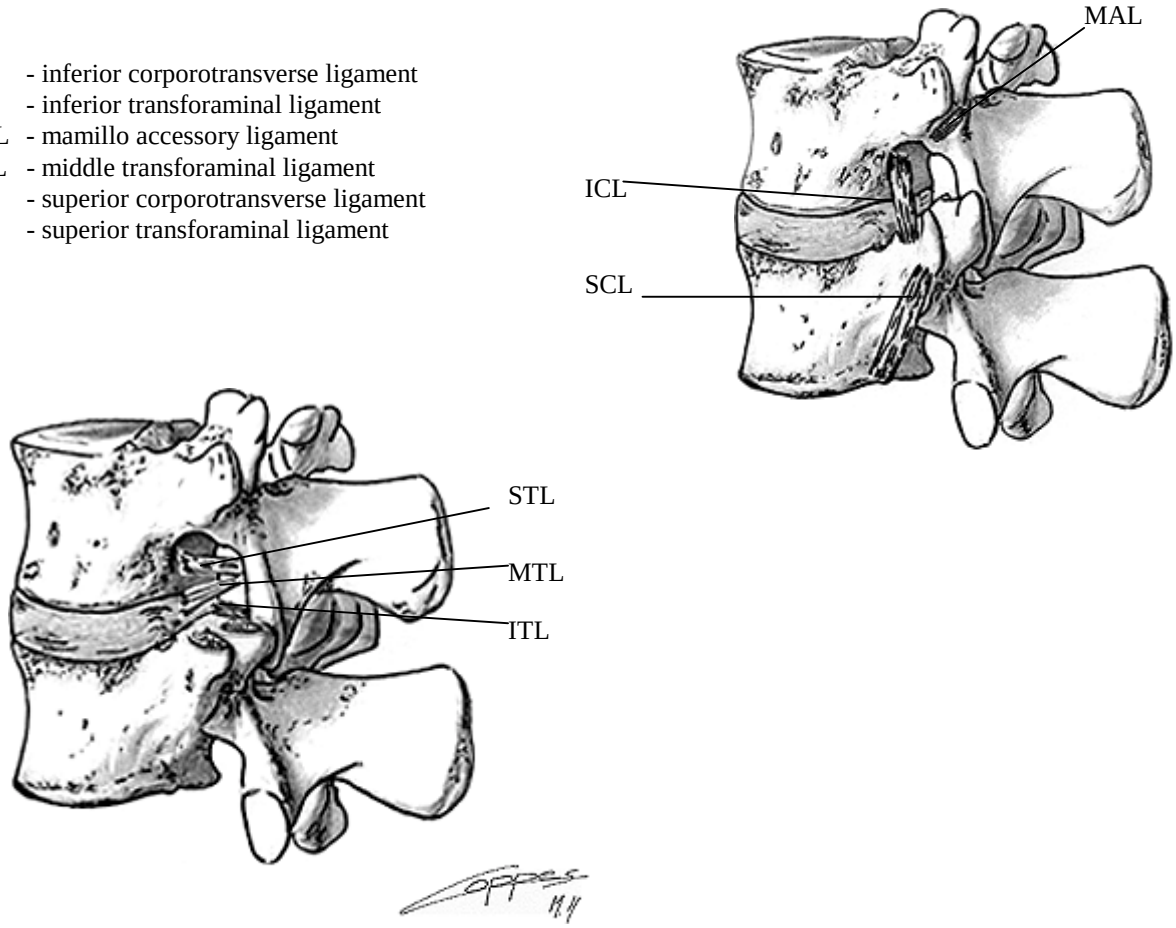


Figure 1.5 False ligaments.

The motion segment

As mentioned before, the motion segment can be considered as the basic functional unit of the spine (figure 1.6). The motion segment includes all articular tissue, the overlying spinal muscles, and the segmental contents of the vertebral canal and intervertebral foramen between two vertebrae and its concept is ideal for experimental studies. Although one motion segment relates two adjacent vertebrae exclusively, it must be considered as a link in a functional chain: the entire spine.[41] The motion segment is viscoelastic, absorbs energy, moves with six degrees of freedom (three translations and three rotations), exhibits coupled motion (motion in one direction affects motion in others), has limited fatigue tolerance, and depends upon its bony and ligamentous components for mechanical tasks.[43]

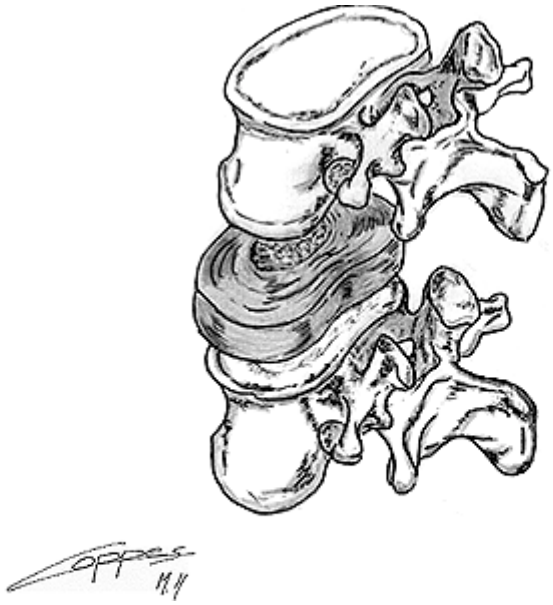


Figure 1.6 Motion segment, basic functional unit of the spine.

1.4 THE LUMBAR SPINE AND LOW BACK PAIN

Any structure of the lumbar spine that is connected to the nervous system can become a source of low back pain when affected by disease or disorder. The way in which the different structures of the lumbar spine are related to low back pain is discussed in Chapter 2. The specific role of the degenerated intervertebral disc in low back pain is discussed in Chapter 3. When certain structures of the lumbar spine are "identified" as a source of low back pain in individual patients, specific treatment can be attempted. In Chapter 5 we present the results of lumbar interbody fusion (Ch 4) in patients with severely disabling low back pain based on spinal degeneration.

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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, Loeser[48] 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.

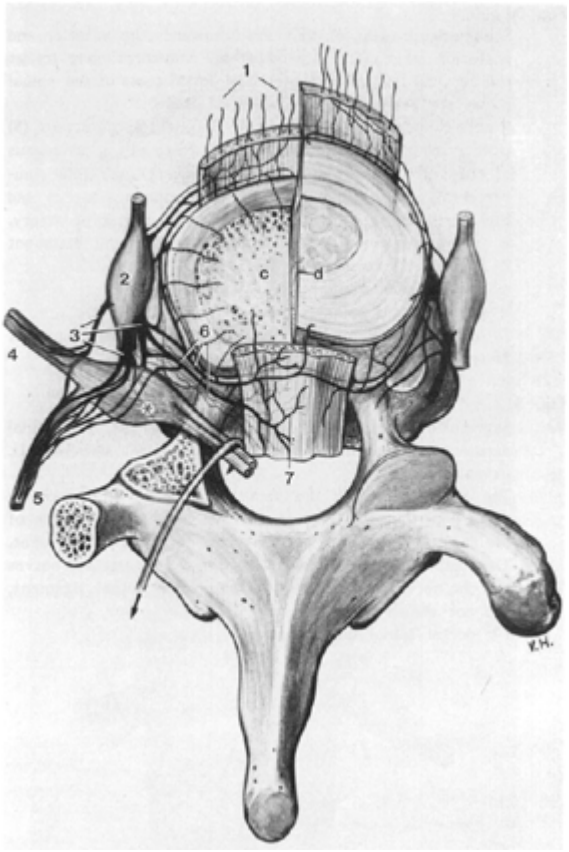
When an attending physician is confronted with a patient suffering from low back pain a combination of anatomical, physiological, and psychosocial factors underlies the patient's pain experience. To what extent each of these components attribute to the pain experience must be evaluated in the individual 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 posesses a nerve supply can become a source of pain when affected by pain-producing tissue damage.[7] 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[8,11,12], Edgar[19], Groen[31-33] and Hirsch[38], 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.[67]



1) nerve plexus of the anterior longitudinal ligament
2) sympathic trunk
3) rami communicantes
4) ventral ramus spinal nerve
5) dorsal ramus spinal nerve
6) sinuvertebral nerves
7) nerve plexus of the posterior longitudinal ligament

c) vertebral body
d) intervertebral disc

Figure 2.1 Schematic drawing of the innervation of the upper lumbar spine according to Groen.[32] (printed with permission)

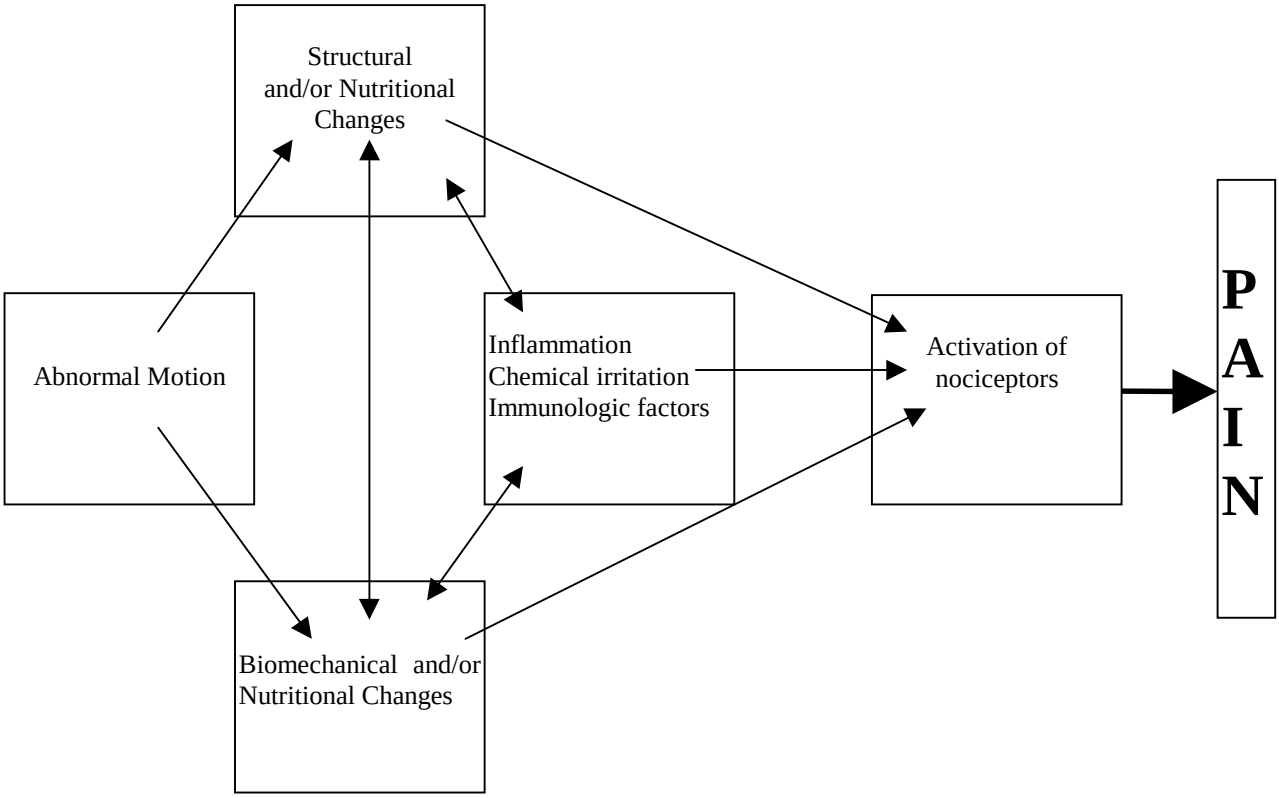


Figure 2.2 Possible mechanisms of low back pain.

Bogduk[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[27] or elicit pain by stretching the joint capsule.
According to Bogduk and Jull[9,10], 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[7]. 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.[7,52,54] 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.[22]

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, spinomesenchephalic tract, spinocervical tract, and the dorsal column.[43] 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.

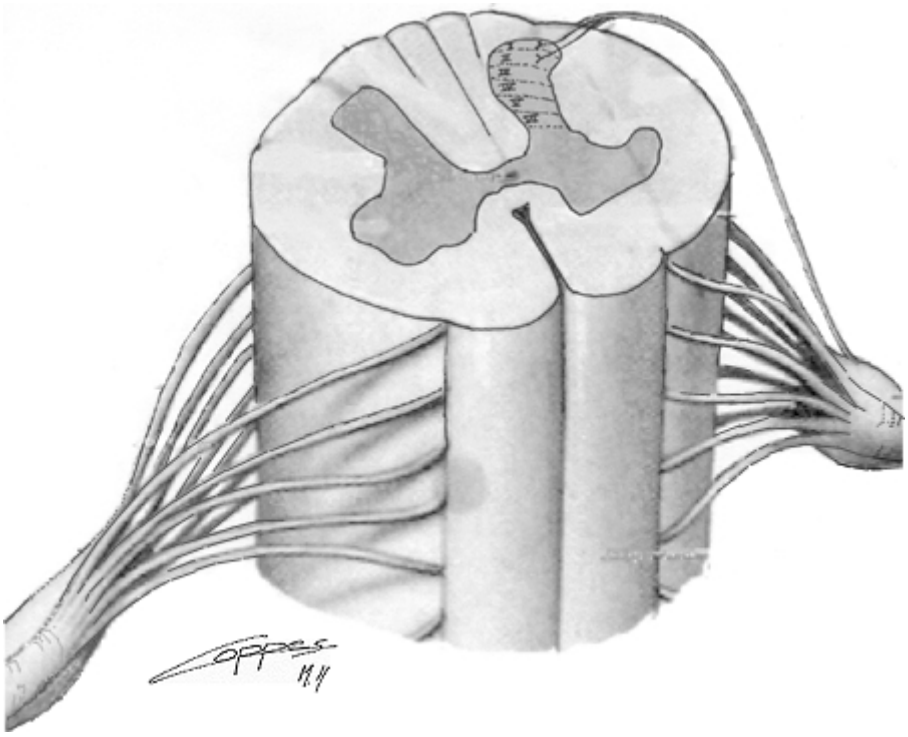
The noxious stimulus activates the nociceptor by depolarizing the membrane of the sensory ending, but the exact mechanisms by which the diverse stimuli depolarize the nerve endings and trigger an action potential are not known.[43] The nociceptors can be activated and sensitized by agents resulting from 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.[34,49] 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[43], 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.



I - lamina 1
II - lamina 2
III - lamina 3
IV - lamina 4
V - lamina 5
VI - lamina 6

Figure 2.3 Synapses of nociceptive fibers in dorsal horn of myelum (laminae according to Rexed[59]).

In the dorsal horn, chemical transmitters transmit the nociceptive signals. The Aδ 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.[42,66]

Of all these transmitters substance P has been studied most extensively. In 1931,Von Euler and Gaddum[20] discovered the polypeptide substance P (SP). Identification of its structure by Leeman et al.[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.[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.[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.[55] Furthermore, SP is present in only 10-20% of primary afferent fibers. The C- and Aδ 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 spinoreticular tract, the spinomesenchephalic 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.[14,16,29,56,65] Only in exceptional cases facet degeneration can occur without preceeding signs of disc degeneration.[64] In addition it has been reported that facet joint pathology may accelerate the degenerative process of the disc.[17,51,62]

The progress of spinal degeneration can be divided into three phases as suggested by Kirkaldy-Willis.[45] 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.[25,47] 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.

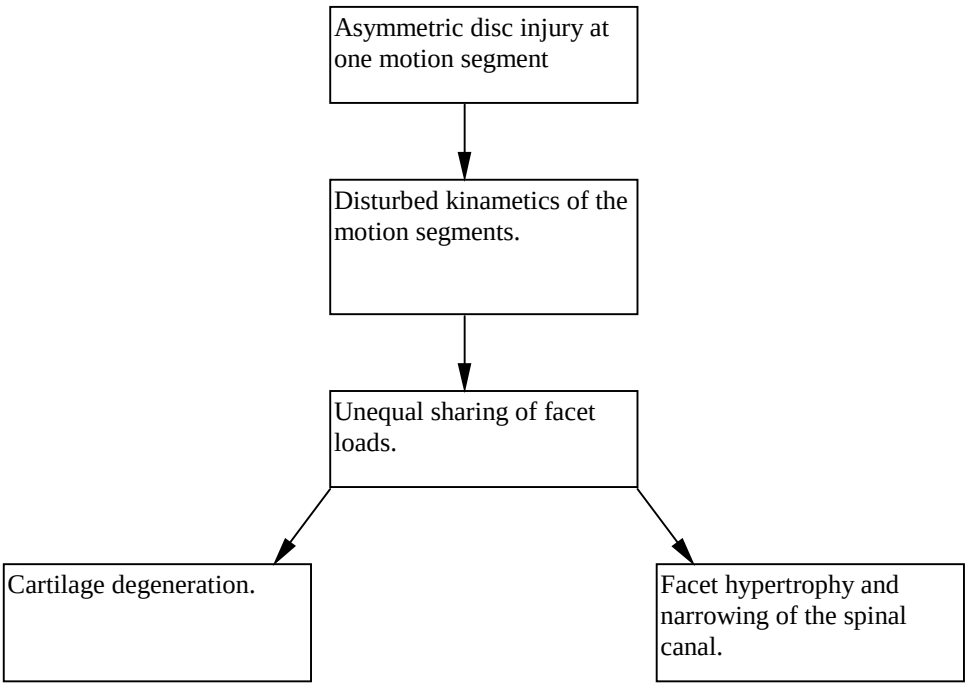


Figure 2.5 Consecutive steps of degeneration of the motion segment.

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.[24] Pain symptoms may result from their contribution in spinal stenosis.[16]

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.[5] 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.[5]

The trabeculae in the vertebral body change in size and pattern with aging and degeneration, resulting in decreased vertebral body strength and density.[2,60,63] Characteristic is the loss of horizontal trabeculae, particularly in the central part of the vertebral body.[2,63] 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.[60,68] Consequently, the vertebral body becomes less resistant to deformation and injury.

The end-plates may, partly due to lacking support of the underlying bone[35], develop microfractures which can accelerate the degenerative process and contribute to the occurence of low back pain.[24] Fractures of the end-plate may extend to a degree that allows nuclear material to extrude into the vertebral body, a fenomenon 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.[26]

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.

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CHAPTER 3

INNERVATION OF "PAINFUL" LUMBAR DISCS

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3.1 INTRODUCTION

The concept of primary discogenic pain, particular in the lumbar spine, is well accepted in the literature.[5,6,10,16,28,36,44,46,49] Damage to the intervertebral disc can produce pain, but no consensus exists on the responsible mechanisms. It seems unlikely that discogenic pain is merely generated by mechanical irritation of sensory nociceptive terminals. Chemical stimuli in a degenerated disc have been reported to play a substantial role as well. In this context, the observations of extremely high phospholipase A2 enzyme activity in herniated disc tissue are very interesting.[43] In addition, a wide variety of substances, with the ability to excite - or increase the excitability of - primary sensory neurons have been reported in the interstitial fluid of the disc. These include prostaglandin E, histamine-like substances, potassium ions, lactic acid, and several polypeptide amines.[6,33,36,49] In this respect, Weinstein et al.[49-52] emphasized the important role of the dorsal root ganglion, which is located in the intervertebral foramen and serves as warehouse for all kinds peptides. It is very likely that the dorsal root ganglion has a pain-modulating function around each motion segment.

Assessment of these data in combination with a thorough study of the anatomic pathways conducting discogenic pain seems indispensable for a better treatment of patients with low back pain.

By means of a whole-mount technique with acetylcholinesterase (AChE), a general neural marker,[3,12,13] it has been demonstrated that intervertebral discs are surrounded by a continuous network of interlacing nerve fibers. Ventrally, this network is constituted by the nerve plexus of the anterior longitudinal ligament and dorsally by the nerve plexus of the posterior longitudinal ligament. At the level of the intervertebral foramens, the anterior and posterior nerve plexuses are interconnected by branches directed medioventrally and mediodorsally, the rami communicantes, which overly the lateral border of the disc.[13] Contributions to the ventral nerve plexus are delivered by the sympathetic trunk, its rami communicantes, and the perivascular nerve plexus of segmental arteries. As early as 1850, Von Luschka had discovered that the dorsal nerve plexus is supplied by the sinuvertebral nerves.[48] Whether the sinuvertebral nerves are connected to both the spinal nerve and the sympathetic trunk or its rami communicantes, or are exclusively connected to the rami communicantes, has been discussed exclusively.[5,17,18,40,45,48,53] Although the ring of nerve fibers surrounding the intervertebral discs, including the sinuvertebral nerve, is exclusively related to structures generally considered as sympathetic, according to Groen et al.[13] this does not imply that these structures are fully sympathetic in function. Recent studies support this.[35,37] Most such nerves may have a sensory function. Furthermore the sympathetic nervous system can

interact with sensory C-fibers, sensitizing nociceptors, which in turn induce further sympathetic activity in the spinal cord.[1]
Classic histologic studies have shown the presence of nerve endings in the longitudinal ligaments and in the most superficial layers of the anulus fibrosus.[9,16,19,29,40,42] In some studies, the innervation of the disc was observed to extend as deep as the outer third of the annulus fibrosus.[5, 54] Most authors described the presence of free nerve endings in these tissues. More complex encapsulated endings were mentioned by Malinsky.[29]

Immunohistochemical studies have demonstrated the presence of small-diameter substance P (SP)-immunoreactive nerve fibers in the posterior longitudinal ligaments.[23,27] Furthermore, the presence of calcitonin gene-related peptide (CGRP)-, vasoactive intestinal peptide (VIP), and SP-immunoreactive nerve fibers has been reported in rat intervertebral discs, although restricted to their outer zone.[34] More recently, the same neuropeptides were identified in the anulus fibrosus of human intervertebral discs.[2] The longitudinal ligaments surrounding the intervertebral disc may act as a source of pain in view of their profuse innervation,[5,13,23] but, in addition, a direct nerve supply to the disc itself may be significant.

The literature thus provides conflicting data with respect to the presence of nerve fibers in the different parts of the human intervertebral discs.[2,5,6,29,54] This may be due to differences in innervation between normal and degenerated discs.

The current study was conducted to get a better understanding of the origin of primary discogenic pain in patients with severely degenerated lumbar discs. The innervation of intervertebral discs and adjacent anterior tissue was investigated by means of AChE histochemistry and neurofilament (NF90) immunohistochemistry. A possible nociceptive nature of nerve fibers was determined by SP immunocytochemistry. Preliminary results of this study have been published previously.[7,8]

3.2 MATERIALS AND METHODS

In 10 patients (age range, 24 - 51 years; mean age, 37.1 years; 6 women, 4 men), the anterior segments of one lower lumbar intervertebral disc (L3-L4, L4-L5, or L5-S1) were excised *en bloc* during anterior interbody fusion for chronic low back pain. The segments measured approximately 3×3 cm and consisted of anterior longitudinal ligament, anulus fibrosus, and nucleus pulposus tissue (Figure 3.1). All patients suffered from unremitting low back pain for several years (mean, 7 years) and had extensive disc degeneration confirmed discographically. On all operated levels an intense pain-related response had been provoked by intradiscal injection of Iopamidol (Dagra, Diemen, The Netherlands), a water-soluble, nonionic and inert contrast agent. Additional injection of 0.5 to 1 ml bupivacaine into the disc through the same needle relieved the pain for 1 to 4 hours. These discography-provocation tests were part of a prospective, protocolized study we are conducting for the selection of lumbar fusion candidates.

Two anterior disc segments were obtained during surgery for a spinal metastatic tumor in two patients (Table 3.1) and served as controls. All 12 discs were embedded in a sugar compound, Tissue Tek (Miles Laboratories, Elkhart, IN), and frozen in liquid nitrogen-cooled isobutanol.[31] Transverse cryostat sections (15 μm) were then obtained. The total number of sections obtained in every disc was 200 to 250. AChE enzyme histochemistry [21,32] and NF90 monoclonal, and in five cases also SP polyclonal immunocytochemistry (Cambridge Research Biochemicals, Northwick, Cheshire. U.K.) were performed on alternate, consecutive sections. The NF90 antibodies (Department of Physiology,

University of Leiden, Leiden, The Netherlands) are capable of detecting the phosphorylated low, medium, and high subunits.[39] For immunocytochemistry, the sections were rinsed three times in phosphate-buffered saline (pH 7.6) containing 0.1% bovine serum albumin (Sigma Chemical Company, St. Louis, Missouri), incubated overnight with the primary antisera NF (1/10,000, ascites) or SP (1/1,500) in moist chambers in phosphate-buffered saline containing 0.1% bovine serum albumin and normal goat serum (1/1000), rinsed again before incubation with the secondary, peroxidase-conjugated, antisera (DAKO, Copenhagen, Denmark) for 2 hours, and finally rinsed and incubated with the peroxidase enzyme. Controls were performed by omitting the first or second antibody for immunocytochemistry, by omitting the substrate, or by heating the section to 100 C to destroy enzyme activity I order to detect nonenzymatic localizations by the substrate or capture agent.

Figure 3.1 Disc segment obtained during anterior interbody fusion operation (patient C2810).

Table 3.1 Series of normal and degenerated discs.

Series	Gender	Level	Age (yr)	Type	AChE/ NF90	Substance P
C 2810	F	L4-L5	29	C	Y/Y	N
C 2918	M	L3-L4	51	C	Y/Y	N
C 2959	M	L4-L5	51	DD	Y/Y	N
C 3187	F	L5-S1	24	DD	Y/Y	N
C 3236	F	L5-S1	39	DD	Y/Y	N
C 3455	M	L4-L5	24	DD	Y/Y	N
C 3524	F	L4-L5	38	DD	Y/Y	N
C 3556	F	L4-L5	43	DD	Y/-	Y
C 3664	M	L5-S1	36	DD	Y/Y	Y
C 4030	F	L4-L5	33	DD	Y/Y	Y
C 4031	M	L5-S1	44	DD	Y/Y	Y
C 4035	F	L4-L5	39	DD	Y/Y	Y

AChE = acetylcholinesterase; NF90 = neurofilament; F = female; M = male; C = control disc; DD = degenerated disc; Y = staining performed; - = staining unsuccessful; N = staining not performed.

3.3 RESULTS

A variety of nerve fibers were found that, according to their diameters, could be grouped in various functional classes of nerve fibers (Table 3.2).

Perivascular small nerves

It was possible to recognize blood vessels on account of the endogenous blood-related peroxidase activity. Most vessels were surrounded by perivascular nerves, which contained both NF90-positive and AChE-positive fibers with a diameter of approximately 0.25 μm. These fibers were exclusively found in the anterior longitudinal ligament and the connective tissue in control discs as well as in degenerated discs. In the anulus fibrosus and nucleus pulposus, no blood vessels were found.

Myelinated bundles of nerve fibers

Myelinated bundles of nerve fibers (ACgE- and NF90-positive) were found in the ligament and the transitional area from ligament to anulus. In all control and degenerated discs, these thick, myelinated bundles were present. They penetrated only the most superficial layers of the anulus fibrosus and were composed of several fibers. The diameters of these bundles varied between 15 and 25 μm (Figure 3.2).

Small free nerve fibers

In all discs, degenerated as well as control, the anterior longitudinal ligament and the outer parts of the anulus fibrosus contained free nerve fibers (AChE- and NF90-positive) with a diameter ranging between 0.25 and 2.5 μm (Figure 3.3). Several of these small free nerve fibers were clustered together in the more superficial layers of the anulus, becoming solitary as they traveled inward.

In 8 of 10 degenerated discs (C 3187, C 3236, C 3455, C 3524, C 3556, C 4031, and C 4035), solitary free nerve fibers of this diameter could be found in the inner areas of the disc - namely, deeper than the outer third of the anulus fibrosus.

In two of these degenerated discs (C 3455, and C 4035), free nerve fibers with a diameter of 0.25 μm were discernible in the periphery of the nucleus pulposus as well (Figure 3.4).

In two discs (C 3455, and C 3556), fine solitary fibers with a varicose-like appearance and of a caliber below 1 μm were abundant in parts of the anterior longitudinal ligament; they lacked a network-like configuration, however.

Mechanoreceptors

Receptors with the morphology of Pacinian corpuscles and Golgi tendon organs were detected in four degenerated discs (C 3187, C 3236, C 3455, and C 3524; Figure 3.5). They were seen laterally and medially in the connective tissue between the anulus fibrosus

and the anterior longitudinal ligament or in the interlamellar spaces at the periphery of the anulus fibrosis. The smallest diameter of both mechanoreceptors was 20 μm and their length exceeded 230 μm, whereas the orientation of the longitudinal axis of these receptors was generally parallel to the direction of the anular fibers. Pacician corpuscles had large perineural capsules consisting of several layers. The NF90- and AChE-positive fibers had a diameter of 2.5 to 3.5 μm at the entrance of the central part f the Pacinian-like endings. The Golgi tendon organs were in general cylindric with or without a thin capsule.

Substance P-positive fibers

In all five discs that had been immunocytochemically stained for SP (C3556, C3664, C4030, C4031, and C4035), positive fibers were present, although sporadically (Figure 3.6). SP-positive axons were always single and detected only in the anterior longitudinal ligament as well as in the outer zone of the anulus fibrosus. Their diameter ranged from 0.25 to 2.5 μm. No SP reactivity was noted in perivascular endings.

Unspecific and specific staining reactivity

Omitting the substrate for AChE gave negative results in the ligament, anulus, and nucleus. Immunocytochemical controls showed absence of the diaminobenzidine reaction product if the first or second antibody was omitted. Because endogenous peroxidase activity was found in larger blood vessels on the surface of the anterior longitudinal ligament, in the normal procedures it was inhibited by 3% H_2O_2 before incubation. In the anulus fibrosus and nucleus pulposus, aspecific staining was sometimes found at cracks and edges.

Table 3.2 Survey of nerve structures present in the various parts of the intervertebral disc.

	Perivascular small nerves		Myelinated large-caliber		Small free nerve fibers		Mechano-receptors	
	C	DD	C	DD	C	DD	C	DD
ALL	+	+	+	+	+	+	-	-
Transitional zone between ALL and AF	+	+	+	+	+	+	-	+ (4/10)
Outer zone AF (outer 1/3)	-	-	+	+	+	+	-	+ (1/10)
Inner zone AF (inner 2/3)	-	-	-	-	-	+ (8/10)	-	-
Nucleus pulposus	-	-	-	-	-	+ (2/10)	-	-

C = control discs (n = 2); DD = Degenerated discs (n = 10); + = presence of nerve fibers; - = absence of nerve fibers; ALL = anterior longitudinal ligament; AF = anulus fibrosus; 1/10, 2/10, 4/10, 8/10 = 1, 2, 4, or 8 of 10 discs (if ratio is not given, it means the finding is seen in all discs).

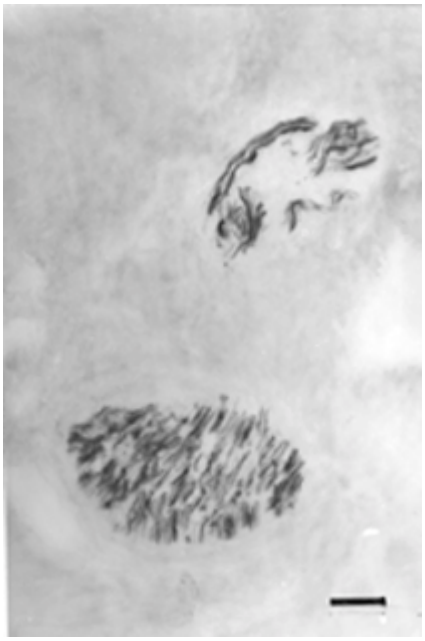
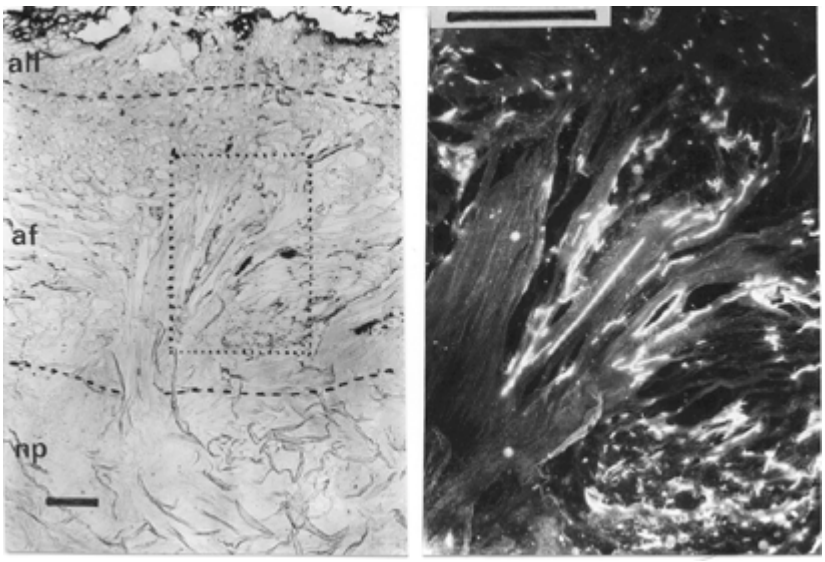


Figure 3.2 Myelinated bundles of nerve fibers in the outer zone of the anulus fibrosus. (Neurofilament (NF90) staining; bar = 5 µm.)



A B

Figure 3.3 Overview of a part of the disc, acetylcholinesterase (AchE) staining. Top contains the anterior longitudinal ligament (all), bottom reaches into the nucleus pulposus (np). **A,** AchE staining. Dotted lines indicate border between the anulus fibrosus (af), the all, and the np. B, Dark-field detail of the central of (**A**) (dotted rectangle), demostrating the ingrowth of nerve fibers in an anular cleft. The nerve fibers appear as white strands in the center of the figure. Bar = 2 µm.)

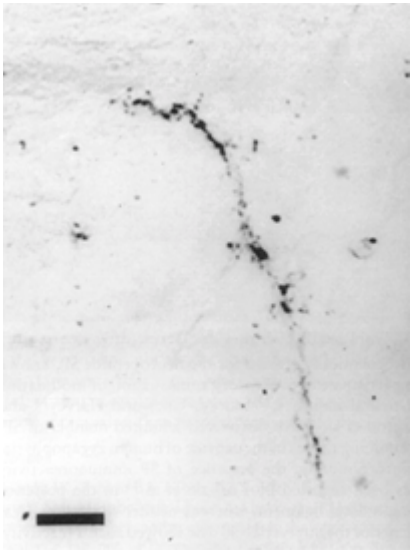


Figure 3.4 Neurofilament-positive fiber localized in the outer part of the nucleus pulposus. (Bar = 2 µm.)

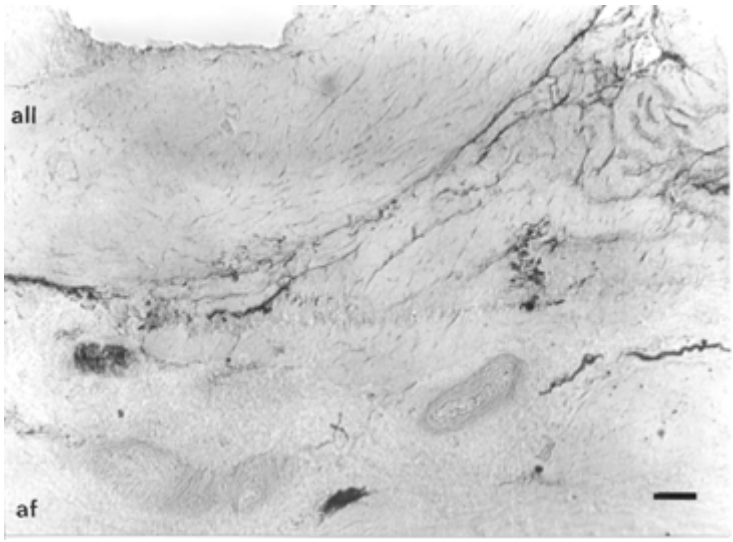


Figure 3.5 Mechanoreceptors immunoreactive to neurofilament (NF90) located between the anterior longitudinal ligament (all) and first lamella of the anulus fibrosus (af). g = Golgi tendon organ; p = Pacinian corpuscle. (Bar = 20 µm.)

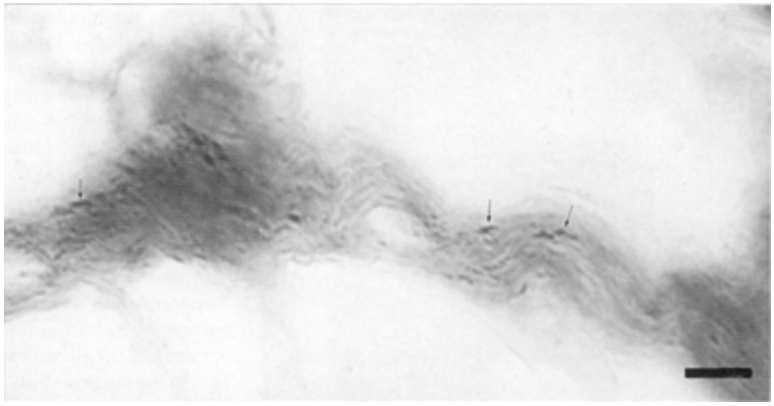


Figure 3.6 Substance P-immunoreactive fibers (arrows) in the outer zone of the anulus fibrosus. (Bar = 5 µm.)

3.4 DISCUSSION

The nerve supply of the intervertebral disc has been the subject of several studies using a variety of disc materials.[2,5,6,9,13,15,19,20,29,34,40-42,45,53,54] These materials were derived from either animal or human species and were of fetal or adult origin.

Because of this wide variety of material it is difficult to draw general conclusions. Yet, a common finding in all the studies on nondegenerated discs is that the innervation of the lumbar disc remains restricted to the outer layers of the anulus fibrosus. There are indications, however, that disc degeneration and perhaps disc injury are associated with centripetal growth of nerve fibers in the disc, which would provide a morphologic basis for true discogenic pain. However the responsible mechanism for the penetration of neural structures deeper into the disc is still poorly understood.

Yoshizawa et al.[54] investigated the innervation of the intervertebral disc in patients with low back pain using anterior sectors of lumbar discs obtained during fusion operations. It was not possible, however, to demonstrate nerve fibers in the inner half of the annulus fibrosus by means of the silver-impregnation method.

In the current study, we investigated “painful” degenerated discs obtained from patients with chronic low back pain. Therefore, a selection was made with regard to both the patient and the disc. The latter involved two inclusion criteria. In the first place, the disc had to be severely degenerated, as shown by discography, and second, injection of fluid into the nucleus pulposus had to provoke a temporary severe increase of their chronic pain. Eight of 10 degenerated discs selected in this way proved to contain nerve fibers throughout various layers of the anulus fibrosus, invading deeper than the outer third of the anulus. The control discs showed innervation only in the outer parts of the disc.

Comparison between AChE and NF90 immunocytochemistry, which both stain specifically for neural tissue, reveals a difference in sensitivity. The NF90 antibody detects only phosphorylated neurofilaments, missing nonphosphorylated ones. Therefore, fewer positive fibers are observed when NF90 is used instead of AChE staining.

However, use of NF90 antibodies provides better recognition of the fine axon structure within a nerve bundle. This can be explained by the presence of AChE activity not only in the axon but in the myelin sheat,[25,26] by which a sharp delineation of the axonal structure is blurred. In the outer anulus zone, thick, myelinated bundles, single fibers, and mechanoreceptors were found. The latter were present in the loose connective tissue between the anterior longitudinal ligament and the anulus fibrosus, and between the outer layers of the anulus proper.

Mechanoreceptors resembling the morphology described for Pacinian corpuscles and Ruffini endings have been considered responsible for proprioception,[29,49] and they may be involved in maintaining muscle tone and in the reflex response.[41] A nociceptive function has been assigned to structures resembling Golgi tendon organs.[41]

Malinsky[29] reported mechanoreceptors in the lateral, ventrolateral, and dorsolateral regions of the disc surface. In addition, we found these receptors in the ventromedial region. In a recent study, Roberts et al.[41] reported the presence of mechanoreceptors in 50% of discs investigated from patients with low back pain and in only 15% of those from pain-free patients with scoliosis. These findings are comparable with those in the current study. Mechanoreceptors could be found in 4 of 10 clinically pathologic and "painful" discs, but in neither of the 2 control discs.

Normally, the adult human disc is avascular. Angiogenesis associated with disc disorders is not an uncommon finding, however. Experimental studies have shown that anular lesions heal by the formation of granulation tissue containing blood vessels.[38] In experimentally injured porcine intervertebral discs, Kääpä et al.[20] even found a dense network of capillaries in the healed anular area 2 weeks to 2 moths after operation. Vascularization of the inner parts of the disc has also been reported in degenerated discs.[47] In the current study, blood vessels were found only in the anterior longitudinal ligaments. They possessed a perivascular nerve network with probably a vasomotor or vasosensory function.

To determine the possible nociceptive action of the small-caliber (Aδ and C) fibers, sections were immunohistochemically stained for the neuropeptide SP, known to participate in the sensory transmission or modulation of neural impulses.[15] Indeed, Giles and Harvey[11] and Ashton et al.[1] have discovered a limited number of SP-containing nerves in the capsule of human zygapophysial joints. Similarly, the presence of SP immunoreactivity has been reported by Korkala et al.[23] in the posterior longitudinal ligament, whereas neither the yellow ligament nor the intervertebral disc showed such a reactivity. In their material, SP-immunoreactive nerves were always found running freely in the stroma but not in the vicinity of blood vessels, although this peptide is known to act as a vasodilator in other tissues.[1,4,24] In the rat, SP, CGRP, and VIP have been identified in the outer anular fibers and supraspinous and intraspinous ligaments,[34,49] but their detection in human discs has proven difficult, as yet.[11,22,23,27] More recently, SP, CGRP, and VIP immunoreactivity was demonstrated in the outer 3 mm of the anulus fibrosus of human intervertebral discs.[2]

Our results relating the detection of SP are in agreement with those of Ashton et al.[2] In the current study, SP staining in clinically "painful" discs showed a very small amount of superficially localized SP-positive fibers, in contrast to greater abundance of AChE- and NF90-positive fibers in the same disc. McCarthy et al.[34] recommended using CGRP instead of SP because the former is more ubiquitous in the investigated nerve cells. In our opinion, however, a marked difference in the abundance of nerves immunoreactive for peptide markers of sensory nerves (e.g., CGRP and SP) or autonomic nerves (e.g., VIP) should not be considered as the most reliable method for assessing the real extent of

sensory fibers because not all the nerve fibers present would show positive staining. Therefore, the presence, but not the absence, of these markers is conclusive for the interpretation of sensory innervation.

To explain the relative lack of detectable SP immunoreactivity, it may be postulated that as with inflamed joints, a “painful” disc contains a larger amount of neurotransmitters. It has been reported that, on account of an increased local release of neurotransmitters, a weaker neuropeptide staining is found in synovium from inflamed joints with respect to normal synovium.[14,30] Thus, it is tempting to state that there is a possibility that the local release of neurotransmitters is greatest in the more degenerated central parts of these discs, leading to a weaker staining for SP immunoreactivity. Finally, the direct processing of the tissue, without prior fixation, may have contributed to the relatively weak detection of SP-immunoreactive fibers.

The relation between painful discs, neurotransmitter distribution, and neuropeptide staining needs further elaboration.

In conclusion, the data presented in this study support a neuroanatomic substrate for discogenic pain perception in patients with severely degenerated discs. However, this report does not allow conclusions to be drawn on the statements that nondegenerated discs have a less extensive innervation than painful, degenerated discs.

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CHAPTER 4

INTERBODY FUSION FOR CHRONIC LOW BACK PAIN

Throughout the medical history fusion operations have been performed in order to immobilize painful joints. Pain of musculoskeletal origin arises from complex neural networks when damaging stimulants such as chemical irritants, heat, and mechanical stresses stimulate peripheral nociceptors. With respect to pain arising from the degenerated lumbar spine, motion, particularly if abnormal in character or degree, often is a potent stimulus to peripheral nociception. Temporary prevention of excessive movements by rest or immobilizing external casts may result in pain relief. When instability or spinal deformities are the cause of pathologic motion, a more permanent correction, and therefore elimination of nociception stimulation, can be achieved by spinal fusion. So, the aim of fusing one or more spinal segments is to stabilize the spine, correct the deformity, and to eliminate painful movement, thereby restoring skeletal alignment, relieving pain, and preventing recurrence. Based on these principles arthrodesis has been applied to the management of painful spinal segments.

4.1 HISTORICAL REVIEW OF SPINAL FUSION

Hibbs[36] and Albee[5] were the first to report clinical results of spinal fusion in 1911. Independently they reported on a novel surgical technique for the treatment of Pott's disease (spondylitis tuberculosa). Hibbs had noticed that the patella became secondarely integrated in the ankylosis after surgical arthrodesis of the knee. He also observed the spontaneous ankylosis of the infected spine and reasoned that surgical acceleration of this process might result in more rapid and reliable consolidation. In order to induce spinal fusion, Hibbs bridged the interlaminar spaces using the spinous processes, a technique that became known as posterior interlaminar fusion. Albee, on the other hand, inserted a tibial graft into the spinous processes in order to provide an internal splint and hasten stabilization of the spine. Although posterior hardware fixation devices (wires and steel bars) had already been described by Hadra[29] and Lange[44], no type of internal fixation was used in these early reports. In 1924, Hibbs reported a fusion method in patients with scoliosis[37] which was quite different from the one publicated in 1911. In this technique, nowadays referred to as the classic Hibbs method of spinal fusion, a posterolateral approach was used allowing a larger area for bone grafting and fusion than the aforementioned posterior interlaminar fusion. All methods of spinal fusion in which fragments of bone are elevated from the laminae and spinous processes and are turned up and down in a transposed manner, are virtually modifications of this technique.[52] In 1929, the first studies on the outcome of lumbosacral fusions performed for degenerative conditions of the spine were reported by Hibbs and Swift.[38] Later, in 1943, Howorth[40] published results of spinal fusion for ruptured lumbar intervertebral discs. It is interesting to note that the development of spinal fusion techniques predates the understanding and surgical treatment of lumbar disc herniation. By 1933, when Mixter and Barr[51] presented

their treatise on disc herniation to the New England Surgical Society, there was a 20-year experience with spinal fusion.

Surgical techniques have markedly changed over the years in an attempt to provide better correction of the deformities, enhance stabilization, and increase the rate of bony consolidation. The evolved fusion techniques can generally be divided into posterior, posterolateral, and anterior approaches. Posterior spinal fusion, such as described by Hibbs and Albee in 1911, is by definition posterior to the pedicles. Unfortunately, this initial technique proved to be biomechanically insufficient and did not allow the use of extensive posterior decompressive procedures. Other techniques were therefore developed by Hibbs himself as well as by others. In 1939, Campbell[12] described posterolateral fusion of the lumbosacral spine in association with sacroiliac fusion. Subsequently, many others[4,8,9,14,48,66] have described various posterolateral fusions techniques (transverse process fusions), but the principle of solid lateral intertransverse fusion remained the same.[70] In comparison with the initial posterior fusion, these procedures yealded superior fusion results and enabled the combination with decompressive procedures and posterior instrumentation.[30]

Cloward was not satisfied with the posterior type of spinal fusion after removal of the herniated disc fragment. The bridging with a graft of the spinous processes and laminae, which are non-weight-bearing surfaces, of one single vertebral segment did not seem physiologically appropriate. He therefore developed a technique which on the one hand restored the height of the intervertebral space and on the other hand immobilized the adjacent vertebral bodies.[16] In this posterior lumbar interbody fusion (PLIF) technique, the bodies (main weight-baring part of the vertebra) become fused by a strong intervertebral graft wedged into the interspace at the site of the ruptured disc. He started his procedure in 1943, and over the years he has reported on more than 1,300 cases treated by PLIF.[6] His fusion and long-term clinical succes rates of both over 90% turned out to be hard to equal by others, who published results varying from 40% up to 95%[60]. Cloward himself reviewed the topic in 1985[15], stating strongly once again that with the PLIF technique good fusion and clinical results can be obtained.

Before the posterior technique was introduced, the spine had already been approached anteriorly by Muller in 1906 for treatment of tuberculosis of the spine.[39] However, the first report on anterior lumbar spinal fusion was not until 1932 by Capener[28], followed by Burns[10] in 1933 who used a tibial graft to transfix L5 to S1 in a 14 year old boy with spondylolisthesis. Modification and variations were then described,[18,23,35,49,59] and in 1948, Lane and Moore[43] were the first to use anterior interbody fusion specifically for discopathies. The fusion as well as clinical results of anterior lumbar spinal fusion (ALIF) varied from less than 20% up to more than 95%,[19,25,26,34,61] comparable to the PLIF results.

As part of the evolution of surgical techniques, internal fixation devices have been developed in order to accomplish greater correction of deformation, enhance stabilization, increase rate and degree of bone consolidation, and reduce the rate of pseudoarthrosis.[27] The introduction of posterior hooks and rods by Harrington in 1962[33] initiated modern posterior internal fixation of the spine. Improvement of the Harrington distraction and compression rod system resulted, among others, in the Luque method of sublaminar wire fixation and the Wisconsin system of fixation with spinous process wires.[58] Next to these methods other devices like pedicle screw systems[41,47,67,69] have been developed in such a way that, nowadays, the spine surgeon has a wide variety of spinal devices in his armamentarium. The question remains how and when to use these different forms of hardware.

4.2 RATES OF SPINAL FUSION

Individual beliefs and style of practice are very important in deciding whether or not to perform spinal fusion, especially in patients with degenerative spinal disorders. Inconsistency regarding the appropriate indication for spinal fusion in this major group of potential spinal fusion candidates may therefore create geographic differences in reported fusion rates (table 4.1).[13,42] These differences in fusion rates are small compared to the differences in the overall back surgery rates in which herniated disc operations are included (table 4.2).

Table 4.1 Rate of lumbar spinal fusion operations for degenerative spine conditions in different countries (number per 100.000 inhabitants).*

	1992	1994	1996	1998
France	15.0	16.6	18.3	20.2
Germany	12.6	13.9	15.3	16.9
Austria	12.9	14.3	15.8	17.4
Spain	4.2	4.6	5.1	5.6
Italy	2.5	2.7	3.1	3.4
Belgium	10.0	11.0	12.2	13.4
The Netherlands	8.8	9.7	10.6	11.7
Denmark	7.0	7.8	8.6	9.4
Norway	8.5	9.4	10.3	11.4
Sweden	8.4	9.3	10.2	11.3
Finland	7.3	8.0	8.9	9.8
Great Britain	9.0	9.9	10.9	12.0
Ireland	9.5	10.5	11.6	12.8
Greece	1.7	1.9	2.0	2.3
Turkey	0.3	0.3	0.4	0.4
South Africa	8.8	9.6	10.7	11.7
Israel	3.0	3.3	3.7	4.1
Portugal	4.1	4.5	4.9	5.5
USA[42]	30.9	-	-	-
Switzerland	4.8	5.3	5.8	6.4
Total	7.7	8.5	9.4	10.3

* Data obtained from Sofamor-Danek

Table 4.2 International comparison of overall back surgery rates.

Country	BSR* per 100.000 inhabitants	No.spine surgeons/million population
USA	158	76
Great Britain	30	18
The Netherlands	115	30
Sweden	52	87

* BSR = back surgery rate

The number of spinal column operations performed, in particular that of lumbar spinal fusion, increased significantly during the eighties. For example, between 1979 and 1990 the rate of lumbar spinal fusions doubled in the US.[21] The magnitude of this increase could not be attributed to differences in age distribution, increase in population size, sociodemographic differences or prevalence of back problems, it rather reflected changes and new concepts of the medical practice (like new fusion techniques and instrumentation).[65] The rates of lumbar spinal fusion appeared to stabilise in the early nineties[21,55,65], a trend which has also been noted in The Netherlands.[63] This stabilization was probably due to more strict selection criteria, especially in the treatment of patients with chronic low back pain. The total numbers of lumbar spinal fusion procedures for degenerative spinal disorders in different countries over the last years are presented in table 4.1.

4.3 BIOMECHANICAL CONSIDERATIONS OF LUMBAR SPINAL FUSION

The spine is to be considered as a mechanical structure. The vertebrae articulate with each other in a controlled manner through a complex system of levers (vertebrae), pivots (discs and facets), passive restraints (ligaments), and activators (muscles). A comprehensive knowledge of spinal biomechanics is of major importance for the understanding of clinical signs and symptoms and management of spine problems.

From a biomechanical point of view fusing one or more spinal motion segments is not physiologic. The normal spine allows specific motion at each level, while arthrodesis prohibits movement. Focus of lumbar spinal fusion in patients with chronic low back pain is on relieving pain and disability and not directly on the mechanical characteristics. Nevertheless, it can be stated that successful clinical results are in some way related to reduced mechanical stresses in particular painful spinal structures.[1]

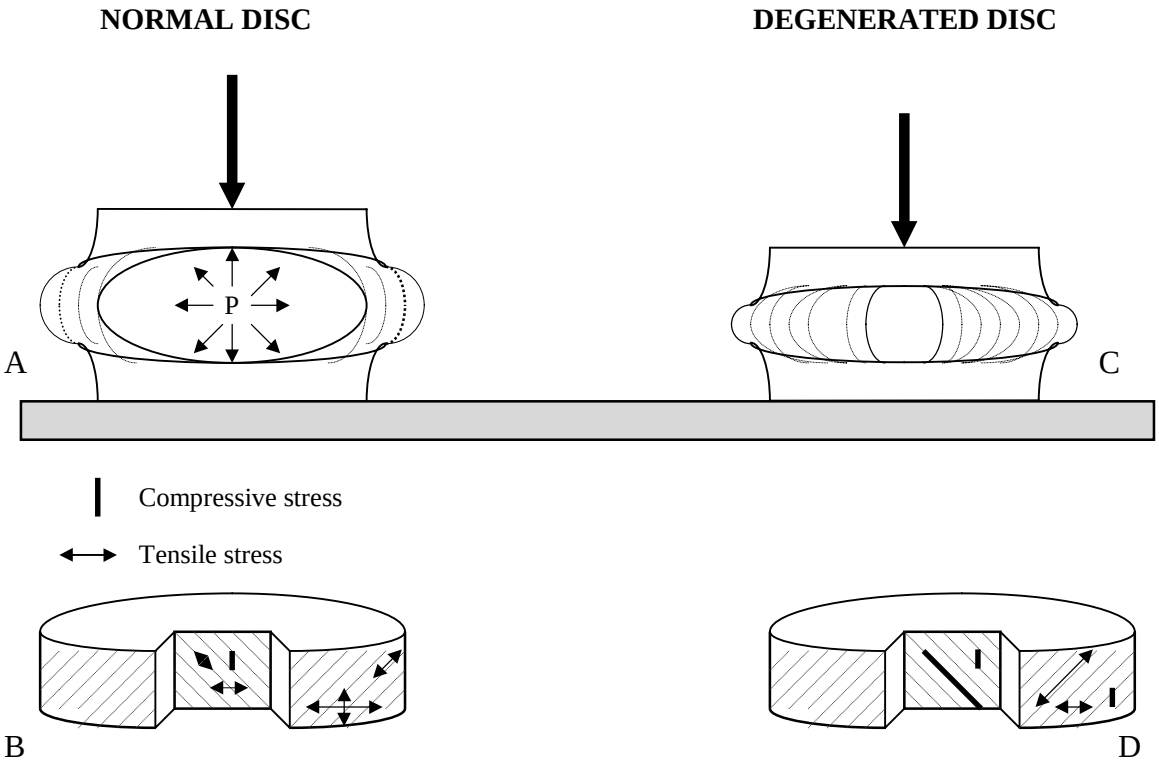
4.3.1 Biomechanics of the intervertebral disc

The intervertebral disc is perfectly designed to alleviate mechanical forces and transmit them in all possible directions. Because of its liquid and elastic nature, the disc can be compressed, redistribute primary vertical forces in the horizontal plane, and subsequently recover from the pressure. When compressive forces are applied to the liquid nucleus pulposus, fluid pressure builds up and pushes the surrounding structures away from the center (tensile stresses). This load-transferring mechanism can only function optimally when the disc water content is high and sufficient fluid pressure can be built up. This is usually the case in early life up to the age of 30. In a healthy intervertebral disc the nucleus is capable of absorbing and retaining large quantities of fluid. Because of its elastic nature, it is the anulus that gives the disc its compressibility and remodelling properties, and prevents bending and twisting of the disc.

The intervertebral disc receives the effects of most forces transmitted from one vertebral body to another. Since the major loading of the intervertebral disc is in the form of vertical compression, it may seem paradoxical that the anulus is optimally constructed to resist tension stresses, but the nucleus transforms the vertical thrust into a radial pressure that is restricted by the tensile properties of the lamellae of the anulus. This results in various stresses in different directions: tensile stresses along the anular fibers,

tensile stresses in a horizontal (tangential) direction, and stresses in an axial direction. Although the basic plan of alternating bands of fibers is one of the obvious sources of the tensile strength of the anulus, this arrangement is not uniform with respect to the directions of the fibers or the degrees of resistance encountered throughout the anulus.[56] The fibers generally become longer, and the angle of their spiral course becomes more horizontal near the outer parts of the anulus. The anulus of the nondegenerated disc has the greatest resistance in the horizontal sections of the peripheral lamellae, whereas the more vertical medial sections are more distensible (figure 4.1).

Fig. 4.1 Nondegenerated and degenerated discs under compression (based on White and Panjabi[68]).



A. Pressure within the nucleus produced by compression pushes the anulus and the two end-plates outward. The disc bulges out in the horizontal plane and the end-plates deflect in axial direction.

B. The anulus is subjective to varying amounts of stresses in different directions. On the outer layers there is a large tangential (peripheral) stress, and a relatively small tensile stress in axial direction. In the inner layers, the stresses are smaller but of the same type, except for the axial stress which is now compressive.

C. In the degenerated disc the compressive load is transferred from one end-plate to the other by way of the anulus only, thus loading the end-plates at the periphery.

D. The stresses in the degenerated disc are different from the healthy one (B). In the outer layers of the disc, tangential (peripheral) stress is much smaller, while the anulus fibers are subjected to nearly twice as much stress. Further, the axial stress is compressive. In the inner layers the fiber stress remains very high, but now is compressive.

The way the disc deals with mechanical stresses has changed when the disc is degenerated. For example, the load-transferring capacity of the degenerated disc is reduced because of the decreased water content; when compressed, the nucleus is not capable of building up enough fluid pressure, resulting in load transfer from one end-plate to the other by the anulus only. The outer anular layers are then submitted to less horizontal tensile stresses, but the tensile stresses along the anular fibers are much higher. Peaks of compressive stress are present in the middle of the anulus, particularly posterior to the nucleus.[2,3] The fiber stress in the inner anular layer remains high but is compressive as well. In severely degenerated discs, structural damage to the vertebral endplates and the anulus often is present. The stress distributions become multiple and irregular in the anulus. It is believed that, in these damaged discs, a cascade of changes causes nerve structures to penetrate deeper into the intervertebral disc and the disc may become painful (see Chapter 3).[22] These observations have been confirmed in patients undergoing spinal fusion and are consistent with findings of provocative discography.[53,62]

4.3.2 Lumbar spinal fusion and biomechanics

Prevention of intervertebral motion by bony union between adjacent vertebral bodies (spinal fusion) is assumed to result in pain reduction. The most logical site to fixate the spinal motion segment, in order to prevent intervertebral movement, is at some distance from its physiologic rotation centers. The rotation center for flexion and extension is close to the nucleus pulposus[57], and for axial rotation the rotation center is in the posterior anulus fibrosis.[17] Theoretically, spinal movement becomes maximally restricted by fixation at some distance from these regions of the disc. Both pedicle screw fixators and anterior plating systems meet this requirement. However, it is unlikely that rigid spinal fixation systems without adding interbody fusion will be capable to maintain the immobilisation of the fused segment for a long period of time. At some moment the fixation systems will permit slight motion and only small compressive deformities are necessary to induce high intradiscal compressive stresses.

Although spinal interbody fusion fixates the spinal motion segment at its fulcrum it has the advantage of additional spinal stability by influencing the intervertebral ligaments which are strong and lie relatively far away from the rotation centers. Normally these ligaments are not effective in inhibiting small spinal movements because they are slack for a certain range of motion, especially when the disc is degenerated.[1,50] However, during spinal interbody fusion these ligaments become tight resulting in enhanced stability.

Thus, a biomechanical basis for spinal fusion in patients with chronic low back pain due to benign spinal degeneration is apparently present. By preventing intervertebral motion and unloading specific areas in the disc, the pain and disability should be relieved. Although interbody fusion stabilizes the motion segment close to the pivot point of flexion/extension movements, it has the advantage of additional stabilization by tightening the intervertebral ligaments.

4.4 SURGICAL TECHNIQUES

Lumbar interbody fusion operations can be divided in posterior lumbar interbody fusion (PLIF) and anterior lumbar interbody fusion (ALIF), based on the approach. The posterior approach through a longitudinal midline incision provides direct acces of all levels of the lumbar spine. The anterolateral retroperitoneal flank approach can usually provide visualisation of the vertebrae L2 to S1.

4.4.1 Posterior lumbar interbody fusion

Cloward[15,16] is credited for fully elaboration of the PLIF-technique. Numerous techniques have evolved that modify Cloward's basic construct, including dowel fusion and cage fusion. We will describe the technique advocated by Cloward.

The patient is placed on the operating table either bending on his knees with his torso resting on a pillow (Salaam position) or prone (Jack knife position). After preliminary soft tissue dissection exposing the posterior elements, the supra- and interspinous ligaments and the flaval ligament are removed. The inferior border of the superior lamina is removed. The medial part of the inferior articular process is cut off which exposes the medial border of the underlying superior articular process. Reduction of this part completes the partial medial facetectomy. The procedure is carried out bilaterally.

After discectomy an osteotome is used to take down the caudal and cranial anulus parts and the end-plates. The lower and upper surfaces are made parallel to each other. Curettes are used quite extensively in cleaning out the intervertebral disc space. The vertebral bodies are distracted using a lamina or interbody spreader. The width and depth of the intervertebral disc space is measured during moderate distraction. Usually grafts with a length of 2.5 to 3.0 cm and a hight of 1.0 to 1.8 cm will do to fill up the obtained disc space. Two full thickness (tricortical) grafts are removed separately from the posterior iliac crest using an osteotome and a power saw. The grafts are cut slightly larger (± 1 mm) than the height of the distracted interspace to achieve firm impaction. After removing the interbody spreader a spacer of the appropriate size is placed on one side of the intervertebral disc space to maintain the distraction. On the opposite side an appropriate size tricortical bone graft is then placed in the intervertebral disc space with slight tapping. While placing the graft, special attention is given to protect the nerve roots passing cranially and medially to the graft. The spacer is then removed and a second bone graft inserted. Occasionally a third graft is inserted after pushing-up a graft medially using a wedging technique with two specially designed chisels: by spreading and turning the chisels, the graft is directed medially allowing space for an additional graft.

The lumbar dorsal fascia is closed over a suction drainage, and the wound is closed in layers. Finally, the iliac crest wound is closed also using suction drainage.

4.4.2 Anterior lumbar interbody fusion

The patient is placed in the supine position on the operating table. The table is handled in such a way that hyperextension of the lumbar spine is provided. A small pillow is placed under the left buttock to elevate the iliac crest. An oblique, left-sided paramedian incision is made, commencing approximately 3 cm lateral of the midline between the umbilicus and symphysis pubis and extending upwards and laterally. The incision is made through the skin and superficial fascia, and the anterior rectus sheath is devided in the line of the skin incision. The rectus muscle is retracted medially. A posterior rectus sheat incision is

made and the retroperitoneal space is entered. Extension of the incision into the aponeurosis of the internal oblique muscles and the transverse muscle can be made to reach the L3-4 and higher levels. The peritoneum is carefully separated by blunt dissection. The psoas muscle, the left ureter and the iliac artery and vein are visualized on the left side.

Several patterns of bifurcation of the common iliac arteries and veins exist. The bifurcation may be opposite to the midline of the fifth lumbar vertebra or at the level of the last intervertebral disc space or even as high as the middle of the fourth lumbar vertebral body. The decision to retract the left artery and vein to the right, in order to expose L4-L5, depends on the height of the bifurcation. Usually, isolation of the L5-S1 interspace is possible just below the bifurcation. Exposure of the L3-L4 interspace can often be achieved without division of any significant vessels; a lumbar vessel lying on the side of the body of L4 may need to be divided.

After exposing the lumbosacral interspace by retracting the left iliac artery and vein to the left side and of the right iliac artery and vein to the right side with blunt retractors, Steinmans spikes are driven bilaterally into the body of the fifth lumbar vertebra. One spike is driven into the rostral part of the first sacral vertebra on the right side. In this way, exposure is maintained during the interbody fusion procedure. The arterial pulse is palpated distally to the spikes in order to assure that excessive tensions on the vessels is prevented.

In exposing the third and fourth lumbar interspace, the left iliac artery and vein and the aorta and vena cava are kept to the right behind two Steinmans spikes. During exposure of these interspaces the change of obliterating the left iliac artery by applying excessive tension on the retractor is greater than at the former level.

The anterior longitudinal ligaments along with the anterior part of the anulus fibrosus is cut and the disc is removed. The space is cleaned out thoroughly, up to the posterior longitudinal ligament. Cartilage surfaces are removed from the vertebral bodies with an osteotome until bleeding bone is encountered and the lower and upper surfaces run parallel to each other. Then the dimensions of the interspace can be measured while enlarging the interspace with a vertebral body distractor.

The iliac crest is prepared by subperiosteal dissection to harvest full thickness bone grafts, i.e. including inner and outer cortex of the ilium. The tricortical grafts are taken slightly larger than the measured height of the interspace so that firm impaction can be effected. Usually graft dimensions vary between 1.0 to 1.8 cm in height and 2.5 to 3.0 cm in length. When the width, which is the third dimension, of the grafts are small, three or incidentally four grafts are inserted. In these cases the previous described wedging technique is used by introducing two specially designed chisels between the lateral part of the intervertebral space and the inserted graft. The spine is then straightened by reversing the hyperextended position of the table.

A suction drain is put in the retroperitoneal cavity. Both fascia layers of the rectus muscle are closed. Subcutaneous tissues are closed and monofylic nylon sutures are placed through the skin. At the donor side the wound is closed in layers using suction drainage.

4.4.3 Minimal Invasive Anterior Lumbar Interbody Fusion (mini-ALIF)

A microsurgical modification of the surgical anterior approach has recently been advocated by Mayer.[47] A standarized, microsurgical retroperitoneal approach to levels L2-

L3, L3-L4 and L4-L5 and a microsurgical transperitoneal approach to L5-S1 are described. The operation is performed with a surgical microscope or with a headlamp and loupes.

Retroperitoneal approach
The patient is placed in a right lateral position on the surgical table. Depending on the level that must be operated on, the table is tilted backwards in the axial plane for 20º (L4-L5), 30º(L3-L4) or 40º(L2-L3). A few centimeters ventral and proximal of the spina iliaca anterior superior, a 4 cm skin incision is made in an oblique direction parallel to the fibers of the external oblique abdominal muscle. The retroperitoneal space is reached by a blunt, muscle splitting approach. The anterolateral attachments of the psoas muscle are dissected from the lateral circumference of the disc space. The lateral border of the anterior longitudinal ligament is exposed in the center of the wound. On rare occasions the segmental vessels of the inferior vertebral body need to be ligated.

In general, no retraction of the left iliac vein or artery is needed. In the anterolateral cortex of the adjacent vertebral bodies, two screws are placed. These screws serve as an anchor for the vertebral bodies. Then the graft bed is prepared using this anterolateral approach. A tricortical graft or a cage is placed into the intervertebral space.

Transperitoneal approach
The patient is placed in a supine Trendelenburg position (trunk tilted 20-30º) with the lumbar spine hyperextended and both legs abducted (the surgeon is standing between the legs). A 4 cm skin incision is made in the midline of the abdomen centered over L5-S1 (usually 5-10 cm cranial from the symphysis). The visceral peritoneum is reached and dissected in the midline. The mesenterium with the ileum and sigmoid colon are pushed into the upper left abdominal cavity. A special spreader is inserted that exposes the promontorium. Five millimeters medial to the right common iliac artery, an incision of the peritoneum parietale is made. The retroperitoneal fat is retracted to the left and the anterior circumference of L5-S1 is exposed. After dissection of the middle sacral artery and vein, the disc is incised and the disc space is cleared. A graft or cage can be placed after completing the preparation of the graft bed.

4.4.4 Spinal instrumentation

A further evolution of the PLIF- and ALIF-techniques was facilitated by the development of a wide array of spinal instrumentation devices.[31,32] The interest for the combined technique of interbody fusion with instrumentation resulted from dissatisfaction with the fusion rates obtained by interbody fusion alone. Indeed, the combined application of these techniques resulted in a increased bony fusion rate.[45,46,74] An additional but also important advantage of internal fixation is the avoidance of need for external bracing post-operatively which also allows the patient to early join a rehabilitation program. The major disadvantages include the risk of nerve root lesioning, increase in operation time, increase of infection rate, and restricted to the anterior fixation device, vascular injuries.[69]

The greatest enthusiasm during the past two decades has been for pedicle screw fixation. The underlying principle is that the pedicle and adjacent vertebral body represent the most secure point of fixation. A great deal of research attention has been given to the optimization of the screw design and the linkage systems (plates and rods).[1,58,64] For the anterior approach plate- or rod systems are mostly used as supplemental lumbar fixation

devices. Each system has its theoretical and practical advantages and disadvantages. Provided advanced surgical skills, rods and screws can be safely applied to the lumbar spine.

Due to the wide variety of systems available we will not discuss the various application techniques of the individual devices.

4.4.5 Post-operative care

The use of a plaster spica from the trunk to one knee is usually prescribed in those patients without internal fixation devices. The plaster corset is worn for a period of three months. During this period, anticoagulation therapy is given prophylactically. Internal fixation devices obviate the need for plaster spica or anticoagulation therapy.

4.4.6 Technique related complications

The PLIF- and ALIF-technique are both complex surgical procedures, but in experienced hands they can be carried out with good clinical results and few complications. The main concern in doing a PLIF-operation is to protect the spinal nerve roots and also the cauda equina from being damaged while inserting the interbody grafts. The major problem associated with ALIF concerns the high complication rate involved with mobilizing the great vessels and handling the presacral plexus. In addition impotence in the male may occur, though this complication may be prevented by careful dissection. There is a high risk of postoperative deep venous thrombosis, which may lead to permanent swelling of the legs and occasionally results in fatal pulmonary embolus (table 4.3).

Table 4.3 Complications of lumbar interbody fusion.[19,30,41,42,47,60]

	Complications	Reported rates
peroperative	dural tears	0% - 15%
	excessive blood loss	sporadic case reports
	intra-abdominal vessel injury	0% - 2.5%
	nerve root injury	0.5% - 10.0%
	nerve injury secondary to donor site	0% - 4.5%
	position related peripheral nerve injury	0% - 1.0%
	visceral injury (bowel, kidney, ureter)	sporadic case reports
postoperative	donor site pain	8% - 45%
	graft extropulsion	0.7%
	incisional hernias	0.7%
	infection - superficial	0% - 3.2%
	- deep	0.5% - 3%
	- discitis	0.5% - 2.7%
	- meningitis	0.1%
	post-sympathectomy syndrome	0.5%
	pseudoarthrosis	5.0% - 60.0%
	pulmonary embolus	0.1% - 1.2%
	retrograde ejaculation	1.0%
	thrombosis - deep venous	1.2% - 3.0%
	- arterial	0.3%

urinary tract infection	2.4% - 10%
urinary retention	0.5% - 38%

4.5 BONE GRAFTING

In order to obtain definite spinal stability by spinal interbody fusion, solid bony union is mandatory. The transplanted bone graft initially provides structural support, but this is temporary. Solid bony union requires bone growth (osteogenesis), the formation of bone forming cells (osteoinduction) and a favorable infrastructure on which new bone can be deposited (osteoconduction).[24] Of course, revascularization and ingrowth of capillaries and osteoprogenitor cells into the bone graft must be present for long-term survival of the bone graft. Therefore, the graft must be carefully selected, harvested, prepared and incorporated. The ideal graft posesses osteogenic, osteoinductive as well as osteoconductive properties. Of all the types of grafts, autogenous bone is considered the most successful in acquiring bony union after spinal interbody fusion. However, autogenous bone has the disadvantage that is must be harvested from the patients themselves resulting in additional morbidity. In this respect other graft types such as allografts, xenografts or ceramics all carry an advantage but they regrettably appear to be inferior in obtaining solid bony union.[7]

BMP

Osteoinductive bone graft substitutes are being researched as supplementary or alternative means to achieve fusion. The goal of such work is to potentially eliminate the morbidity associated with autograft donor sites and to decrease the incidence of pseudarthrosis. The use of human bone morphogenetic proteins (BMP's) and recombinant human bone morphogenetic proteins (rh BMP's) as osteoinductive bone graft substitutes or expanders have recently gained considerable research interest. Animal studies of osteoinductive growth factors in spinal fusion have revealed high fusion rates.[20] No similar conclusive study on humans has been published until now.

Tissue engineering

The recent identification of embryonic stem cells offers a new approach to repair damaged tissues. Until now researches are a long way from being able to produce fully differentiated cells out of embryonic stem cells that can be used to create or repair specific organs. A more immediate goal would be to isolate so-called progenitor cells from tissues. Such progenitors cells have taken some of the steps towards becoming specialized. Because not yet fully differentiated the progenitor cells remain flexible enough to replenish several different cell types. Caplan et al.[11] for instance have isolated progenitor cells from human bone marrow that can be prompted in the laboratory into either osteoblasts that form bone or chondrocytes that compose cartilage. In the next decade major problems such as contamination of the cultures with connective tissue (fibroblasts) and the relatively small amount of growing cells that actually can be cultivated remain to be solved.

4.6 CONCLUSIONS

Although spinal fusion operations have been performed since the beginning of this century, no consensus exists on the indications to perform lumbar spinal fusion in degenerative chronic low back pain cases. Since general guidelines are lacking, differences in belief of individual spine surgeons result in great geographic variations in spinal fusion rates. Generally, a lot of surgeons hesitate to perform interbody fusion in this group of patients because of the complexity of the operation and high failure rates in multilevel arthrodesis. Partially responsible for disappointing results are poor patient selection, improper diagnosis, and inability to identify the pain moderator. However, new techniques that minimize the operation (mini-ALIF) and enhance the fusion rates (spinal instrumentation) have been developed and fairly good till excellent results have been reported in highly selected patients with single level fusions. Arthrodesis may therefore result in pain relief in some patients.

Facts to keep in mind when considering lumbar spinal fusion are:

1. Successful outcomes of lumbar spinal fusion depend on medical as well as on complex psychosocial and workplace factors. In each individual with chronic low back pain these factors must be assessed and a selection must be made based on strict in- and exclusive criteria.

2. Permanent spinal stability can be achieved by interbody fusion with or without the use of internal fixation devices but not by fixation devices alone.

3. A technically successful and solid fusion does not necessarily result in a satisfactory clinical outcome, and conversily postoperative pseudarthrosis is not synonymous with clinical failure.

Future studies may provide better insight in the various causes of chronic low back pain and provide objective tests for this condition. Only then scientific based selection of patients for lumbar spinal fusion will become possible.

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CHAPTER 5

OUTCOME OF INTERBODY FUSION IN SELECTED PATIENTS WITH DEGENERATIVE CHRONIC LOW BACK PAIN

5.1 INTRODUCTION

When dealing with patients with chronic low back pain, nonoperative methods are to be considered firstly. Treatments recommended include exercise, traction, acupuncture, transcutaneous electrical nerve stimulation, bracing, biofeedback, drug therapy, facet denervation, manipulation, and group education in back schools.[1,3,5,6,8,9,10,23,25,29,30,31,38,42] However, a part of patients experiencing chronic low back pain is not helped by any of these means. Lumbar spinal fusion can, in some of the patients who are severely disabled by the chronic low back pain and in whom no other treatment has been effective, result in (at least some) pain relief.[39,41,43,46,54,55] There is hardly any debate on the indication of spinal arthrodesis in low back pain resulting from serious congenital or acquired deformities, such as progressive spondylolisthesis, unstable fractures, inflammatory processes or neoplastic destruction.[4,11,13,14,21,22,32,50] However, much controversy exists whether to use spinal fusion in an attempt to control chronic low back pain in so-called benign segmental degeneration.[20,26,35,37,49,51,61] Dependent on clinical, radiographic or biomechanical criteria, in the literature this condition has been referred to by various circumscriptions such as “chronic low back pain”, “chronic lumbosacral sprain/strain”, “chronic degenerative disc disease”, “discogenic low back pain”, and “segmental instability”.[61] Unfortunately, the correlation between radiographic, biomechanical, and clinical findings is not clear and specific symptoms of motion segment instability have yet to be defined. Uncertainty about the diagnosis of this condition in combination with disappointing outcomes of various non-specific treatments has frustrated patients as well as physicians. As a result of this, with respect to the indication to perform spinal fusion in these patients, controversy persists.

Although the concept that degeneration of the spinal motion segment may give rise to pain is commonly accepted, it is not clear to which of the constituent elements (facet joints, ligaments, muscle, disci or bone) the pain is to be attributed. Any structure in the lumbar spine that contains sensory nerve supply may become a source of nonremittant pain when affected by pain producing tissue damage. Local innervation has been demonstrated in most tissues of the motion segment and more recent reports indicate an innervation of the degenerated lumbar disc (Ch 3). These findings support the concept of discogenic pain in which pathologic conditions of the disc, such as internal anular disruption and disc resorption, can cause low back pain.

In the group of chronic low back pain patients we have tried to select a group of patients in which the degenerated disc seemed to play a central role in pain production and in which arthrodesis of the painful lumbar segment might result in pain relief. The patients were prospectively selected using strict in- and exclusion criteria, the painful disc

was localised by discography and arthrodesis was either by anterior- or posterior lumbar interbody fusion.

5.2 MATERIALS AND METHODS

Between 1980 and 1990 in the Leiden University Medical Center, 157 patients with severely disabling chronic low back pain were selected for lumbar interbody fusion. Patient selection involved the inclusion criteria: 1) the pain is localised in the lower back either or not radiating into one or both legs following a non-radicular pathway. The limb pain must be essentially different from the limb pain in patients with disc ex/protrusion; the pain has developed gradually, is not contained to a well defined radicular area, and may be present in both limbs; 2) complaints last more than 1 year; 3) congenital or acquired anomalies of the lumbar spine have been excluded; 4) no benefit from various non-surgical types of treatment; 5) no obvious psychosocial distress; 6) pain related disability to economic and/or social activities; 7) no neurological deficits related to the actual condition; 8) clinical and radiological absence of nerve root compression; 9) marked reduction or total disappearance of symptoms while wearing a lumbar brace; 10) discographically proven disc degeneration (table 5.1) and temporary pain provocation at discography.

History taking
The intake interview included information on patient's demographic characteristics, family history of pain, current family relationships, work and career adjustments, nature and onset of pain, reactions to pain, reactions to treatment, history of other medical problems, history of psychiatric status, reported pain and limitations, coping methods in relation to low back pain and self-assessment of treatment effects so far. These factors were evaluated in multiple personal communications.

Physical examination
On physical examination, all the patients had some degree of low back dysfunction. During flexion of the lumbar spine the movements were nonfluent and there was a limited mobility. The typical fixation of the involved lumbar segments as often seen in the presence of radicular involvement was absent. A neurological examination was performed.

Radiological investigation
Plain radiographs invariably showed degenerative changes of the lower lumbar spine. Patients with congenital or acquired anomalies of the lumbar spine were excluded. Caudography was performed in all cases to ascertain absence of nerve root compression.

Discography
If an interbody fusion operation remained optional after the aforegoing selection methods, investigation was continued by discography at L3-L4, L4-L5, and the L5-S1 levels consecutively. The pain experienced at the injection of the radio-opaque dye (Iopamiro®) into the nucleus pulposes was recorded as to nature and intensity. Under fluoroscopic guidance, 0.5-1.5 cc of the dye was injected transdurally into the discs. The discographic patterns were classified in 4 stages of disc degeneration (see table 5.1). Pain reproduction was recorded as absent, atypical, or typical (when injection reproduced and intensified the

patient's usual back symptoms). Only evidently degenerated discs, i.e. stage II and III, in combination with a positive typical pain provocation remained candidates for an interbody fusion operation. Patients with an intervertebral disc that appeared to be degenerated but did not cause pain during discography were excluded. This test excluded 20 patients who had notably degenerated discs but without pain reproduction at any of the injected discs.

Table 5.1 Discographic patterns according to Courzal.

Discographic Degeneration stage	
0	normal disc; roundish or bilobulated of the nucleus; unfissured anulus.
I	well outlined nucleus fissures in the inner anulus fibrosus.
II	degenerated disc with fissures leading to the outer edge of the anulus.
III	complete radial fissure with leakage of contrast into the epidural space.

External immobilisation

After discography the patients were asked to wear a plaster spica (Baycast®) from the trunk to one knee for 4 weeks. In this period the pain had to resolve slowly, and the pain had to return shortly after removing the cast. The (almost) complete disappearance of complaints during immobilisation in the spica was a consecutive selection criterion. Oral anticoagulants were prescribed during this period.

Surgical technique

The choice between anterior or posterior interbody fusion was made at random and depended mainly on the attending surgeon's preference at the time of the operation. Tricortical grafts (auto- or allografts) derived from the iliac crest were used for the interbody fusions. Homologous bone grafts were used sporadically.

The administration of low dosage of heparin was started one day before the operation. Antibiotic prophylactics (cloxacillin or erytromycin) were given intravenously at induction of anaesthesia and for one day postoperatively.

Postoperative treatment

During the first postoperative week, the regime consisted of immobilisation on a "Stryker frame". Patients were then mobilised in a thoraco-lumbar plaster spica (Baycast®) including one upper leg for 3 months. A detachable plastic spica enclosing only the trunk was prescribed during the fourth month. Anticoagulants were continued for three months.

Evaluation of fusion status

The fusion results were evaluated after at least 1 year by an independent radiologist. Criteria for evaluating the fusion status were the following:

A. Definite fusion: Definitive bony trabecular bridging across the graft/host interface, no detectable motion on flexion-extension radiographs, and no gap at the interface.
B. Probable fusion: No definitive bony trabecular crossing, but no detectable motion and no identifiable gap at the interface.
C. Possible pseudarthrosis: No bony trabecular crossing, no motion, but an identifiable gap at the interface.

D. Definite pseudarthrosis: No traversing trabecular bone, definitive gap at the interface, and motion on flexion-extension radiographs.

A and B were considered as successful fusions, while C and D were considered as failed fusions.

Clinical outcome

All 157 patients were postoperatively evaluated after 1 and 3 years. The clinical outcome was scored using the Macnab classification[27]: excellent, good, fair, and poor (table 5.2). These grades of success could be condensed in two outcomes: satisfactory and unsatisfactory. Assessment of the results with respect to the back pain was fully based upon the patient's own description.

Table 5.2 Explanation of Macnab classification.

Classification	Explanation
Excellent recovery	(almost) complete relief of back/leg pain.
Good recovery	occasional pain in back/leg but obvious improvement; would have surgery again
Fair recovery	little or no change in back/leg pain; would not have surgery again
Poor recovery	pain worse than before surgery

Statistical analysis

Statistical analysis was performed using Confidence Interval Analysis (Gardner & BMJ 1989).

5.3 RESULTS

5.3.1 Demographic data and procedures

All 157 patients (77 men, mean age 42, range 24-61; 80 women, mean age 38, range 22-58; figure 5.1) with long-term severely disabling low back pain preoperatively (mean 7.4 years, range 1- >10 years; table 5.3) were postoperatively evaluated after 1- and 3 years. In about one-half of the patients, pseudoradicular pain co-existed. Hundred-and-one patients (64%) already underwent prior low back surgery (156 operations).

Of the 157 interbody fusion operations performed, 85 were by a PLIF-procedure and 72 by an ALIF-procedure (figure 5.2). Fifty-one patients had a one-level fusion, most commonly affecting the lumbosacral level L5-S1 (n=32), followed by L4-L5 (n=18) and L3-L4 (n=1). Hundred-and-two patients had two levels of involvement most commonly L4-L5 and L5-S1 (n=94), followed by L3-L4 and L4-L5 (n=6) and by L3-L4 and L5-S1 (n=2). A three level fusion was performed in 4 patients. Tricortical grafts derived from the iliac crest were used to interbody fusion. It is obvious that the harvesting site - anterior or posterior part of the iliac crest - depended on the choice for PLIF or ALIF. Autografts were used in the majority of patients (94% of the total of 267 fusion levels were autogenous). Eight patients received allografts and 9 patients, who underwent a multilevel fusion, received a combination of both auto- and allografts.

Table 5.3. Duration of symptoms preoperative.

	years	number of patients (n=157)
duration	1-5	64

5-10	49
> 10	44

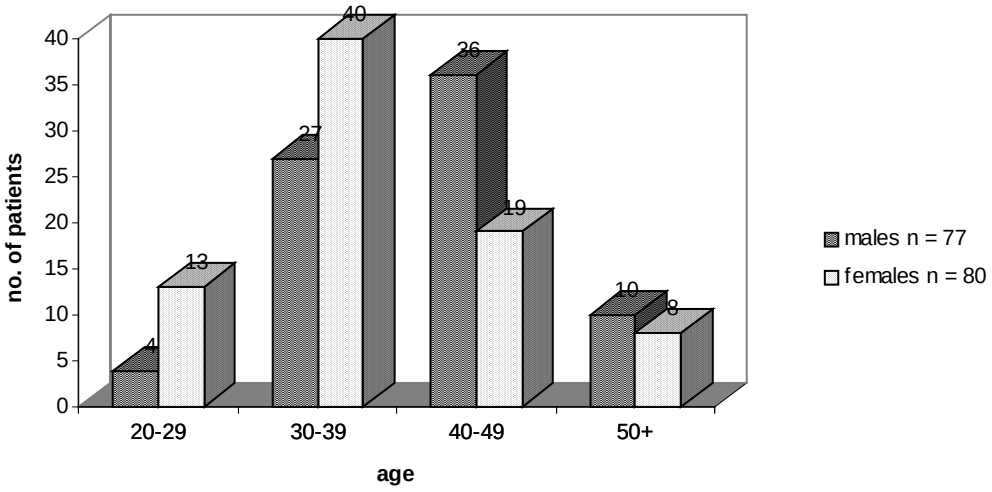

Figure 5.1 Patient sex and age distributions.

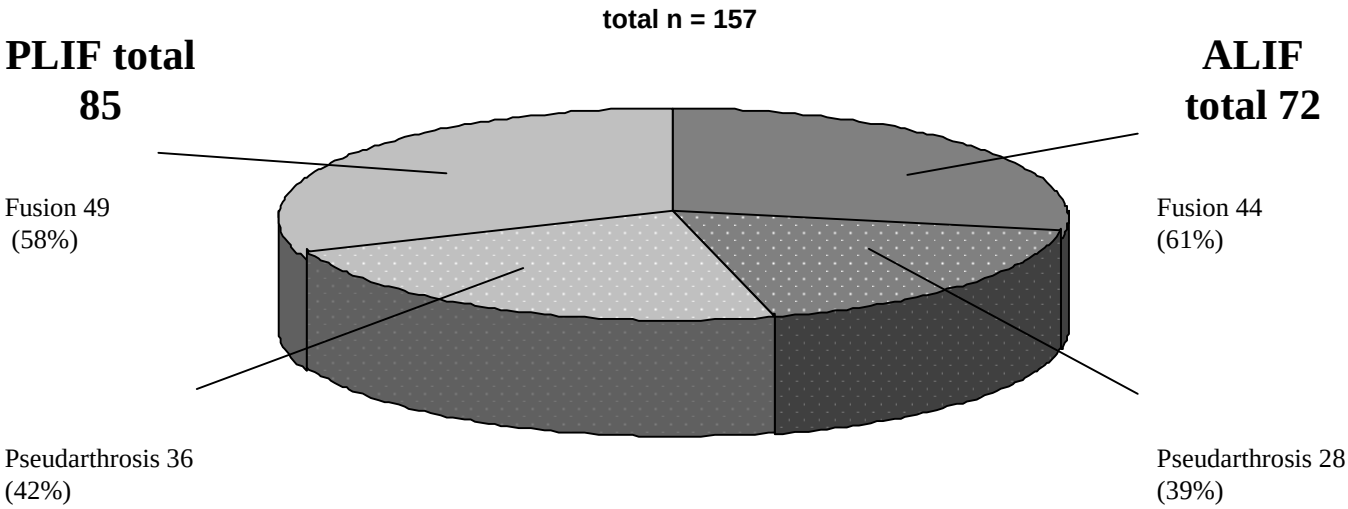

Figure 5.2 Fusion results and type of approach.

5.3.2 Outcome

5.3.2.1 Outcome: clinical

An overall patient satisfaction was achieved in 67% of the total number of patients after 1 year. This percentage remained unchanged at 3 years follow-up. Clinical outcome was not related to sex, age or type of surgical approach. Better clinical results are seen in the one level operated than in the multi-level operated group (76% vs. 63%), but the difference was not significant. Patient satisfaction was strongly correlated with fusion status (95%CI (0.17-0.46)), indicating that patient satisfaction was higher in the group that showed bony union on radiographs at all operated levels. In the one-level group an overall satisfaction of 76% was reported, but of the patients in this group who showed bony union, 89% was satisfied. In the two level fusion group, the overall patient satisfaction was 63% compared to 74% of the patients who had bony union at both levels (figure 5.3).

5.3.2.2 Outcome: fusion

Ninety-one (60%) of the patients were judged to have “solid bony union” (fusion status A and B) of all operated levels. Fusion failed to occur in 66 patients (40%) (fusion status C and D). Fusion results were best in the one-level operation group (71%) (figure 5.3). No significant difference was noted between different age groups, gender and the type of surgical approach. Of the 267 interspaces grafted in 157 patients, 190 levels (71%) obtained bony fusion and 77 levels (29%) did not. The lumbosacral interspace was grafted 132 times and 100 (76%) were judged solid. Bony union was achieved in 66% of the 122 operated L4-L5 interspaces; at L3-L4, 77% of the 13 operated levels achieved bony union. There was no difference in fusion results between the autogenous and homologous graft groups.

5.3.3 Complications

The complications are shown in table 5.4. We subdivided this in three categories: pre-, intra-, and postoperative sequels.

Preoperative
Discography resulted in discitis in two patients. After identification of the responsible microorganism, the patients were treated with bed rest (2-3 weeks) and antibiotics (6 weeks).

Intra-operative
One patient suffered a transient extensor paresis of one foot. Ulnaropathy as a result of nerve compression at the sulcus ulnaris was found in two patients after an ALIF procedure. In both patients the symptoms disappeared spontaneously within 6 months postoperatively.

Donorsite-related peripheral nerve injury occurred in 4 patients. The lateral femoral cutaneous nerve was involved 3 times and a combination of the ilioinguinal nerve with the genitofemoral nerve once. These donorsite nerve injuries recovered spontaneously within days to weeks (range 3 days-6 weeks) except for the latter. A 36-years old diabetic

patient had persisting complaints of injury of his left ilioinguinal- and genitofemoral nerves.

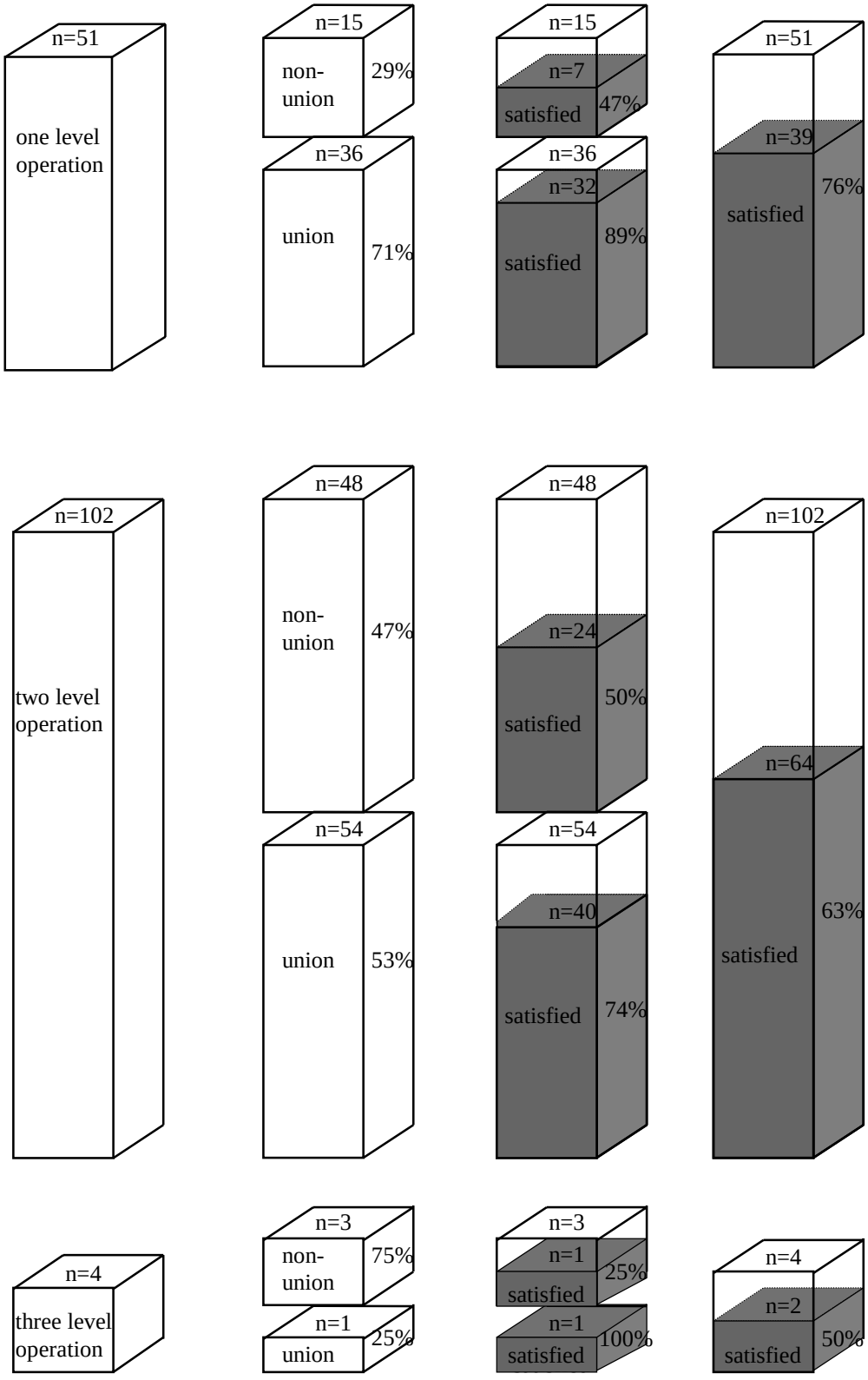

Figure 5.3. Relation between levels of fusion, fusion status and patient satisfaction with a follow-up of 3 years.

Postoperative

There were 9 wound-related complications. Four superficial wound hematomas (2 in the abdominal wall and 2 in the iliac crest area) resorbed spontaneously. One patient developed an abdominal cicatrical hernia, necessitating repair. Four bacterial wound infections were treated by drainage (2 superficial abdominal wounds) or by drainage and antibiotic medication (2 donor site wounds).

In addition, transient urinary retention was relatively common during the first two days postoperatively. Intermittent catherisation was started when spontaneous miction failed to occur. After two days of catherisation, 3 patients needed a temporal urine catheter for one week. One patient developed a pyelonephritis that could successfully be treated with antibiotic medication. There was no thrombosis or thrombo-embolism in this series.

Graft donorsite pain was a common complaint, particularly in the early postoperative phase (table 5.5). In nearly one quarter of the patients this pain persisted for 3 months. At one year after surgery less than 10% of the patients identified donorsite pain. This percentage decreased after 3 years to 1%.

Table 5.4. Complications of spinal fusion.

Complication	number of cases	%
preoperative		
discitis (discography)	2	1,2%
peroperative		
transient paresis (foot extensors	1	0,6%
transient ulnaropathy	2	1,2%
nerve injury secondary to donorsite	4	2,5%
postoperative		
wound hematoma	4	2,5%
incisional hernias	1	0,6%
wound infection	4	2,5%
urine retention	12	7,7%
requiring urine catheter	3	1,9%
pyelonephritis	1	0,6%
ileus requiring NG tube	5	3,3%

Table 5.5. Donorsite pain.

duration of iliac crest pain	anterior iliac crest (n=65)	posterior iliac crest (n=48)	total (n=149)
< 3 months	16 (24%)	18 (21%)	34 (23%)
1 year	7 (11%)	5 (6%)	12 (8%)
3 years	1 (1,5%)	1 (1%)	2 (1,3%)

5.4 DISCUSSION AND CONCLUSIONS

Discussing the results of this study presents a challenge to scientiffic warrented assessment because the included patients had no definite diagnosis. All the patients suffered from chronic low back pain in combination with degenerative changes in the lower spine and had exhausted all modalities of non-operative treatment. A term frequently used for these degenerative conditions of the lower spine causing low back pain is "segmental instability". [16,19] However, a clear definition of, and specific criteria to diagnose segmental instability are lacking. [15,36,56] Therefore, the symptom chronic low back pain itself is often used as the major "diagnostic" criterion for further treatment.[19,52,53,57,58] In order to better delineate this group of patients we have added some specific selection criteria.

Discography

Out of the patients with chronic low back pain, we seeked those patients with an important "discogenic" component by discography. We do not think that MRI can replace discography in this patient selection. In a mainly MRI-based categorisation by Zdeblick[61], patients with segmental degeneration are grouped into those with spondylosis, discogenic pain, or facet syndrome. In spondylosis MRI shows disc space narrowing, loss of water content of the disc and marrow changes of the adjoining end-plates.[33] Patients with signs of discogenic low back pain have relatively normal radiographs but MRI may show decreased signal intensity within the disc (often called "black disc").[45] Finally, patients with facet syndrome show signs of joint degeneration on MRI. Unfortunately, this MRI-based categorisation is not useful in selecting "discogenic" pain because spondylosis, painful disc degeneration and facet syndrome are not complete different entities. In fact spondylosis and facet syndrome are sequelae of disc degeneration[2] and consequently there is overlap as seen on MRI.

In conclusion, the morphometric status of a motion segment, including the disc, can be visualised by MRI while information obtained during discography is restricted to the disc.[17] However, discography can, in addition to the morphometric disc status, provide information on the painfulness of the disc. When degenerated changes are accompanied by a pain response on injection of saline or contrast material a discogenic cause of the low back pain becomes more likely. We therefore think that in future studies the levels for discography can be determined by corresponding levels of abnormal MRI findings.

Discographically observed degeneration of a disc does not necessarily mean that this disc is a source of low back pain since grossly degenerated discs can be asymptomatic.[60] Seventeen percent of the operated patients in this study had at least one severely degenerated disc that did not cause pain on discography. These levels could be ignored and only the degenerative levels with positive pain reproduction were fused in these patients. It is still unclear to what extent positive pain reproduction corresponds with successful surgical outcomes. Calhoun et al.[7] showed an 88% surgical success rate in patients with positive pain reproduction at discography, but even regardless the discographic outcome, surgery was still successful in 82%. Despite this and other

ongoing criticism of discography (Holt[24], Scheiderman[47], Shapiro[48], Nachemson[34]), many surgeons gratefully use discography in deciding whether or not, and what levels to fuse.

External spinal immobilisation

Preoperative spinal immobilisation by casts[44] or by external spinal skeletal fixation (ESSF)[12,28,40,59] is used to create a "temporary fusion". This temporary fusion can be of help in selecting patients with permanent internal fusion. ESSF is believed to be superior to casting because of its more rigid immobilisation and its accuracy in selecting the lumbar spinal motion segments. However, ESSF is an invasive procedure in which, under general anaesthesia, an external frame is placed on percutaneously placed screws. The predictive values of ESSF and casting on the clinical outcome of spinal fusion are similar[12,44] that implies a preference for temporary immobilisation by casting.

In this study we have obtained an overall fusion rate of 60% which is rather disappointing. Fusion results were highest in the group of patients who underwent a one-level fusion operation. Clinical outcome results were best in patients after a single level fusion who in addition showed bony union. The satisfaction percentage in these patients came close to 90%. The presence of a clear correlation between clinical satisfaction and bony union should incite us to strive for a solid bony union. Several studies[11,18,20,21,35,49] report an improvement of the fusion rate using additional pedicle fixation (pedicle screws and fixation rods). The fusion rates claimed in these studies vary between 85% and 100%. After internal fixation it is also possible to mobilise patients in the early days postoperatively and without the use of a lumbar spica. We therefore now advocate the combination of interbody fusion with spinal instrumentation.

In conclusion, it is our opinion that in patient selection for spinal fusion, it is important to gain an insight into the amount of pain and the concomitant disability. Likewise, the patient's and surgeon's expectations on the effect of a lumbar fusion must be discussed. The patient might expect to be pain-free and return to a high functional level, while the surgeon simply hopes to alleviate some of the pain and improve the patient's function modestly. Therefore, in deciding whether a patient with chronic low back pain might benefit from lumbar spinal fusion, patient characteristics as well as medical factors must be evaluated carefully. The results of this study, not with standing scientific shortcoming, show that handling strict criteria to selected patients, lumbar spinal fusion is successful in the majority of cases. Especially when one-level pathology becomes one of the inclusion criteria, lumbar spinal fusion has the better results.

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Chapter 6

A 10- TO 20-YEAR FOLLOW-UP OF LUMBAR INTERBODY FUSION FOR DEGENERATIVE CHRONIC LOW BACK PAIN

6.1 INTRODUCTION

The discussion on performing lumbar fusion in patients with severe disabling chronic low back pain due to benign segmental degeneration continues.[4,12] General accepted guidelines are not available and the combination of poor patient selection, improper diagnosis and inability to identify the pain moderator have caused over-all disappointing results. Nevertheless, in highly selected patients fairly good till excellent results have been reported.[3,10] To the best of our knowledge there are no publications on the long-term clinical outcome of interbody fusion in this patient category. Long-term results of lumbar fusion have been presented in e.g. spondylolisthesis[7,13,16] and spinal stenosis.[8] In case of spondylolisthesis, clinical success rates ranging from 76% up to 92% are maintained over a period of 10 years, although Takahashi[16] shows a decline in clinical success after 30 years down to 52%. Long-term clinical success rates of posterior lumbar interbody fusion for spinal stenosis vary from 70% up to 80%.[8] However, decompression surgery without fusion for spinal stenosis due to degenerative arthritic changes producing claudication equals or even exceeds these results.[15]

The purpose of this study was to investigate the long-term results of interbody fusion in patients with chronic discogenic low back pain. Between 1980 and 1990, in the Leiden University Medical Center, lumbar interbody fusion was performed in 157 highly selected patients with discogenic low back pain. Patient selection was based on strict in- and exclusion criteria as described in Chapter 5. The choice between posterior lumbar interbody fusion (PLIF) or anterior interbody fusion (ALIF) was made at random and depended mainly on the attending surgeon's preference at the time. Tricortical grafts (auto- or allografts) derived from the iliac crest were used for the interbody fusion. No additional hardware was used. The postoperative regime consisted of immobilization in a "Stryker frame" during woundhealing followed by mobilization in a thoraco-lumbar plaster spica (Baycast®) for three months. A detachable brace was prescribed during the fourth month. The clinical outcomes were prospectively evaluated 1 and 3 years postoperative by an independent observer using the Macnab classification.[11] The degree of pain relief was scored as excellent, good, fair or poor (see Ch 5; table 5.2). A successful clinical outcome was achieved when the Macnab classification was excellent or good. Failure was synonymous with fair and poor.

The initial group of 157 patients (see Ch 5) with chronic severely disabling low back pain consisted of 77 (49%) men (mean age 42, range 24-61) and 80 (51%) women (mean age 38, range 22-58). Of the 157 interbody fusion operations performed, 85 (54%) were by a PLIF-procedure and 72 (46%) by an ALIF-procedure. Fifty-one patients had a one-

level fusion, most commonly affecting the lumbosacral level L5-S1 (32 patients), followed by L4-L5 (18 patients) and L3-L4 (1 patient). Hundred-and-two patients had two levels of involvement most commonly L4-L5 and L5-S1 (94 patients), followed by L3-L4 and L4-L5 (6 patients) and by L3-L4 and L5-S1 (2 patients). A three level fusion was performed in 4 patients. An overall clinical success rate of 67% after 1 and 3 years was obtained and has been described.

6.2 MATERIALS AND METHODS

Of the initial 157 patients, 66 (42%) had changed their address since their last control and could not be traced for long-term follow-up. Of the remaining 91 patients, 9 subsequently died from unrelated causes and 7 patients had emigrated abroard. This leaves a total of 75 (48%) patients to be evaluated 10-20 years after the procedure. The nature of the study was explaned to all patients in a letter that accompanied the patient-completed evaluation form. They all agreed and completed the evaluation process (100% of those available). The long-term clinical results were obtained by a postal questionnaire that existed of a Macnab classification[11], a Roland-Morris[14] disability questionnaire and additional questions concerning remainder medical conditions, psychological state and current medication. The Roland-Morris score (see Appendix) consists of a summation of 24 yes/no questions concerning the disability due to low back pain. Every positive response scores one point so a high score on the Roland-Morris score indicates increased disability. The patients themselves completed the postal questionnaire.

Data Analysis. Statistical analysis was performed using SPSS® 7.5 for Windows (SPSS Inc, Chicago, Illinois) and Confidence Interval Analysis (Gardner & BMJ 1989). The long-term clinical outcome and disability status were compared to the 1- and 3 year clinical outcome, using a Spearman correlation.

6.3 RESULTS

The long-term clinical outcome and disability status was evaluated in 75 patients with a mean follow-up of 16.2 years (range 10-20 years). Thirty-six patients (48%) were men (mean age 38,7, range 24-59) and 39 (52%) were women (mean age 38,9, range 22-59). Of the 75 lumbar interbody fusions that were performed, 45 (60%) were by PLIF and 30 (40%) by ALIF. Twenty-two patients had a one-level fusion, 49 patients had two levels of involvement and four patients had a three-level fusion.

The long-term patient satisfaction after lumbar interbody fusion in the responding group was 71% (n=53). The long-term Macnab classification strongly correlated with the Roland-Morris (RM) disability score (Spearman correlation coefficient –0.743; table 6.1). Satisfied patients had a mean RM-score of 7.4 (range 0-23) indicating a low level of disability while the unsatisfied patients had a mean RM-score of 18.4 (range 3-24) indicating a high level of disability (table 6.2).

Table 6.1 Relation between the Macnab classifications and the Roland-Morris score (Spearman correlation coefficient).

	Macnab1-year	Macnab3-year	Macnab>10-year	Roland-Morris
Macnab1-year	1.000	0.923	0.418	-0.228
Macnab3-year	0.923	1.000	0.400	-0.241
Macnab>10-year	0.418	0.400	1.000	-0.743
Roland-Morris	-0.228	-0.241	-0.743	1.000

Table 6.2 Ten year clinical outcome and the Roland-Morris disability-score.

10-year clinical outcome	Range in RM-score	Mean RM-score
Excellent	0-12	7,4
Good	3-23	9,7
Fair	11-22	18,0
Poor	3-24	19,0

RM-score = Roland-Morris score

The 1-year, the 3-year and the long-term clinical outcomes are presented in table 6.3. The initial clinical success rate of 69% after 1 year shows a minor increase to 71% after more than ten years. Although the overall clinical success rate is about the same after 1-, 3- and more than 10-years, further analysis of table 6.4 shows that individual changes in clinical outcome over time occur. From the 52 (69%) satisfied patients after 1 year, 8 (15%) became unsatisfied more than 10 years postoperatively. On the other hand, 9 (39%) out of 23 initially unsatisfied patients improved. Of the patients who worsened, 5 were women and 3 were men. All of them had a multi-level fusion, 7 were operated by PLIF and 1 by ALIF. In this worsened group, an initial pseudarthrosis was seen in 3 cases. Of the patients who improved, 6 were women and 3 were men. Three patients had a one level fusion while 6 had a multilevel fusion. Five operations were by PLIF and 4 by ALIF. Initial pseudarthrosis was seen in 4 of the improved patients.

Table 6.3 1-year, 3-year, and long-term clinical success rate of interbody fusion.

Outcome	Satisfied	Unsatisfied
After 1 year	52 (69%)	23 (31%)
After 3 years	53 (71%)	22 (29%)
After > 10 years	53 (71%)	22 (29%)

Table 6.4 1-year, 3-year and long-term clinical outcome results of interbody fusion.

	Excellent 21*		Good 31*		Fair 20*		Poor 3*	
	3y	>10y	3y	>10y	3y	>10y	3y	>10y
Excellent	20	8	1	10	0	2	0	0
Good	1	9	28	17	3	7	0	0
Fair	0	4	2	3	17	4	1	2
Poor	0	0	0	1	0	7	2	1

* number of patients and clinical outcome after 1 year.

Of the 48 patients with early established radiological fusion, 77% had a long-term satisfied clinical outcome on the Macnab classification compared to 59% of the patients with initial pseudarthrosis. This difference in proportion was not statistically significant. The mean RM-score in patients with initial radiological fusion was 9.0 compared to 13.5 in patients with initial pseudarthrosis ($P<0.05$: student t-test). A better long-term clinical outcome was seen in patients with a one level fusion (86%) compared to patients with a multilevel (two or three) fusion (64%)(95%CI (0.03-0.42)). Patients with a one level fusion had a mean RM-score of 7.2 compared to a mean RM-score of 12.1 in patients with a multilevel fusion ($P<0.05$: student t-test).

6.4 DISCUSSION AND CONCLUSIONS

Patient satisfaction on clinical success rate in the present series amounted 70% and corresponds to the outcome in other publications on lumbar fusion in a comparable group of patients which report success rates between 30 and 90%.[4] Although in the majority of cases clinical success rate is maintained for a long period of time we have figured out that individual clinical satisfaction may change significantly in a minority of cases (n=17). There is no good explanation for these changes. Apparently measurements of the clinical outcome are time-specific and submitted to variables.

A remarkable finding was that the long-term clinical outcome in patients with initial fusion discrepant differed from the patients with initial pseudarthrosis on the Roland-Morris questionnaire and not on the Macnab classification. At the time of treatment we believed in the hypothesis that the chronic low back pain was caused by movements in a particular motion segment. By achieving a solid interbody fusion these painful motions were prevented and as a result symptoms would subside. The outcome that nearly 60% of the patients with initial pseudarthrosis had a long-term satisfactory clincal results either means that the assumed theory is incorrect or that bony union eventually occurred. Unfortunately the latter possibility is not likely since the same result was seen in the initial group of 157 patients. In that group 50% of pseudarthrosis cases had a successful clinical outcome. A third possibility is the presence of inaccuracies in the determination of postoperative radiological bony union or in the evaluation of the clinical outcome.

The accuracy of predicting solid arthrodesis by radiographs is limited as illustrated by Brodsky[2]. In his study, 175 patients were included who either had internal fixation devices removed after lumbar spinal fusion or who were re-operated for failed back surgery. The pre-operative radiological assessment was compared to the surgical findings. Noncorrelations were present in 36% of plain radiographs, in 41% of polytomographs, in 38% of bending films and in 43% of CT-scans. Other investigators have confirmed the inaccuracy of imaging techniques in evaluating spinal fusion.[1,5,9] Although progress in computed tomography and magnetic resonance imaging is being made, currently most reliable technique is probably offered by roentgen stereophotogrammatric analysis (RSA) (see Ch 7).

Howe and Frymoyer[6] have evaluated 14 different questionnaires on the determination of end results in single lumbar disc surgery. They found out that the satisfactory outcomes ranged from 60% to 97% depending on the questionnaire being used. Especially when a questionnaire with groups rated as excellent, good, fair and poor were ultimately reported as satisfactory and unsatisfactory the finesse was lost. There is only a fine line between a good and a fair result but the shifts from one to another may have significant effects on the results reported as satisfactory and unsatisfactory. We used the Macnab classification

for the clinical outcome evaluation because the Macnab is practical and widely used. To make the difference between a good and fair result on the Macnab classification more obvious we added another condition: would the patient undergo the same procedure again? When a patient scored good on the Macnab but would not have surgery performed again he was scored as fair. A patient who would have surgery done again but with a fair result on the Macnab was scored as good. Howe and Frymoyer[6] also emphasized the importance of the person presenting the results. A patient tends to report better results to his surgeon than to an independent person.

In conclusion, in this retrospective study on 75 highly selected patients with discogenic low back pain treated with lumbar interbody fusion, the initial overall clinical outcome was maintained over a long period of time. The best long-term clinical results were obtained and maintained in patients with a one-level fusion. There was a statistical difference in the long-term clinical outcome between initial fusion and pseudarthrosis on the Roland-Morris disability questionnaire but not on the Macnab classification. The result from this study must be interpreted carefully since reliable evaluation of fusion status and clinical outcome is not feasible. More accurate methods for determining fusion status and clinical end results of lumbar spinal surgery need to be developed in the future.

Appendix: Roland Morris Questionnaire[14]

When your back or leg hurts, you might find it difficult to do some of the things you normally do. This list contains some sentences people have used to describe themselves when they have back pain. When you read a sentence that describes you today, put a check in the yes column. If the sentence does not describe you, check the no column.

Yes	no	
		1. I stay at home most of the time because of my back problem.
		2. I change position frequently to try and get my back comfortable.
		3. I walk more slowly than usual because of my back problem.
		4. Because of my back problem, I am not doing any of the jobs that I usually do around the house.
		5. Because of my back problem, I use a handrail to get upstairs.
		6. Because of my back problem, I lie down to rest more often.
		7. Because of my back problem, I have to hold on to something to get out of an easy chair.
		8. Because of my back problem, I try to get other people to do things for me.
		9. I get dressed more slowly than usual because of my back problem.
		10. I only stand up for shorts period of time because of my back problem.
		11. Because of my back problem, I try not to bend or kneel down.
		12. I find it difficult to get out of a chair because of my back problem.
		13. My back is painful almost all the time.
		14. I find it difficult to turn over in bed because of my back problem.
		15. My appetite is not very good because of my back pain.
		16. I have trouble putting on my socks (or stockings) because of the pain in my back.
		17. I only walk short distances because of my back pain.
		18. I sleep less well because of my back problem.
		19. Because of my back pain, I get dressed with help from someone else.
		20. I sit down for most of the day because of my back.
		21. I avoid heavy jobs around the house because of my back.
		22. Because of my back pain, I am more irritable and bad tempered with people than usual.
		23. Because of my back problem, I go upstairs more slowly than usual.
		24. I stay in bed most of the time because of my back.

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Chapter 7

A FAST AND ACCURATE TECHNIQUE TO EVALUATE SURGICAL LUMBAR FUSION

7.1 INTRODUCTION

In evaluating fusion status after lumbar interbody fusion, plain radiographs - often with additional bending films - are widely used. However, the accuracy of predicting solid arthrodesis by radiographs is limited as illustrated by Brodsky.[2] In that study, 175 patients were included who either had internal fixation devices removed after lumbar spinal fusion or who were re-operated for failed back surgery. The pre-operative radiological assessment was compared to the surgical findings. Noncorrelations were present in 36% of plain radiographs, in 41% of polytomographs, in 38% of bending films and in 43% of CT-scans. Other investigators have confirmed the inaccuracy of imaging techniques in evaluating spinal fusion.[1,3,6] Although progress in computed tomography and magnetic resonance imaging is being made, one generally assumes that the only way to be sure about fusion status is surgical exposure.[2,6]

Whatsoever, since routine surgical exploration after posterolateral or interbody fusion is not feasible, non-invasive techniques are required that at least can accurately determine whether the vertebrae are rigidly connected or not. Roentgen Stereophotogrammetric Analysis (RSA) enables this assessment. Up to the 1970's, the development of RSA was slow and it was not generally used. In 1974 Selvik[9] introduced a complete RSA-system that included instrumentation for implantation of tantalum landmarks, devices for calibration of the roentgen set-up, and comprehensive software. RSA can be applied to assess growth, volume changes, and movement of bony structures. The main application of RSA is to assess the micromotion of orthopaedic implants with respect to the surrounding bone.

RSA has been used in only a few studies assessing the mobility of the lumbar spine after fusion. In these studies anteroposterior radiographs of the spine in supine and erect positions were made.[4,5,8] The so far limited application of the RSA-technique is probably explained by the need for specific hardware and specially educated investigators. RSA is also time-consuming since manual detection, labeling of markers and the RSA-calculations of each radiograph take approximately one hour.

In order to reduce the total analysis time of RSA-radiographs, a software package has been developed that is able to perform the measurements of the coordinates automatically in digital RSA-images (RSA-CMS, MEDIS, Leiden, The Netherlands). The software package runs on a PC with the Windows NT operating system. RSA-CMS can handle scanned conventional radiographs (Vrooman et al.[10]) or direct radiographs in DICOM-format. The use of Digital Roentgen Stereophotogrammetric Analysis (D-RSA) with direct radiographs in DICOM-format has not been reported previously.

In this study, D-RSA was tested for its applicability in the assessment of fusion after lumbar spinal arthrodesis (posterolateral or interbody) using lateral bending films.

7.2 MATERIALS AND METHODS

The validity and variability of D-RSA were tested by rotating a standardized cylinder with tantalum markers in relation to a calibration box. The cylinder was rotated in the y-direction (see figure 7.1). By changing the position of the roentgen tubes, the sensitivity of D-RSA on differences in the external parameters was tested.

D-RSA

To determine lumbar spinal fusion status by D-RSA from digital lateral bending images the following was needed: 1) well placed tantalum bone-markers; 2) a biplanar radiographic system and a calibration box, and 3) a computer and calibrated D-RSA software. Since D-RSA provides a fully automatic analysis of digitally acquired lateral bending images, no specially trained investigators were needed.

1) Insertion of bone-markers

For the kinematic analysis, at least three tantalum markers with a diameter of 0.5-1.0 mm had to be inserted in a non-linear manner and well separated in at least two dimensions in each of the L4, L5, and S1 lumbar vertebrae. We used six bone-markers (Ø 1.0 mm) in each vertebra to make sure that enough markers could be detected automatically and no interactively correction by an observer was needed. The bone-markers of the lumbar vertebrae were placed into the vertebral body through each pedicle screw hole in a standardized manner. The first marker was introduced at the ending ventral of the pedicle screw hole, the second in a caudal-lateral direction and the third in a caudal medial direction (Fig. 7.2A). We also standardized the insertion of the bone-markers in the sacral vertebrae. The first marker of the sacral vertebra was inserted through the hole of the pedicle screw in a cranial-lateral direction, the second 1 cm lateral of the S1 foramen, and the third in the middle of the S1 and S2 foramen (Fig 7.2B). The markers were placed on each side of the S1 vertebra resulting in a total of 6 markers within the sacrum. The bone-marker positions were accessible for both posterolateral- and interbody fusion techniques. The tantalum markers were placed on a piece of bone wax (Ethicon bone wax, Johnson & Johnson), then each marker was scooped on the top of a simple biopsy needle (Ø 1.2-1.5 mm) and the marker was pushed into place by a mandarin. No specially designed implantation device was needed. We tested stainless steel and titanium hardware (pedicle screws, spinal rods and straight slotted connectors, ISOLA System AcroMed®, Cleveland, Ohio, USA) for fixation of the L4-5 and L5-S1 levels.

2) Radiographic examination

A calibrated reference cage with tantalum markers was placed under the soft-bone and radiographed simultaneously by two roentgen tubes at 1.0-1.5 meter distance at a 20- 30° angle from a lateral position (Fig. 7.3). When a scattergrid was applied, a more precise distance and angle of the roentgen tubes had to be used due to the specified grid focus. Flexion and extension from a neutral position were recorded in relation to the axes with a standardized orientation in relation to the soft-bone. For the experiments, normal radiation exposures were used (80-90 kV, 7-8 mAs). The acquisition of all the images was based on storage phosphor technology.

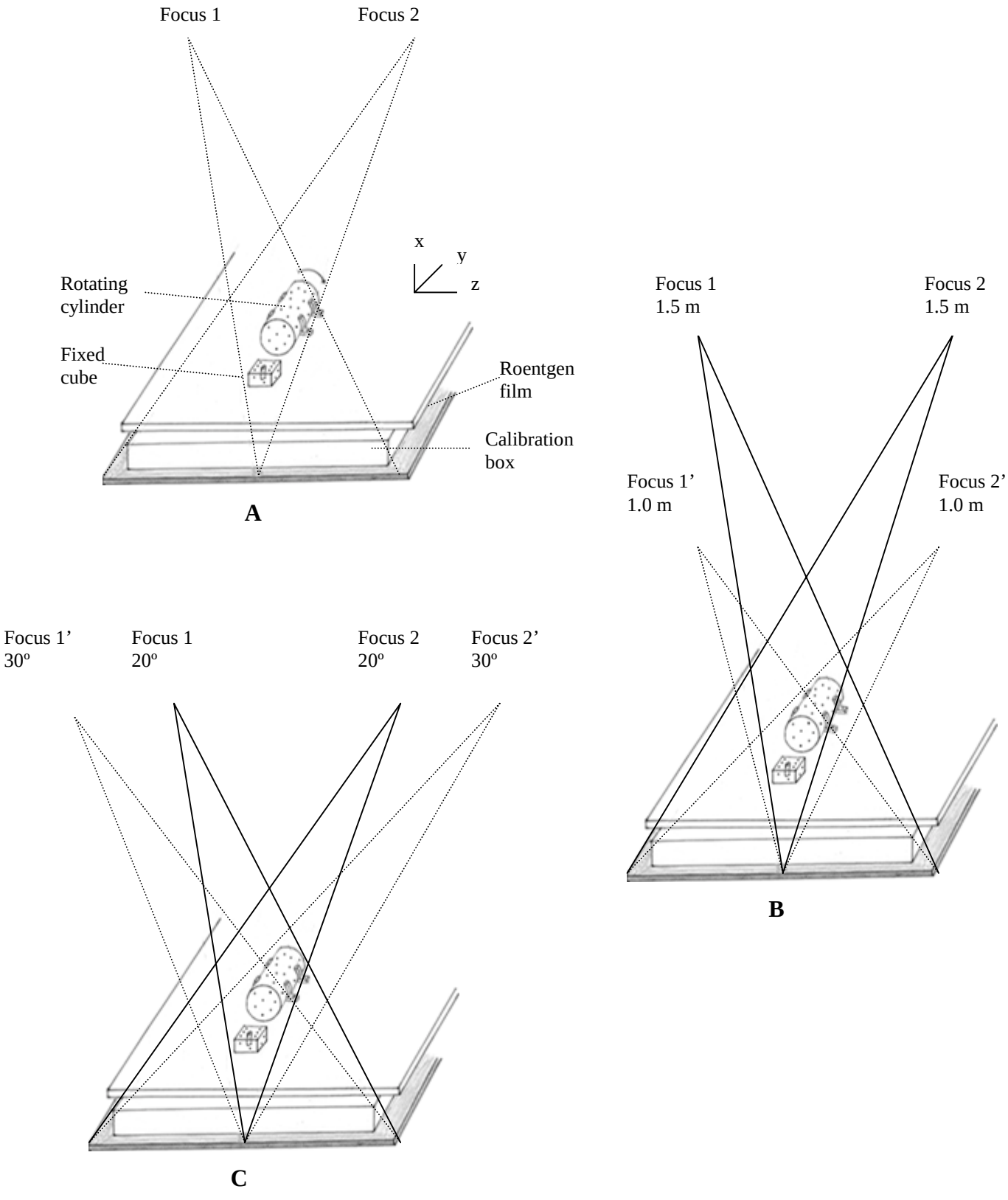

Figure 7.1 Testing validity and variability of D-RSA using a standardized cylinder and cube with tantalum markers

The cylinder was rotated along the y-axis (A) (see table 7.1), and the distance of the roentgen tubes was changed from 1.0 to 1.5 meters while the cylinder was not rotated (B) (see table 7.2). Finally, the angle of the roentgen tubes was increased from 20º to 30º without rotation of the cylinder (C) (see table 7.2).

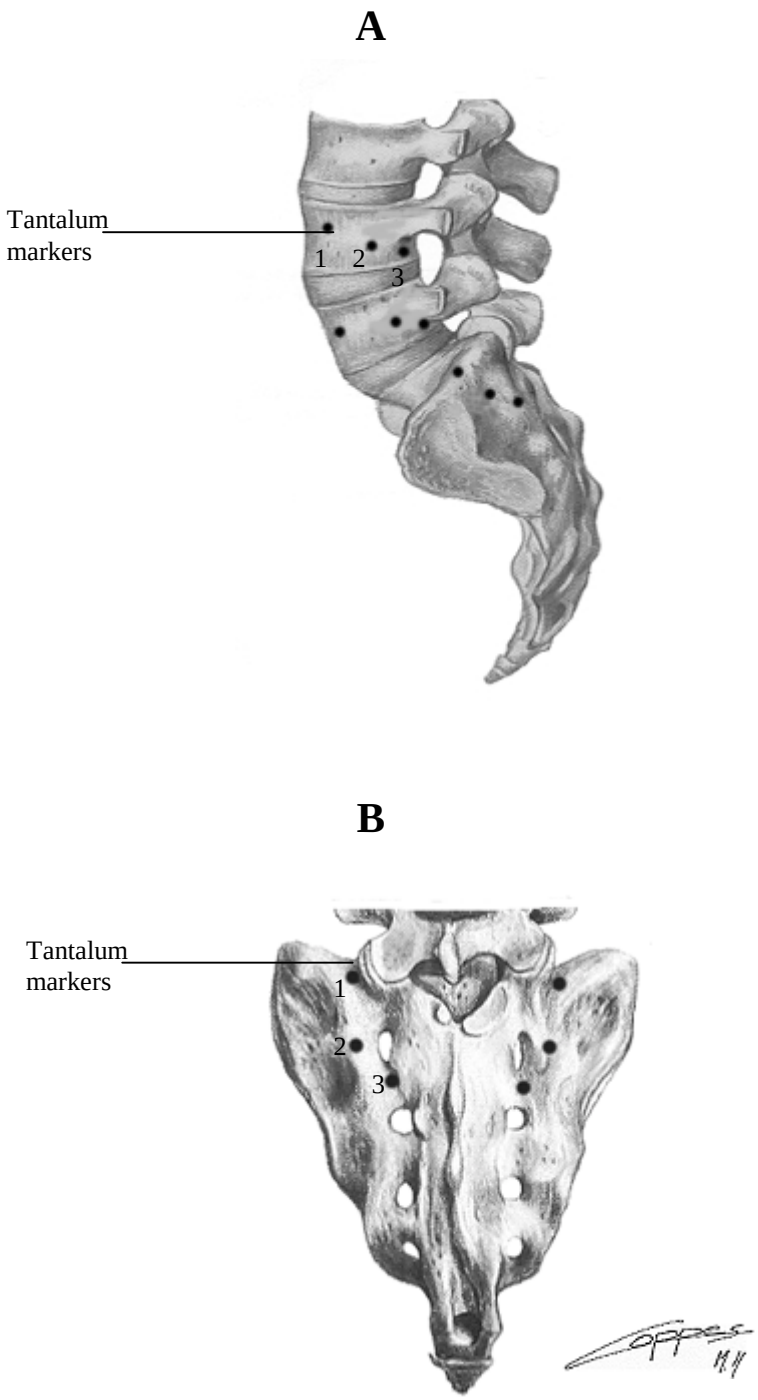

Figure 7.2 Placement of tantalum markers in the L4, L5 and S1 vertebrae.
A: lateral view of L3-sacrum. The markers of the lumbar vertebrae were placed through each pedicle screw hole: the first marker was placed ventrally of the pedicle screw hole, the second in a caudal-lateral direction in the corpus just beyond the pedicle, and the third in a caudal-medial direction to the caudal end-plate. The markers were placed in each pedicle screw hole so totally 6 markers were inserted in each vertebra.

B:posterior-anterior view of sacrum. The first marker of the sacral vertebra was inserted through the hole of the pedicle screw in a cranial-lateral direction, the second 1 cm lateral of the S1 foramen, and the third in the middle of the S1 and S2 foramen. A total of 6 markers was also inserted in the sacrum.

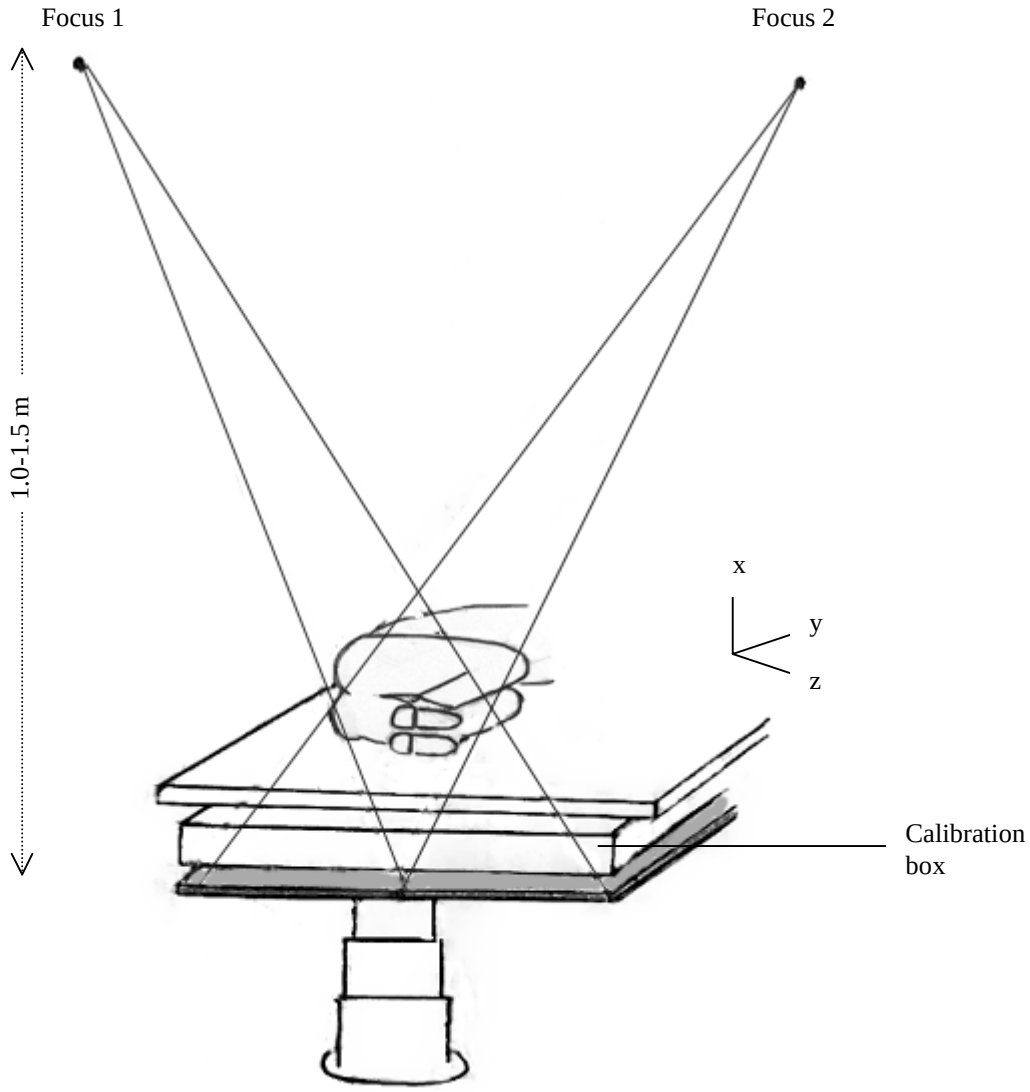

Figure 7.3 Biplanar radiographic system
The biplanar radiographic system consisted of two roentgen tubes positioned at a distance of 1.0-1.5m in a 20-30° angle from the object. A calibration box with tantalum markers was placed under the object. The lumbar spine was radiographed in flexion and extension from a lateral position.

3) Computation of movements

The digital roentgen data were transferred to a computer with RSA-CMS software. The software identified and numbered the tantalum markers of the calibration box and the soft-bone in a standardized manner (Fig. 7.4). Thereafter, the three dimensional (3-D) coordinates of each bone-marker were determined in flexion and extension. From the 3-D coordinates, the ranges of motion (ROM's) consisting of three translational components (Tx-lateral; Ty-axial or vertical; Tz-anteroposterior) and three rotational angles (Rx, Ry, and Rz representing flexion/extension, axial rotation, and lateral bending, respectively), were computed.

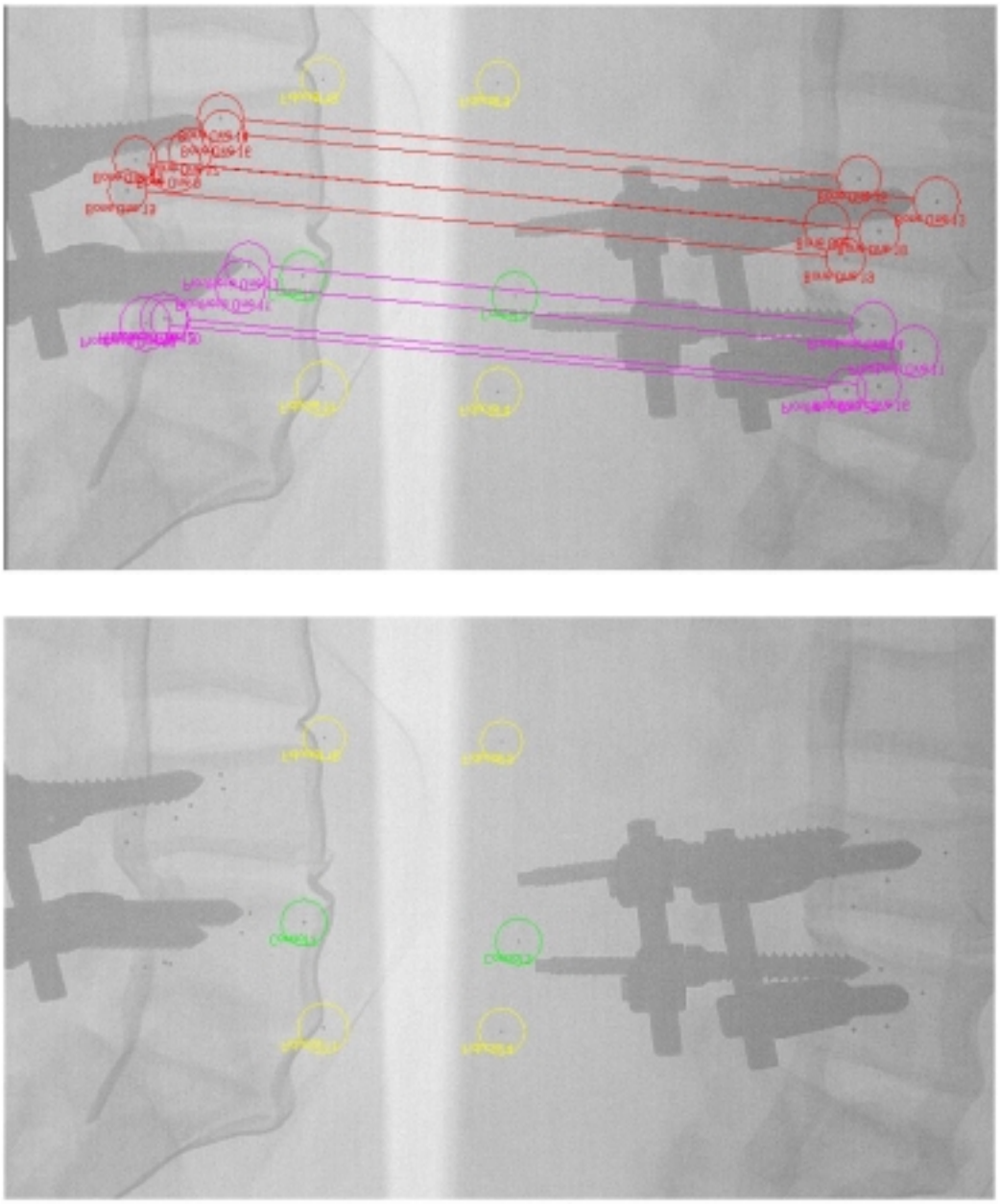

Figure 7.4 Stereopair of the L4-5 level in extension
The tantalum markers of the calibration box and the soft-bone were identified and numbered in a fully automatic manner.

7.3 RESULTS

7.3.1 Standardized cylinder rotation

The standardized cylinder was rotated by hand over approximately 15º and 30º. The D-RSA measurements are shown in table 7.1. Subsequently, the position of the roentgen tubes in relation to the cylinder was changed. The main concern in positioning the tubes was to get an image including all the markers of the calibration box. First, the distance of the roentgen tubes to the cylinder was changed from 1.0 to 1.5 meters and the range of motion (ROM) was calculated. Then the angle of the roentgen tubes in relation to the cylinder was changed from 20º to 30º. These differences in the position of the roentgen tubes had a minimal effect on the translation and rotation (<0.4 mm and < 0.4º; Table 7.2).

7.3.2 Soft-bone experiments

By placing the tantalum markers in the described positions in the soft-bone, the computer could easily identify and number the markers. The translational and rotational changes during flexion and extension could be determined in about four minutes. Translations of the fixated lumbar soft-bones during flexion and extension were in a range of 0.04-0.3 millimeters and rotations in the range of 0.04-0.7° (Table 7.3).

Table 7.1 Accuracy of D-RSA measurements.

	T-x (mm)	T-y (mm)	T-z (mm)	R-x (°)	**R-y (°)**	R-z (°)
Rot-0º	-0.07	-0.01	0.06	-0.11	**-0.11**	-0.01
Rot-15º	-0.19	0.01	-0.48	-0.11	**16.19**	-0.05
Rot-30º	0.15	0.01	-0.26	-0.414	**32.20**	-0.22

T = translation R = rotation

A standardized cylinder was rotated by hand in the y-direction over approximately 0º, 15º and 30º. The rotational changes measured by D-RSA are shown in the table. See also **figure** 7.1A.

Table 7.2 Translational and rotational changes with differences in the external parameters.

	T-x (mm)	T-y (mm)	T-z (mm)	R-x (°)	R-y (°)	R-z (°)
Distance	-0.11	-0.08	-0.37	0.34	0.05	-0.05
Angle	-0.11	-0.13	0.01	-0.04	0.28	-0.02

T = translation R = rotation

The distance from the roentgen tubes to the cylinder was changed from 1.0 to 1.5 meters (see also **figure** 7.1B). The angle of the roentgen tubes varied between 20° and 30° (see also **figure** 7.1C).

Table 7.3 Range of motion of the fixated lumbar spine during flexion and extension.

	T-x (mm)	T-y (mm)	T-z (mm)	R-x (°)	R-y (°)	R-z (°)
L4-L5	-0.28	-0.11	0.15	0.12	-0.18	-0.72

L5-S1	0.08	-0.15	-0.04	0.04	-0.34	-0.07

T = translation R = rotation

Once the tantalum markers were well placed and visible between the hardware it did not matter what type of hardware (stainless steel or titanium) was used to fixate the lumbar vertebrae. However, since tantalum has a higher density on radiographs than titanium, markers positioned in the projection of the titanium hardware could easily be detected with increased radiation exposure or with the use of a scattergrid (Fig. 7.5). The tantalum markers in the projection of stainless steel hardware could not be detected.

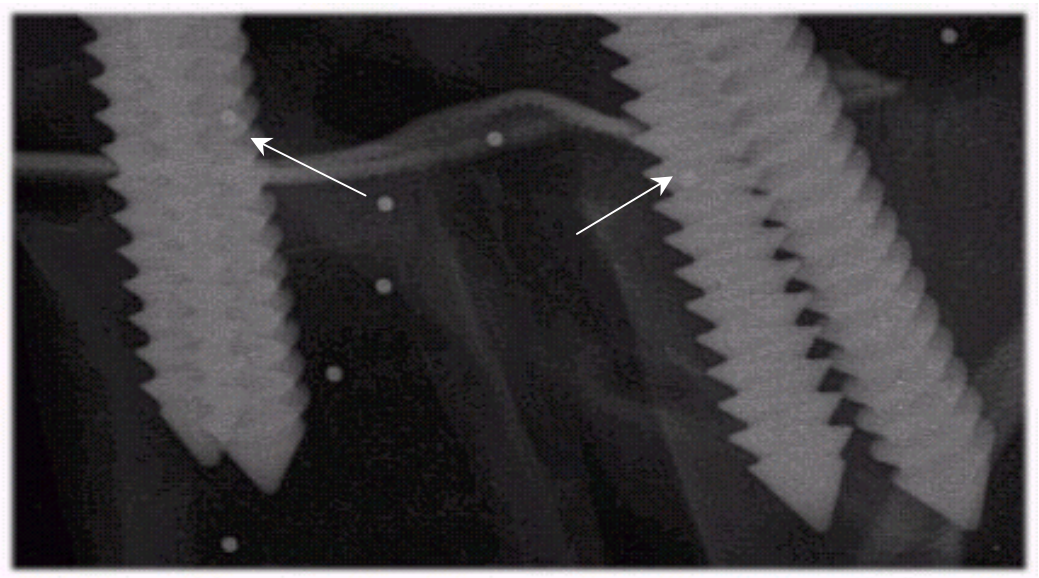

Figure 7.5 Visualization of malpositioned markers
When titanium hardware was used to fixate the lumbar vertebrae, using a higher voltage or a scatter grid could easily detect tantalum markers in the projection of the hardware.

7.4 DISCUSSION AND CONCLUSIONS

The classical goal in performing lumbar spinal fusion is to obtain a solid fusion. Many reports claim fusion rates up to 90% or more using a posterolateral- or interbody fusion technique with or without hardware. In these studies fusion results are assessed either by conventional radiographs, bending films or computed tomography (CT). We question these outcomes since it appears that radiological findings have a positive correlation with the surgical observations during re-operation in only 57-69 % of the cases depending on the imaging technique used.[1,2,6] In addition to the findings by Brodsky[2] , Kant[6] compared the plain radiographs with the surgical findings in 75 patients who had persistent low back pain after lumbar fusion and found a positive correlation in only 68% of the patients. The noncorrelates included false positive as well as false negative findings. Blumenthal[1] found an overall agreement between radiological and surgical findings of 69% in a study of 49 patients.

The high rate of inaccuracy of different imaging techniques possibly explains the poor correlation between radiological findings and clinical outcomes after lumbar fusion. In our previous study (Ch 5) on 157 highly selected patients with severely disabling chronic low back pain treated by lumbar interbody fusion 91 patients showed solid fusion on bending films. Out of these 91 patients, 73 (80%) had a satisfying clinical outcome. However, of the 66 patients with radiological pseudoarthrosis, 32 (48%) also had a good clinical result. A false-positive correlation between radiological findings and clinical outcome might explain the persisting of low back pain symptoms after radiological solid fusion while a false-negative correlation could lead to a successful clinical outcome without radiological fusion.

In evaluating spinal fusion, a special problem arises with the widely used interbody cages. The function of these cages is to stabilize spinal segments by distraction as well as by allowing bone ingrowth and fusion. A prerequisite for spinal fusion is the formation of bone tissue. Cages that allow as minimal end-plate destruction as possible are proposed to prevent postoperative loosening of the cage during spinal motion. However, there is no imaging modality by which the status and vitality of graft material inside a cage can reliably be assessed. Kuslich et al.[7] reported that radiolucency around the cage and/or angulation greater than 5 degrees on bending films are signs of lack of fusion. This may be true, but it is not allowed to turn this statement around since absence of radiolucency around the cage or angulation less than 5 degrees does not necessary indicate that fusion has occurred. Although D-RSA measures motion rather than fusion we believe that the ranges of motions (ROM's) detectable by D-RSA are so small that it reliably indicates whether or not fusion has occurred.

In this study, the established RSA technique is modified into a digital and fully automatic method for determining three-dimensional lumbar spinal motion in a highly accurate manner. With the current version of the software, total analysis time of one stereo radiograph is about 4 minutes, which is less than, for example, a CT-reconstruction of the lumbar spine. Since routine surgical exploration of spinal fusion is not preferable, a reliable technique to confirm fusion or pseudarthrosis such as D-RSA is needed. We conclude that the D-RSA-technique enables accurate assessment of the stabilizing effect induced by lumbar fusion.

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CHAPTER 8

GENERAL DISCUSSION

In this Ph-D thesis, several factors involved in the origin and substaining of low back pain are discussed, focusing on role of the degenerating intervertebral disc.

In general, when surgical treatment of low back pain is considered, an exact localisation of the causing anatomical or functional structure is necessary. Any structure of the lumbar spine that is connected to the nervous system can become a source of pain when affected by disease or disorder. In case of "discogenic" low back pain a major source of the pain is thought to be modulated via nociceptive fibers in the intervertebral disc. It appears that the discs from some selected patients with chronic low back pain are more and deeper innervated than the discs from individuals without back pain symptoms (Ch 3). One of the hypotheses in this study contends that degeneration of the intervertebral disc causes motion of the involved segment to become painful. By stabilising the motion segment any movement will be eliminated and the symptoms disappear. Out of the large group of patients with chronic low back pain we have tried to select patients who fit in this "discogenic" low back pain concept and might benefit from a lumbar arthrodesis. Since undoubtedly chronic low back pain covers a complex combination of pathophysiological, psychological and social factors a strict selection was performed (Ch 5). A lumbar interbody fusion was performed in 157 patients.

Interbody fusion for "discogenic" low back pain

An important aim of this study was to evaluate the clinical outcome after lumbar interbody fusion in these patients. In other words, do patients with "discogenic" low back pain benefit from lumbar interbody fusion? We discussed the postoperative clinical results after 1-year, 3-years and more than 10 years. The initial overall clinical satisfactory result of about 70% was maintained over the years. This does not support the belief that the ongoing degeneration process of the adjacent segments of the spine causes low back pain symptoms later on. Neither do these results implicate that less mobility and natural fusion of spinal segments later in life in the aged spine leads to fewer complaints. The natural history of chronic low back pain is unknown.

In publications on non- (or less) selected low back pain patients as well as on non-surgical studies in patients with chronic low back pain clinical success rates between 60 and 70% are reported.[10] A study by Rhyne[8] even shows an improvement in 68% of patients with chronic low back pain and painful disc degeneration after discography and without any treatment. This might implicate that in our highly selected group of in patients with "discogenic" low back pain, interbody fusion was not justified as proclaimed by many clinical investigators including Nachemson.[7] In our point of view, a surgical intervention is only to be considered when clinical success rates clearly exceed the sucess rates of non-surgical, less invasive, treatments (or the natural cause which is regrettably unknown).

In our study, the superior clinical outcomes were noted if the degeneration process remained limited to one level as shown by discography. Initially ¾ of these patients were satisfied with a clear tendency of further improvement over time (long-term satisfying result 86%). After a two level operation an overall satisfactory clinical outcome of approximately 65% was obtained. The latter results did not change with time. Based on these results we conclude that lumbar interbody fusion can be considered in selected patients in which degeneration is also limited to one segment of the lumbar spine.

Bony union correlates with satisfactory clinical outcome. Eighty procent of the patients with bony union, as observed by an independent radiologist, were satisfied. However, of the patients with radiological pseudarthrosis 50% also had a satisfactory clinical result. These results could confirm the inaccuracies in the determination of fusion as described by several investigators (Ch 6 and Ch 7). At present, no reliable non-invasive methods are available to confirm bony union apart from the D-RSA method as described in chapter 7. Only in presence of definitive bony trabecular bridging across a graft-host interface or clear motion on flexion-extension radiographs the fusion status is certain. Without the application of D-RSA the majority of the fusion results of interbody fusion can not reliably be assessed in the remainder of cases. We therefore strongly recommend the use of this novel technique in radiological evaluation of interbody fusion results.

In the literature superior fusion results have been reported with additional instrumentation using pedicle screws and rods. Taking in consideration the uncertainty of the virtually effected fusions, we believe that the overall fusion result of only 60% in our series could have been improved by the additional use of hardware. Another advantage of instrumentation is that the patients can be mobilised immediately after surgery and obviates wearing a lumbar spica.

In the aforementioned study we performed either an anterior or posterior interbody fusion. The surgical procedures are technically difficult. Particularly the ALIF is associated with a known high complication rate. To minimize complications, minimal invasive procedures have been developed for the anterior approach (Ch 4).

Shortcomings

In this study insight in the psychosocial situation of the patients was sought by multiple personal communications. Although personality and emotional factors were assessed as thoroughly as possible standardisation of scores was not obtained. A growing body of literature demonstrates that psychological factors, as assessed by the Minnesota Multiphasic Personality Inventory (MMPI), are significantly related to back pain.[1,2] The MMPI is a self-administered examination of 566 true/false questions, and it focuses on three clinical scales: hypochondriasis, depression, and hysteria. Scoring high on these personality traits predicts poor outcomes of lumbar fusion operations. One of the most limiting factors of using the MMPI is the relatively high numbers of false-positive findings, as shown by Leavitt[6]. Other shortcomings of the MMPI are its nonpractical use and long administration time. Nevertheless the MMPI can be used as a predictor of poor responses to any treatment, either conservative or surgical.[2,5,9] In patients with elevated scores on the hypochondriasis, hysteria and depression scales, one is dissuaded from surgical treatment.

In this thesis limitations in the selection and evaluation of surgical management of chronic low back pain patients have been listed. First of all, we performed interbody fusion to prevent painful motion at the degenerated intervertebral junction while objective

criteria to assess slight segmental motion between lumbar vertebrae are not present. It is therefore not possible to evaluate the effect of lumbar interbody fusion on these presumed motions. A second limitation in the management of "discogenic" low back pain patients by interbody fusion is the postoperative evaluation of the fusion status. Brodsky et al.[3] and others have shown that radiological evaluation of fusion status and findings at surgical exploration only correspond in about 60% of the cases. Therefore, despite the involvement of an independent radiologist and strict fusion criteria (see Ch 5), the reliability of the fusion outcome can be questioned. This limitation was not only encountered in our study but is a common problem in studies on this issue. A third limitation is the evaluation of the clinical outcome. Some investigators such as Howe and Frymoyer[4] have shown significant differences in the surgical outcome of the same patient population when evaluated by different criteria. The authors who claimed the best results utilised questionnaire designs that were exclusively based on subjective criteria (pain level and satisfaction with results). Therefore a combination of these subjective criteria with the use of functional criteria (e.g. Roland-Morris scale) is recommended.

Current approach

Based on current knowledge and available techniques we believe that a lumbar interbody fusion operation can be offered to a strictly selected patient group with "discogenic" low back pain. Preoperative psychological testing by an independent psychologist using standardised psychological tests such as the MMPI appears mandatory. MRI is useful in determining the levels of lumbar disc degeneration. Only the discs displaying degenerative changes on MRI are additionally tested on pain provocation by discography. In this sequence only patients with painful degeneration at one lumbar level are considered to probably benefit from interbody fusion. On theoretical basis we prefer the use of a minimal invasive anterior fusion technique in combination with a posterior pedicle screw-rod fusion system. The additional hardware is used to improve the fusion results and facilitate post-operative mobilisation. We strongly recommend the use of D-RSA to evaluate the post-operative fusion status.

Future directions

In the future more objective selection criteria need to be elaborated. In the discogenic back pain concept a "painful segmental instability" is conceived. It were useful to obtain "objective" information on not only the painfulness (discography) but but also on the segmental instability. The latter likely can be obtained by using the D-RSA technique preoperatively. After a percutaneous transpedicular placement of tantalum markers (neuronavigation) in the vertebrae the range of motion of the different segments can be assessed. This preoperative placement also allows a better insight in the immobilisation capabilities of a lumbar orthesis.

The use of human bone morphogenetic proteins (BMP's) as a osteoinductive growth factor in spinal fusion seems promising but needs further investigation in prospective randomised studies on humans. New stand-alone interbody cages are developed. Whether these cages can equal the results using grafts or cages with additional hardware has to be evaluated in prospective studies as well. For both types of studies mentioned above an

accurate follow-up of the effect of the procedures on intervertebral motion can be obtained with the use of the D-RSA technique as described in Chapter 7.

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Summary

A neurosurgeon deals with chronic low back pain patients almost daily. Most of these patients still have complaints of low back pain despite many different previous therapies. Surgical treatment is only to be considered in few cases of chronic low back pain sufferers. From this large group of chronic low back pain patients we have tried to select a small group of patients who might benefit from spondylodesis. This thesis is about the selection and treatment of this patient group. Their assumed source of pain and the results of surgical treatment will also be discussed.

Chapter 1. This chapter is a general introduction to the classification of low back pain, the epidemiology of low back pain and the clinical anatomy of the lumbar spine. A general accepted classification of low back pain is not present, at the moment, mainly because we deal with a symptom (pain) without a definite diagnosis. In most cases of low back pain, the findings on physical examination, radiographs, and histopathological studies do not correlate. Therefore, a strict pathophysiological classification is not possible. Many people (70-80%) in Western society will experience a period of low back pain at least once in their life. Fortunately in only 1% of the cases the symptoms will last for more than one year. However, the social-economic consequences of this group of chronic low back pain patients are considerable, due to the direct medical costs and the losses from earning and productivity. The total costs for low back pain in The Netherlands were estimated at 1.7% of the gross national product. The anatomy of the lumbar spine and the motion segment as the functional unit of the spine are also discussed.

Chapter 2. In this chapter, the neuranatomical mechanisms of low back pain are discussed in detail. The innervation of the different structures of the motion segment, de nociceptors and the pain pathways are subsequently described. Emphasis is laid on low back pain due to spinal degeneration. Degeneration of the lumbar spine is a sequence of biochemical, biomechanical, and physiological changes due to normal ageing. The degeneration process starts in the intervertebral disc and eventually affects all the structures of the spine. The degenerative changes of the different parts of the motion segment are discussed.

Chapter 3. In this chapter the innervation of discographically confirmed degenerated and “painful” human intervertebral disc was investigated. The innervation of intervertebral discs had previously been extensively described in fetal and adult animals as well as in humans. However, little was known about the innervation of severely degenerated human lumbar discs. The question was posed whether a disc that was removed for low back pain possesses an increased innervation compared with normal discs. The objective of this study was to determine the type and distribution patterns of nerve fibers present in degenerated human intervertebral discs. Therefore, the presence of nerve fibers was investigated using acetylcholinesterase enzyme histochemistry, as well as neurofilament and substance P immunocytochemistry. From 10 degenerated and 2 control discs, the anterior segments were excised and their nerve distribution studied by examining sequential sections. In all specimens, nerve fibers of different diameters were found in the

anterior longitudinal ligament and in the outer region of the disc. In 8 out of 10 degenerated discs, fibers were also found in the inner parts of the disc. Substance P-immunoreactive nerve fibers were sporadically observed in the anterior longitudinal ligament and the outer zone of the anulus fibrosus. These findings indicate a more extensive disc innervation in the severely degenerated human lumbar disc compared with normal discs. The nociceptive properties of at least some of these nerves are highly suggested by their substance P immunoreactivity, which provides further evidence for the existence of a morphologic substrate of discogenic pain.

Chapter 4. This chapter starts with a historical review of spinal fusion. The estimated number of spinal fusions performed in different countries are compared. Biomechanical considerations as well as different surgical techniques for interbody fusion and their complications are discussed. Special attention has been given to the minimal invasive anterior lumbar interbody fusion (mini-ALIF)-technique. In the last section of this chapter, bone grafting and the latest developments in the use of bone morphogenetic proteins and stemcells to improve bony union are discussed.

Chapter 5. This chapter is a prospective study that evaluates the outcome of lumbar interbody fusion in highly selected patients with severely disabling low back pain due to disc degeneration. Using strict in- and exclusion criteria, discography and external immobilisation, 157 patients with “discogenic” low back pain were selected for interbody fusion. An anterior or posterior interbody fusion was performed using tricortical iliac crest grafts. All the patients were operated in a 10-years time period. The postoperative regime consisted of immobilisation in a thoraco-lumbar plaster spica including the upper leg for three months. The clinical results were evaluated 1 and 3 years after the operation while the fusion results were obtained at least 1 year after the procedure by an independent radiologist. An overall clinically successful outcome was obtained in 67% of the patients after 1 and this percentage maintained unchanged at 3 years follow-up. A solid bony union was obtained in 60% of the patients. Patient satisfaction was statistically higher in those who showed bony union on radiographs. The best clinical results were seen in patients with a single level fusion and additional radiographic bony union. In all the patients, no major surgical complications were noted. This study shows that applying strict criteria results in a highly selected group of patients in which lumbar spinal spinal fusion is successful in the majority of cases. Especially when one-level pathology is taken as one of the inclusion criteria, lumbar spinal fusion renders satisfying results.

Chapter 6. This chapter describes a retrospective analysis of the long-term clinical outcome and disability status after lumbar interbody fusion in highly selected patients. In the literature on lumbar spinal fusion in patients with chronic low back pain and benign segmental degeneration only early outcomes are given. The objective of this study was to evaluate for the first time the long-term outcome of lumbar interbody fusion for discogenic low back pain and to relate this to the 1-year and the 3-year clinical outcome. Out of 157 patients with disabling chronic low back pain treated by interbody fusion between 1980 and 1990, 75 patients were evaluated at minimally ten years after the procedure. The long-term outcomes were obtained by a postal questionnaire, which consisted of a Macnab classification, a Roland-Morris disability questionnaire and additional questions concerning other medical conditions, psychological state and current medication. The patients themselves completed the questionnaire. The long-term results were related to the initial fusion status, the number of levels fused, the type of surgical

approach, gender and the age of the patients. A successful clinical outcome of lumbar interbody fusion for disabling chronic low back pain was obtained in 71% after more than 10 years (mean 16.2, range 10-20 years) compared to 69% after 1 year and 71% after 3 years. The long-term Macnab classification correlated well with the Roland-Morris disability score. Patients with a one level fusion had a significant better long-term clinical success rate than patients with a multi-level fusion (86% versus 64%). Although patients with initial radiological fusion had a long-term clinical outcome superior to patients with initial radiological pseudarthrosis (77% versus 59%), this difference was not significant. There was no difference in long-term clinical outcome between types of surgical approach, gender and age of the patients. It is concluded that the early overall clinical outcome of lumbar interbody fusion for highly selected patients with “discogenic” low back pain was maintained over a long period of time. The better long-term results were obtained in patients with a one-level fusion.

Chapter 7. In this section a study is presented on the modification of the established film based roentgen stereophotogrammetric analysis (RSA) into a simple, widely applicable and fully digital technique for determining fusion after lumbar spinal arthrodesis. This novel digital roentgen stereophotogrammetric analysis (D-RSA) technique was validated using a standardized cylinder and a calibration box. Consequently, six 1.0-mm tantalum markers were inserted in anatomically appropriate positions of the L4, L5 and S1 lumbar vertebrae in soft-bones. The L4-L5 and L5-S1 levels were fixated with two types of hardware: stainless steel and titanium hardware (pedicle screws, spinal rods and straight slotted connectors, ISOLA System AcroMed®, Cleveland, Ohio, USA). Digital roentgen stereo pairs of the lateral lumbar spine in flexion and extension were obtained using a biplanar radiographic setup. The acquired digital images of flexion and extension were fully automatically analyzed to determine three-dimensional (3-D) lumbar vertebral motion across the different segments. The study shows that D-RSA is a valid method that fully automatically determines three-dimensional lumbar spinal motion in a highly accurate manner within minutes. With this technique it will be possible to assess an accurate follow-up of the stabilizing effects of lumbar spinal fusion.

Samenvatting

Tijdens poliklinische spreekuren worden neurochirurgen dagelijks geconfronteerd met patiënten met chronische lage rugpijn. Als regel hebben deze patiënten, voorafgaand aan hun poliklinische bezoek, reeds vele vormen van behandeling voor rugpijn ondergaan, zonder (blijvend) succes. Chirurgische behandeling is echter zelden aangewezen, en de eerlijkheid gebiedt ons te zeggen dat de neurochirurg deze patiënten vaak zo snel mogelijk uit verdere behandeling zal ontslaan.

De vraag is of toch niet voor individuele gevallen een chirurgische oplossing overwogen moet worden. Uit de grote groep van chronische lage rugpijn patiënten hebben wij getracht een kleine groep te selecteren voor wie een spondylodese zinvol leek. Dit proefschrift gaat over de selectie en behandeling van deze patiëntengroep. De vermeende oorsprong van hun pijnklachten en de resultaten van de operatie zullen eveneens worden besproken.

Hoofdstuk 1. In dit hoofdstuk worden de verschillende classificaties van lage rugpijn, de epidemiologie van lage rugpijn en de anatomie van de lage rug besproken. Een algemeen aanvaarde classificatie van lage rugpijn bestaat momenteel niet. De belangrijkste reden is dat we te maken hebben met een symptoom (pijn) zonder duidelijke diagnose. In de meeste gevallen bestaat er een discongruentie tussen de bevindingen bij lichamelijk onderzoek, radiologisch onderzoek en histopathologische studies. Dit leidt er toe dat classificatie volgens strikte pathofysiologische criteria niet goed mogelijk is. De meerderheid van de bevolking in geïndustrialiseerde Westerse landen (70-80%) zal tijdens het leven te maken krijgen met lage rugpijn. Gelukkig zullen deze klachten bij maar 1% van hen langer dan 1 jaar duren. De sociaal-economische consequenties hiervan zijn echter zeer groot. Geschat wordt dat 1,7% van het Bruto Nationaal Product in Nederland besteed wordt aan de gevolgen van de lage rugpijn problematiek. Hierbij zijn zowel de medische kosten als de arbeidsongeschiktheidskosten en het verlies aan productiviteit voor de samenleving inbegrepen. De anatomie van de lage rug met het bewegingssegment als functionele eenheid wordt in het laatste deel van dit hoofdstuk besproken.

Hoodstuk 2. In dit hoofdstuk worden de neuro-anatomische mechanismen van lage rugpijn besproken. Achtereenvolgens komen de innervatie van de verschillende structuren van het bewegingssegment, de nociceptoren en de pijn mechanismen aan de orde. Degeneratie van de lage rug is onderdeel van het natuurlijke verouderingsproces. Het vindt stapsgewijs plaats en begint in de tussenwervelschijf waarna ook andere delen van het bewegingssegment mee gaan doen. De degeneratieve veranderingen in de verschillende delen van het bewegingssegment worden besproken.

Hoofdstuk 3. In dit hoofdstuk wordt de innervatie van, discografisch aangetoonde, ernstig gedegenereerde tussenwervelschijven onderzocht. De innervatie van normale humane tussenwervelschijven is genoegzaam bekend. Echter, wat er gebeurt met deze innervatie na ernstige degeneratie van de tussenwervelschijf is niet goed beschreven. Gebruik

makend van acetylcholinesterase-enzymhistochemische kleuringstechnieken en neurofilament- en substance P-immunochemische kleuringstechnieken werd de innervatie van 10 gedegenereerde en 2 controle tussenwervelschijven onderzocht. In alle tussenwervelschijven werd in het buitenste deel (het ligamentum longitudinale anterior en de buitenste ringen van anulus fibrosus) zenuwweefsel aangetoond. In 8 van de 120 gedegenereerde tussenwervelschijven werden deze zenuwvezels ook in diepere delen van de anulus gevonden. Substance P-immunoreactieve zenuwvezels werden sporadisch aangetoond in de buitenste lagen van de anulus en in het ligamentum longitudinale anterior. Deze bevindingen duiden op een meer uitgebreide innervatie in de gedegenereerde tussenwervelschijf ten opzichte van de normale tussenwervelschijf. Het feit dat sommige zenuwvezels substance P-immunoreactief waren, zou goed kunnen passen bij een nociceptische aard van deze vezels. Deze bevindingen tonen een morfologisch substraat voor discogene pijn aan.

Hoofdstuk 4. Dit hoofdstuk begint met een overzicht van de geschiedenis van arthrodese van de lage rug. Het geschatte aantal uitgevoerde spondylodeses in verschillende landen wordt met elkaar vergeleken. Biomechanische overwegingen alsmede verschillende operatietechnieken met betrekking tot intercorporele spondylodese worden besproken. Hierbij wordt speciale aandacht besteed aan de complicaties van de operatie en aan de minimale anterieure operatietechniek (mini-ALIF). In het laatste deel van het hoofdstuk wordt ingegaan op de eisen die gesteld worden aan het bot dat tussen de wervels wordt geplaatst ter verkrijging van een spondylodese. Nieuwe ontwikkelingen, waarbij gebruik wordt gemaakt van bone morphogenetic proteins (BMP’s) en stamcellen, worden besproken.

Hoofdstuk 5. Dit hoofdstuk behandelt een prospectieve studie waarbij de resultaten besproken worden van een intercorporele spondylodese bij geselecteerde patiënten met ernstige invaliderende chronische lage rugpijn. Gebruik makend van strikte in- en exclusie-criteria, discografie en externe immobilisatie, werden 157 patiënten geselecteerd bij wie een “discogene” oorzaak van de rugklachten aannemelijk leek. Bij deze patiënten werd een anterieure of posterieure fusie verricht met behulp van tricorticale crista iliaca grafts. Postoperatief volgde, gedurende drie maanden, immobilisatie in een Baycast corset. Het klinische resultaat werd na 1 en 3 jaar beoordeeld. De fusieresultaten werden gedurende minimaal 1 jaar vervolgd en door een onafhankelijke radioloog geïnterpreteerd. Een bevredigend klinisch resultaat werd bij 67% van de patiënten gevonden na zowel 1 als 3 jaar. Een radiologische fusie werd gezien bij 60% van de patiënten. Het klinisch resultaat was statistisch significant hoger bij patiënten met een radiologische fusie. De beste klinische resultaten werden verkregen bij patiënten die op 1 niveau zijn geopereerd en tevens een radiologische fusie van dit niveau laten zien. Ernstige complicaties deden zich in deze studie niet voor. Dit onderzoek laat zien dat strikt geselecteerde patiënten met chronische lage rugpijn baat kunnen hebben bij intercorporele spondylodese. Het beste resultaat bij deze groep patiënten lijkt behaald te kunnen worden indien de aanwezigheid van monosegmentale pathologie als inclusiecriterium wordt gehanteerd.

Hoofdstuk 6. In dit hoofdstuk wordt een retrospectief onderzoek verricht naar het klinische lange termijn resultaat van een lumbale intercorporele spondylodese bij de patiënten uit hoofdstuk 5. Bij de beoordeling van de resultaten van een dergelijke operatie bij patiënten met chronische lage rugpijn worden in de literatuur als regel alleen de initiële resultaten vermeld en ontbreken de lange termijn resultaten. Het doel van deze studie is de

beoordeling van de klinische lange termijnresultaten bij een groep geselecteerde patiënten, geopereerd in verband met ‘discogene’ lage rugklachten, en deze te vergelijken met het initiële resultaat 1 en 3 jaar postoperatief. Vijfenzeventig patiënten konden minimaal 10 jaar (spreiding 10-20 jaar; gemiddeld 16,2 jaar) na hun operatie geëvalueerd worden. De patiënten kregen een vragenformulier toegezonden bestaande uit: een 4-punts Macnab-classificatie (beoordeelt de klinische tevredenheid), een disability scale volgens Roland-Morris (beoordeelt functionele status) en een aantal aanvullende vragen. De resultaten van dit retrospectieve onderzoek werden vergeleken met de prospectieve gegevens verkregen 1 en 3 jaar na hun operatie tijdens poliklinische controles. Tevens werd naar een relatie gekeken tussen de klinische lange termijnresultaten en het initiële fusieresultaat, geopereerde niveaus, operatieve benadering, geslacht en leeftijd. Minimaal 10 jaar na de operatie gaf 71% van de geopereerde patiënten aan tevreden te zijn over het bereikte resultaat (Macnab-classificatie). Het eerste jaar na de operatie gold dit voor 69% van de patiënten en het derde jaar voor 71% van de patiënten. De lange termijn Macnab-classificatie correleert goed met de Roland-Morris disabilty score. Patiënten geopereerd op 1 niveau hadden een significant beter lange termijns klinisch resultaat in vergelijking met patiënten geopereerd op meerdere niveaus (86% versus 64%). Hoewel de patiënten met een (initiële) radiologische fusie een beter lange termijn resultaat hadden dan patiënten met een pseudarthrose (77% versus 59%) was dit verschil niet significant op de Macnab-classificatie. Er werd geen relatie gevonden tussen lange termijnresultaat en: operatieve benadering, geslacht en leeftijd. Voor de geselecteerde patiëntengroep in deze studie geldt dat het initiële klinische resultaat behouden blijft gedurende een lange periode. De beste resultaten werden verkregen bij de patiënten die op 1 niveau werden geopereerd.

Hoofdstuk 7. In dit hoofdstuk wordt de conventionele roentgen stereophotogrammetric analysis (RSA)-techniek gemodificeerd tot een snelle en makkelijk bruikbare digitale versie van deze techniek. Deze nieuwe digitale röntgen stereophotogrammetric analysis (D-RSA)-techniek wordt vervolgens geschikt gemaakt voor de beoordeling van lumbale arthrodese. Validatie van het systeem vindt plaats met behulp van een gestandaardiseerde cilinder met tantalum markers en calibratiebox. Vervolgens worden, gebruik makend van soft-bones, in de wervels L4, L5 en S1, op van tevoren vastgestelde plaatsen, 1 mm doorsnede tantalum bolletjes geplaatst. Per wervel worden 6 van deze bolletjes aangebracht. De wervels worden vervolgens met behulp van pedicelschroef-plaat-systemen (chirurgisch staal en titanium hardware) aan elkaar gefuseerd. Gebruik makend van twee roëntgenbuizen worden van deze soft-bones laterale digitale stereo-röntgenfoto’s in flexie en extensie gemaakt. De verkregen digitale opnames worden geheel automatisch bewerkt waarbij in een driedimensionaal (3-D) vlak bewegingen van de wervels ten opzichte van elkaar gemeten kunnen worden. De nauwkeurigheid van deze methode is kleiner dan 0,5 mm voor translatiebewegingen en kleiner dan 0.5º voor rotatie. Deze studie laat zien dat met digitale roentgen stereophotogrammetric analysis (D-RSA) in enkele minuten, volledig automatisch, microbewegingen zeer nauwkeurig aangetoond kunnen worden. Deze techniek maakt het mogelijk fusieresultaten na een spondylodese te vervolgen en het uiteindelijke resultaat te beoordelen.

Nawoord

Dit proefschrift heeft op papier slechts één auteur. Dit suggereert dat het schrijven hiervan een één-mans-aktie is. Zij die mij zijn voorgegaan weten dat niets minder waar is. Mede dankzij de hulp en steun van anderen is dit proefschrift tot stand gekomen. Hiervoor ben ik een groot aantal mensen dank verschuldigd. Een aantal wil ik met name noemen.

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Curriculum vitae

De auteur van dit proefschrift werd op 5 juni 1958 te Vlaardingen geboren. In 1977 behaalde hij het gymnasium B diploma aan het Titus Brandsma Lyceum te Oss. Na een éénjarige parkeerstudie (rechten) kon hij in 1978 een begin maken met de studie Geneeskunde aan de Rijksuniversiteit Leiden. Tijdens deze studie was hij als student-assistent verbonden aan de afdelingen hart-revalidatie en neurochirurgie. Na het behalen van het arts-diploma (1985) volgde een AGNIO-schap neurochirurgie in het Academisch Ziekenhuis Leiden. Vanaf 1986 was hij als arts-assistent in opleiding op deze afdeling werkzaam (opleider H. v. Dulken). De opleidingsperiode bevatte één stagejaar neurologie in het Academisch Ziekenhuis Leiden (Prof. Dr. G.W. Bruyn), één jaar algemene heelkunde in het St. Antonius Ziekenhuis te Leidschendam (Dr. H. Wamsteker) en een (wissel)stage neurochirurgie van drie maanden in het Academisch Medisch Centrum Amsterdam (Prof. Dr D.A. Bosch). Per 1 januari 1992 werd hij als neurochirurg geregistreerd. Van 1992 tot medio 1994 was hij als staflid verbonden aan het Academisch Ziekenhuis Leiden. Sindsdien is hij werkzaam als neurochirurg in het Academisch Ziekenhuis Groningen.