Low Back Pain and Everyday Activities

The influence of axial rotation on low back pain

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The influence of axial rotation on low back pain

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De invloed van axiale rotatie op lage rugklachten

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Patents on Rotary Continuous Passive Motion

- European patent nr. 0574073
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- Japanese patent nr. 2990324
- Canadian patent nr. 2097737
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Contents

Voor jou en alle mensen

CHAPTER 1

General Introduction

Background

Back pain is the second most common pain after headache and is one of the most frequent syndromes presented in primary care [20]. Epidemiological studies on the prevalence and incidence of low back pain (LBP) have confirmed the major impact of this problem [3,4,7,12,15,18,20]. Andersson (1999) reported that up to 85% of the population will get LBP once or more during their lifetime; he also found that back problems were the most common cause of activity limitation in those aged under 45 years and the fourth most common cause in those aged 45 to 64 years [4]. Costs of LBP in the Netherlands in 1991 were estimated to be $ 5 billion [21]. Moreover, the incidence of back pain continues to increase in industrialised lands. Murphy and Volinn found a 22% increase in chronic LBP in the USA and a 35% increase in activity limitation from back pain between 1987 and 1994, but a reduction thereafter until 1998 [13]. However, an historical review by Allan and Waddell concluded that human beings have had back pain throughout history and that it is no more common or severe than it has always been [2].

Current knowledge

Pain has always been interpreted as a sign of disease or injury. Although this interpretation is probably true for most patients with acute back pain, it becomes less likely in the case of chronic back pain [15].

LBP has a variable aetiology, which is best described by the "biopsychosocial" model of Gordon Waddell [23]. LBP is usually classified as either specific or non-specific, i.e. back pain with or without an obvious pathophysiological cause. Specific causes include the lumbar radicular syndrome, rheumatic diseases, tumours, metastasis and osteoporosis, as well as back pain due to internal diseases and extreme deviations in posture [16]. Specific causes are found in 5-10% of all cases of LBP. According to the Dutch guidelines the term "non-specific LBP" is applicable when no specific cause can be found, which is the case in 90-95% of patients with LBP [16].

Thus, LBP is mainly a non-specific disorder without distinct diagnostic criteria [15,16]. Until now no reliable differentiation with regard to structural lesions has been made for non-specific LBP [16]. Because no specific cause can be found, it is difficult to treat the disorder in an appropriate way. Therefore national and international guidelines propose the use of non-categorical treatment for non-specific LBP, derived from evidence-based clinical studies [1,11,16]. Many of the systematic review activities have been conducted by the Cochrane Collaboration and the Cochrane Back Review group [9,21].

Guidelines

National and international guidelines, such as from the Quebec Task Force in 1983, have been followed by recommendations from the USA in 1994 [5], the UK in 1996 [22], the Netherlands in 1996 [16] and from other countries for the management and treatment of LBP. A comparison of the clinical guidelines from 11 different countries showed the diagnostic and therapeutic recommendations to be very similar [11]. Guidelines limited to recommendations for activities of daily life as well as for occupational activity and exercises have been issued by the Paris Task force on Back Pain [1].

Treatment, then and now

Although strict bed rest was the accepted practice from the late 1800s until the early 1970s, current practice based on clinical reports is to encourage patients to get out of bed as soon as possible [2,9]. Without objective signs of radiculopathy (as in specific LBP) patients are strongly encouraged to maintain or resume their normal activities, as far as the pain allows [1,2,8,9,16]. These recommendations also encourage an active exercise program in cases of sub-acute and chronic LBP. Similarly, a return to occupational activities is also advocated, except in the case of *acute* LBP [1,14].

Although recommendations based on scientific evidence are encouraging mobility, activities of daily living, exercises and occupational activity, routine medical practice tends to resist this encouragement. Even today it is common practice that physicians still restrict rather than encourage physical activity and work in patients with LBP [19]. Argument may be a supposed direct pain provocation and the old adagio : "*let pain be your guide*", but also the idea that some activities are risk factors on their own [1,8,19].

Rationale for the current studies

During the course of time, recommendations for the treatment of LBP have changed. There is now a tendency to support the idea that physical activity can be valuable for LBP. Although there are numbers of randomized controlled trials that showed that activity and exercise are essential for the recovery of non-acute, non-specific LBP [11,17], there is still a lack of agreement with general practice [19]. It seems that old axioms and "biomechanical models" are in conflict with new experience and recommendations.

Therefore, the aims of this study were to investigate the influence of activities of daily living on low back pain and to establish better understanding of which activities of daily living are advisable and which are not. Furthermore, we related these daily activities to a physical quantity of the spine as a parameter, with the aim to develop a treatment modality which reduces the negative determinants.

The studies in this thesis are reported in chapters 2 to 6.

Chapter 2 explores how far normal activities of daily living provoke pain in patients with LBP. Chapter 3 investigates the amount of spinal shrinkage caused by the spinal load from five activities of daily living, and Chapter 4 studies the number of spontaneous spinal axial rotations during such activities. In Chapter 5 a new seating device with rotary continuous passive motion (RCPM) to avoid the static component during sitting is tested on patients with LBP. Finally, Chapter 6 explores the influence of the frequency of these rotary dynamic stimuli.

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CHAPTER 2

Influence of Daily Life Activities on Pain in patients with Low Back Pain

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L.L.J.M. van Deursen MD 1 C. J. Snijders PhD 1 , J. Patijn PhD 2

1 Department of Biomedical Physics and Technology, Faculty of Medicine and Health Sciences, Erasmus MC University Rotterdam, the Netherlands

2 Neurologic Department, Academic Hospital Maastricht, the Netherlands

Summary / Abstract

Few data are available on the influence of daily life activities on pain in patients with low back pain (LBP). Therefore, on their first visit to a clinic for musculoskeletal disorders and manual medicine, 100 patients were asked by means of a questionnaire which activities of daily life caused them pain. This questionnaire was deliberately used prior to routine anamnesis and physical examination and separate from a clinical diagnosis. Exclusion was made for patients with highly acute LBP, i.e. pain for less than 6 days. Four physicians each asked 25 unselected and undetermined LBP patients.

From the total patient group, 85% experienced pain on sitting, 78% on a partly bent position, 73% on standing, 70% on standing up out of sitting, 66% on sauntering, 60% on total forward bending, 47% on lying down, 23% on walking, and 15% experienced pain on cycling.

This results show that total forward bending provokes less pain than a partly bent forward position. An even larger contrast exists when comparing static sitting with dynamic sitting, such as during cycling. Static activities, even lying down, are more pain provoking than dynamic activities.

Data on which daily life activities provoke pain may play an essential role in the further elucidation of non-specific low back pain.

Keywords: Low Back Pain; Anamnesis; Activities of Daily Life

Introduction

In the clinical practice, low back pain (LBP) patients present with a variety of symptoms, but few patients report a loss of sensibility or muscle strength in the lower extremities. In a small number of cases X-ray, MRI or blood testing may give a decisive answer about possible causes. The vast majority i.e. 90-95%, however, receives the diagnosis of non-specific LBP, or LBP "e causa ignota" [9,10]. Within the anamnesis most attention is paid to specific LBP items with the aim to detect or exclude this 5-10% specific LBP. This is done because most non-specific LBP spontaneously disappears in due course [9,11,15,18]. In clinical practice patients are also asked about daily activities at home or at work, but such questions are often considered indicators of functional status rather than risk factors in their own right [1,9].

Generally, clinicians do not include questions about pain provoking situations in daily life other than to establish a specific diagnosis or factors influencing the prevalence of LBP. An interesting issue, however, is which activities provoke pain in cases of non-specific LBP. According to the International Paris Task Force on Back Pain, there is no direct information on the relation between back pain and either mobility or activities of daily living [1]. To our knowledge, only few studies have reported on this issue, based on the statements and diaries of study participants with previous or present low back pain [2,7,13]. There seems no consistent pattern of reported experience. On the other hand there are a lot of studies concerning working activities as being risk factors for LBP [19]. Also activities characterized by an awkward posture, by the same posture for a long time, or by often bending and rotating the trunk increased the risk for LBP [16]. Therefore, we undertook an anamnestic investigation on LBP patients focusing on which activities of daily life provoke pain.

Unusually we deliberately asked LBP patients (with or without leg-pain) without first investigating them for a clinical diagnosis in order to avoid an investigators bias and disagreement for diagnosis. Statistically 90-95% would show up with non-specific LBP while 5-10% would have specific LBP.

Based on earlier routine answers during anamnesis, we expected the least pain problems with the most dynamic activities.

Material and Methods

Four physicians working in a clinic for musculoskeletal disorders and manual medicine, each questioned 25 patients presenting with LBP at their first visit to the clinic. Patients were not selected but patients with highly acute LBP, for less than 6 days, were excluded from this investigation, because patients with acute lumbago are mostly complaining about pain during all postures and activities. The male / female ratio was 43/57 , mean age was 40.8 years (SD 8.4 years) and mean duration of LBP was 68,3 months (SD 71,4 months).
Before being investigated according to the normal procedure with LBP anamnesis and physical examination, the patients were questioned using a questionnaire. The nine questions could be answered with a "yes" or "no": "Do you or do you not experience pain", during: 1) sitting, 2) standing up out of a sitting position, 3) walking, 4) sauntering, 5) cycling, 6) lying down, 7) standing, 8) totally bent forward with a rounded back, 9) partly bent forward position.

Results

All questions were answered by all 100 patients, except for one question. One patient never cycled so could not answer the question about pain during cycling; therefore, for this particular question we had only 99 answers.

Figure 1 presents an overview of the questionnaire results.

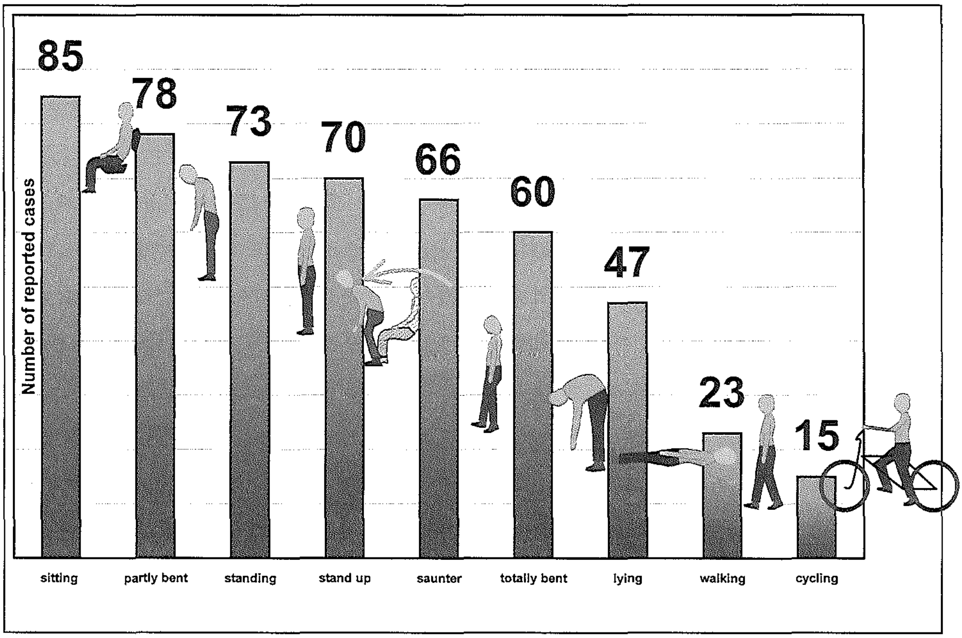

Figure 1. Data on patients' low back pain, related to postures adapted in everyday activities (n=100 patients)

Discussion

It appears that most pain problems occurred with sitting, followed by the partly bent posture. Surprisingly, almost half of the patients experienced pain lying down, whereas walking and cycling caused the least problems.

This results show that total forward bending is less pain provoking than a partly bent position. An even larger contrast exists when comparing static sitting with dynamic sitting, such as during cycling.

Although some clinicians still advise bed rest as a treatment for LBP, general opinion now supports early resumption of normal daily activities, even when pain is present [1,8,9]. The finding that 47% of our patient group still has pain complaints when lying down supports this trend. The results of this study are similar to those of Biering-Sorensen [2], but he reported "stooping" to be the most common aggravating factor, followed by the sitting position; however, no description was given concerning the degree of stooping, whereas in our study a distinction is made between a partly and a totally bent posture. In Biering-Sorensen's study, the greatest relief of LBP was achieved by lying down followed by walking around [2], which partly agrees with our results. We are fully aware of the limitations of our questionnaire as there is no description on sitting posture or length, as on walking and cycling speed as well as on the quality of the bed. Also the restriction of giving only a yes or no means that there was little room for nuance. Questions about a certain activity, such as cycling, produce a general score. Within this activity, however, more or less pain-provoking situations can be distinguished. For example, most patients experience pain due to a bump in the road or axial shock. When sitting on a chair a prolonged period of sitting mostly promotes pain; the same holds for standing. In walking, the speed, distance and step length are often decisive. If large steps are painful a radicular pain is often felt similar to that in straight leg raising, whereas pain provoked by walking a short distance can be indicative of neurogenic claudication. Running is often reported as beneficial in contrast to sauntering.

In our patients there was significant pain provocation in the partly bent posture, such as during vacuuming, brushing teeth, washing dishes or sweeping a floor. No clear explanation for this has emerged, but we suggest a possible ligament strain of the iliolumbar ligaments in combination with the "click-clack" phenomenon [5,17]. Transient pain at mid-range was described by Cyriax as a painful arc on the way down in flexion, or on the way up from trunk flexion; he describes this painful arc as pathognomonic of a disc lesion [3].

The favourable effect of movement on pain experience is in agreement with our clinical experience and former investigation on passive dynamic sitting [6]. Evidence is found in enhanced disc nutrition and improvement of the control of the neuromuscular skeletal system. [4,12,14]

The LBP anamnesis is generally focussed on the 5-10% specific LBP. Because of the medical importance of specific LBP it is understandable that anamnestic questions aiming at the diagnosis or exclusion of specific LBP have priority. However, this implies that questions and possible answers concerning the 90-95% non-specific LBP

are accepted as being less important. The fact that non-specific LBP seems to be a universal, benign, self limiting condition [9,20] tends to support this lack of interest.
In the present study we asked 100 non-selected LBP patients about activity-related pain. Because we expect that 90-95% of this population has non-specific LBP, we consider the results to be representative for non-specific LBP, whereas no conclusions on specific LBP can be drawn from this study.
A possible influence on the outcome of this questionnaire could have the fact that our clinic has more chronic LBP patients than acute or subacute LBP patients. Such a selection of LBP patients could lead to an anamnestic outcome with more specific LBP patients, because non-specific LBP is generally accepted as being self-limiting on the short term [9,18]. On the other hand, most of chronic LBP patients coming to our clinic had already consulted a neurologist in order to exclude specific LBP.
Although clinicians may be familiar with the general results of this study, data on this issue are scarce. We know of no other study which provides information about what activities the LBP patient should avoid or perform, except for the non categorical treatment advice to maintain activities as far as pain allows [1]. The present study meets this demand by indicating which activities of daily life mostly provoke pain, and to what extent.

In our opinion, data on the influence of daily life activities on LBP could play an important role in the further elucidation of non-specific LBP. It also triggered us to investigate a new seating device and lumbar disc mechanics in dynamic sitting [4,6]. Such information may also lead to a better understanding and treatment of LBP "e causa ignota".

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CHAPTER 3

Relationship between everyday activities and spinal shrinkage

Submitted to Clinical Biomechanics

L.L. van Deursen MD[1], D.L. van Deursen PhD[1], C.J. Snijders PhD[1]

[1] Department of Biomedical Physics and Technology, Faculty of Medicine and Health Sciences, Erasmus University Rotterdam, the Netherlands

Summary / Abstract

Objective: Purpose of this study was to determine the spinal load in several activities of daily life and to assess a relationship with low back pain (LBP).
Background: LBP is thought to be related to spinal load. In a clinical evaluation of LBP as provoked by everyday activities, we found a relationship between static activities and intradiscal pressure as measured by Nachemson. However, an analogue relationship between dynamic activities like walking and cycling and spinal load is doubted and never shown.
Methods: Spinal load was ascertained by stadiometric measurement of the decrease in standing height, so-called "spinal shrinkage", quantified by the exposure of a 1-hour adopted posture or activity. 10 Subjects performed 5 daily life activities: standing, sitting, walking, cycling and lying down.
Results: Following average values for shrinkage were measured: standing -7.4 mm (SD 0.5); sitting -5.0 mm (SD 0.6); walking -7.9 mm (0.5); cycling -3.7 mm (SD 0.4) and lying down + 0.4 mm (SD 0.5).
Conclusion: A relationship was found between spinal shrinkage during static activities and intradiscal pressure as measured by Wilke. Although Wilke found also higher intradiscal pressure in walking than in standing, no significant difference in shrinkage was found between standing and walking. Where we expected a higher spinal load during cycling compared to normal sitting, we found significantly less shrinkage during cycling. No relationship was found between the amount of spinal load measured by spinal shrinkage and the occurrence of LBP during the same activities found in a previous study. This also raises doubts about the use of the Intradiscal pressure model for LBP and supports the growing tendency to recommend activities and exercises for LBP.

Keywords : Spinal shrinkage; Activities of Daily Life; Spinal Load; Intervertebral disc pressure; Low back pain.

Introduction

Bending and lifting are reported to be overloading activities with a high risk of low back pain (LBP) [4,16,21,28,43]. The main reason for this assumption is based on the *in vivo* intervertebral disc (IVD) pressure measurements by Nachemson [28-36]. An understanding of the loading of the spine is considered essential for health care; in prevention, treatment and therapy of LBP, because of an assumed direct relationship between LBP and high IVD pressure or spinal overload [3,4,16,17,19,21,25,26,29,30,35,44]. The assumption that a lower disc pressure is preferable has led to recommending bed rest for LBP over the last decades [3].
Direct measurements of spinal loading by means of *in vivo* studies are normally avoided because of concerns about the possible negative effects of introducing a pressure-needle transducer into the disc; therefore *in vivo* data are scarce. The most important *in vivo* data are from the pioneering IVD pressure measurements recorded by Nachemson during the 1960s and 1970s [28-36] and recently expanded by Wilke et al. [44] and Sato et al. [38].
A frequently used indirect method to determine spinal load is based on the exact measurement of spinal length. Eklund and Corlett [15] described the possibility of measuring body height with stadiometry, and presented a relationship between spinal shrinkage and spinal loading. Hereby changes in body height are used as a measure of disc compression. More shrinkage means a higher stress on the spinal column, considered to be physically more demanding [17]. The use of stadiometry is generally accepted as a method of assessing body or trunk height variation during exposure to different loading conditions. Nevertheless, much attention has to be paid to the measurement technique, diurnal changes, measuring moments and to the prior events before measurement [12,40,42]. Spinal creep was determined in various studies [2,5,15,17,18,19,22,39] by using a stadiometer to quantify the spinal load. With respect to the circadian variation measured by Tyrrell *et al.* [40], stadiometry was also used to quantify the spinal load during different lifting techniques [12,14], during hyperextension [25,26], to examine different sitting postures [2,22] and to quantify the effect of rest schedules during sedentary work [18] and the influence of

whole body vibration [39]. We used stadiometry to compare a conventional office chair with an experimental seat, which provides rotary continuous passive motion (RCPM) in order to relieve low back pain during sitting [6,8,9].

In an earlier clinical study we asked patients with LBP which activities of daily life provoked their pain [7]. Because LBP and low back complaints are thought to be related to the loading on the spine, we expected to find a relationship between back complaints and the supposed spinal load during these activities.
Therefore, the aim of the present study was to determine the spinal load of five normal everyday activities, i.e. lying down, standing, sitting, walking and cycling, in order to compare spinal load with our previous clinical findings [7], and to see whether stadiometry could be a useful parameter for LBP research. Moreover, we wanted to compare the spinal load as measured by spinal shrinkage with the IVD pressure as measured during these activities by Nachemson [28-36], Wilke et al. [44] and Sato et al.[38] in order to evaluate a non invasive easy method with a more sophisticated but invasive method.

Materials and Methods

Spinal length was measured with a stadiometer, an apparatus that has been described by others [2,5,9,12,14,15,17,18,25,26,27,39,40]. The stadiometer was made according to the design of van Dieën and co-workers (Figure 1)[14]. In order to reproduce the same posture, the frame is inclined 10 degrees backward. This apparatus is designed to decrease the natural degrees of freedom of the body, using special supports to immobilize the legs, knees, pelvis, spinal curvature and head. The position of the feet, knees and the lumbar and spinal support are adjustable for each individual.

Figure 1 shows the Stadiometer as used.

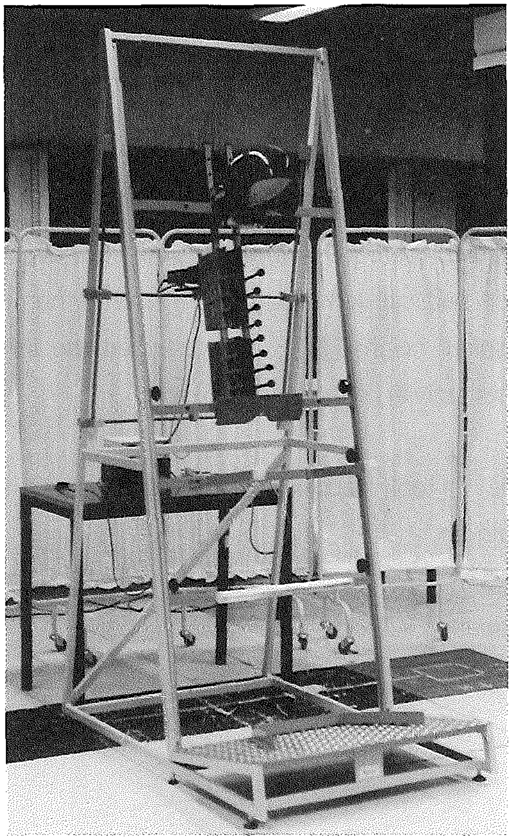

Figure 1: Stadiometer

The length of the spine is measured with a web cam, which focuses on a dot put on the body located on the processus spinosus of C7 (the vertebra prominens). For optimal reproducibility of the measurements we used the repeated measurement technique according to van Dieën, although others prefer an "in place" measurement technique [14,42]. Reproducibility and measuring faults were controlled by a training procedure and by taking the mean value of five repeated measurements during each measurement moment, to keep the individual standard deviation in reproducible standing below 1 millimetre, which serves as the overall measurement error.
In body length measurement the influence of the circadian variation in stature height is important, with the greatest variability being present when rising from bed [2,40]. Also important is the immediate influence of prior events, since the viscoelastic

behaviour of the IVD is highly affected by periods of load and relaxation. Therefore, it is possible that body length increases or decreases in sitting, depending on a prior event of low or high spinal loading [6]. Therefore, we decided to start all activities immediately (i.e. within 5 minutes) after rising from bed after a period of 8 hours sleep. This was done partly because changes in height are most rigorous in the early morning and thus more sensitive, but also to control for the prior events. A period of 8 hours bed rest was chosen because remaining in bed after a normal night's rest does not further increase spinal height [27]. We observed the influence of five different activities (1 hour per activity) on spinal shrinkage.

Ten healthy subjects (Table 1) took part in this investigation. All subjects were trained in reproducible standing.

Table 1 : Data on the participating subjects

Subject	**Gender**	**Age** (years)	**Height** (cm)	**Weight** (kg)
1	F	59	160	78
2	F	49	176	70
3	F	46	172	64
4	F	62	176	69
5	F	29	176	60
6	M	18	181	78
7	M	29	178	90
8	M	32	174	72
9	M	58	181	86
10	M	62	175	74

On different days the following protocols were followed: 1) sitting on an office chair (Drabert Entrada) while reading or doing computer tasks, 2) standing erect, 3) lying down on bed, 4) walking with an average speed of 5 km/h on the street and 5) cycling on a home trainer with a constant speed of 12 km/h. Each activity was done for 1 hour. The subjects were measured before and immediately after each activity.

Pain experience of LBP patients during the same activities found in an earlier study [7] is shown in Figure 2.

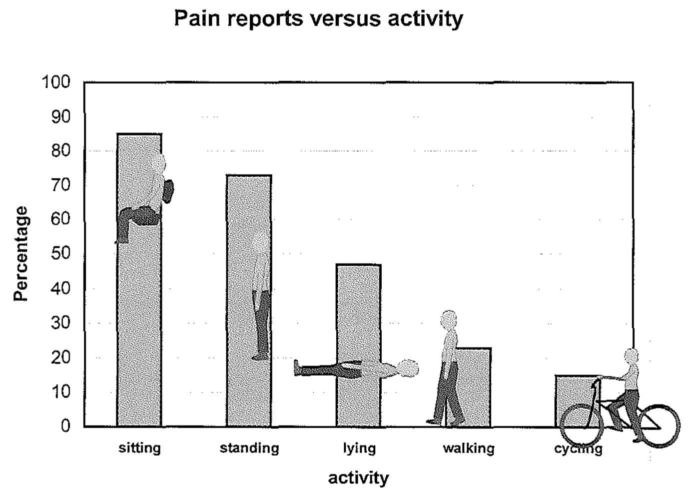

Figure 2: Pain experience during five everyday activities in LBP patients (n=100)

The paired t-test was used for statistical analysis.

Results

All individual changes in body height were recorded with the stadiometer. In all cases the individual standard deviation for reproducible standing in the stadiometer was less than 1 millimetre. Table 2 shows that the averaged values for shrinkage were: lying down + 0.4 mm (SD 0.5), relaxed standing -7.4 mm (SD 0.5), sitting – 5.0 mm (SD 0.6), walking -7.9 mm (0.5) and cycling – 3.7 mm (SD 0.4).

In all subjects there was more shrinkage during standing than sitting and more shrinkage during sitting than cycling. Although three subjects had less shrinkage during walking than standing, overall there was a slight increase in shrinkage during walking.

Subject #	Sitting		Standing		Walking		Lying		Cycling	
	Shrinkage [mm]	*S.D. [mm]*	*Shrinkage [mm]*	*S.D. [mm]*	*Shrinkage [mm]*	*S.D. [mm]*	*Shrinkage [mm]*	*S.D. [mm]*	*Shrinkage [mm]*	*S.D. [mm]*
PP1	-3.9	*0.8*	-7.1	*1.0*	-6.7	*0.4*	0	*0.4*	-2.7	*0.2*
PP2	-4.3	*0.3*	-5.2	*0.4*	-8.7	*0.4*	0.3	*0.7*	-3.7	*0.2*
PP3	-5	*0.5*	-7.4	*0.4*	-8.7	*0.6*	0.9	*0.5*	-4.1	*0.3*
PP4	-4.4	*0.3*	-5.9	*0.2*	-6.8	*0.6*	0.3	*0.5*	-3.2	*0.4*
PP5	-5	*0.5*	-6.4	*0.4*	-6.2	*0.5*	0.2	*0.4*	-4.4	*0.3*
PP6	-8	*0.7*	-14.8	*0.7*	-10.1	*0.5*	0.8	*0.6*	-4.2	*0.8*
PP7	-4.6	*0.5*	-5.7	*0.4*	-8	*0.3*	0.0	*0.8*	-3.1	*0.4*
PP8	-5	*0.5*	-6.5	*0.3*	-7.9	*0.3*	0.7	*0.3*	-3.2	*0.5*
PP9	-7	*1*	-9.3	*0.5*	-9.8	*0.5*	0.2	*0.6*	-6.1	*0.4*
PP10	-3.1	*0.6*	-6	*0.4*	-6.5	*0.5*	0.9	*0.2*	-2.5	*0.4*
Total	**-5.0**	*0.6*	**-7.4**	*0.5*	**-7.9**	*0.5*	**0.4**	*0.5*	**-3.7**	*0.4*

Table 2 : Individual shrinkage [mm] during different activities.

The paired t-test revealed no significant difference between walking and standing ($p=0.617$), whereas all other between-activity differences were significant ($p<0.034$).

Figure 3 shows spinal shrinkage in the present study compared with pain experience in LBP patients recorded in an earlier study [7].

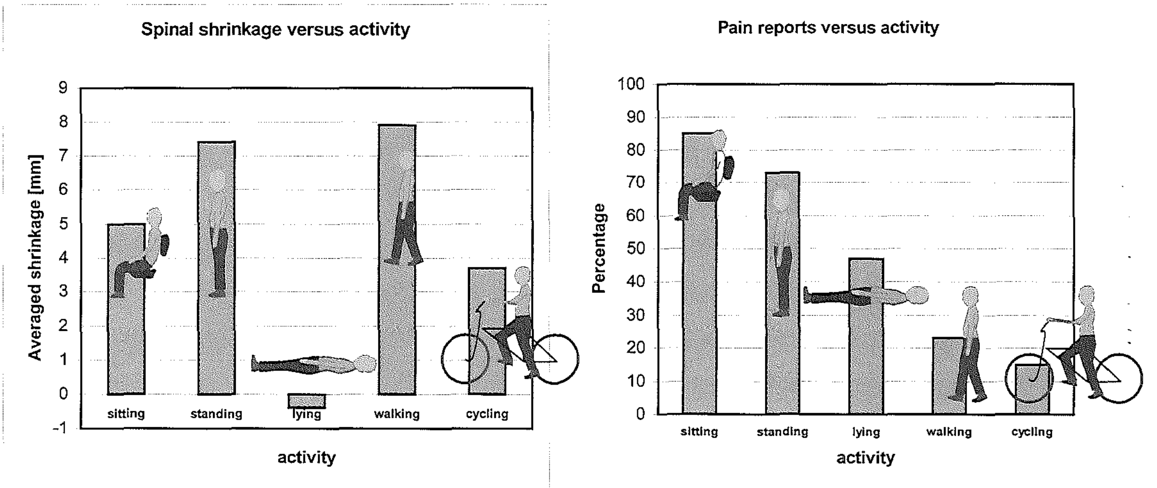

Figure 3 : Averaged values (mm) of subjects (n=10) measured in different activities with spinal shrinkage (Left), and pain reports from a questionnaire in a group of patients with low back pain (n=100) in similar activities (Right)

Discussion

In contrast to our expectation, no relationship was found between the occurrence of LBP and spinal load as measured by spinal shrinkage in this study.

As shown in Table 2, the greatest spinal shrinkage was found for walking and standing, while sitting and cycling had lower values. During lying down there was a slight increase of body height immediately after a preconditioning period of eight hours bed rest. Although walking shows the greatest spinal shrinkage this was related to a low occurrence of LBP, whereas standing has great shrinkage and a high occurrence of LBP (Figure 3). Noteworthy is that the most pain occurs during sitting and the least occurs in cycling, whereas there is little difference in spinal shrinkage between these two activities.

Unexpectedly, during lying down a pain occurrence of 47% was reported [7]; in contrast with the slight increase in body height measured in this study.

Earlier studies reported that spinal load was greatest during sitting, followed by slight bending, standing upright and lying down, based on IVD pressure measurements [29]. There is a good relationship between those findings out of static activities and the pain experience as found in our previous study [7]. However, the main difference with our present study is that we also measured dynamic activities. Restricting measurements to only static positions in earlier studies has resulted in three decades of recommending bed rest as a first choice for LBP.

In previous studies we found a difference between static and dynamic sitting: less spinal shrinkage and less pain during sitting with dynamic stimuli [6,8,9]. During sitting with rotary continuous passive motion (RCPM) we found significantly less shrinkage even though gravity load is thought to be the same in sitting with or without RCPM. A possible explanation for this phenomenon was given by van Deursen et al. [11], who found an instantaneous increase of disc height and decrease of intradiscal pressure during rotation up to 2 degrees. Therefore the use of spinal shrinkage as a method to assess spinal load seems to be useful only in static situations and not in dynamic situations.

In the present study sitting resulted in less spinal shrinkage than standing. This is in contrast to the IVD pressure measurements reported by Nachemson [29] and Sato et al [38], but in agreement with the data from Wilke et al.[44].

Because IVD pressure during walking was only measured once by Wilke et al.[44] and not during cycling, we cannot compare spinal shrinkage and IVD pressure measurements for dynamic activities such as walking and cycling.

Based on the results of the present study we propose to reconsider the importance of spinal load and spinal motion for LBP. We found that low spinal load, if static, can cause much pain, whereas a relatively high load, if dynamic, can cause less pain. Therefore we conclude that for LBP the amount of activity is of prime importance and that spinal load plays a secondary role.

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CHAPTER 4

The number of spinal axial rotations in everyday activities related to low back pain

Submitted to Spine

Leo L van Deursen MD 1, Dirk L van Deursen PhD 1, Chris J Snijders PhD 1

1 Department of Biomedical Physics and Technology, Faculty of Medicine and Health Sciences, Erasmus University Rotterdam, the Netherlands

Summary /Abstract

Objective : The main aim was to establish the number of spinal axial rotations during everyday activities, secondary aim was to assess the relationship between low back pain (LBP) complaints during those activities and the established number of axial rotations of the spine.

Background : It is reported that LBP patients may benefit from movement. We previously demonstrated that small axial rotations of the spine relieved pain in sitting and that cycling and walking result in less pain than sitting and standing. However, the number of axial rotations during these activities has not yet been investigated.

Methods : Five men without LBP were instrumented with infrared diodes to measure axial rotation of the spine between the levels Th8 and L4 during standing, sitting, walking, cycling and lying down on the side.

Results : The average number of rotations per second above one degree increased in the following order of activities: sitting (0.13; SD 0.04), standing (0.18; SD 0.11) lying down (0.34; SD 0.12), walking (0.77; SD 0.07) and cycling (0.98; SD 0.10). Comparison of these results with pain experienced by LBP patients during the same activities in an earlier study, showed an inversed order.

Conclusion : The number of axial rotations of the spine in several everyday activities is inversely proportional to the pain appearance experienced by LBP patients. Least frequently pain is experienced in cycling, while most frequently pain is experienced during sitting. This is the first study which relates LBP appearance to a mechanical parameter.

Key words: Spine, Low Back Pain, Activities of Daily Life, kinematics.

INTRODUCTION

Amongst other factors, the incidence of low back pain (LBP) is related to the spinal load during daily-life activities [4,16,26,27,35,37,42,46]. Although some activities seem to be riskful, lack of spinal motion is nowadays unanimously dissuaded [1,41,43,44]. Therefore, in contrast to the earlier prescription of bed rest in LBP, according to the International Paris Task force on Back Pain, the maintenance or progressive resumption of activities of daily living is authorized in acute and subacute cases and is recommended in case of chronic LBP. This is recommended as far as the pain allows and given the absence of specific data in the literature [1]. A number of controlled clinical trials show significant benefits in pain, disability, physical impairment, psychological distress, or work loss during resumption of activities or exercises [5,6,15,18,19,21,24,28,29,30,36,38,43]. No specific physiotherapy exercise was found to be most beneficial by Koes et al. [22]. However, there are no explanations as to why movement is beneficial in LBP. The most obvious assumptions are that neuromuscular function is improved and that disc nutrition is enhanced by movement. Holm and Nachemson compared the discs of sedentary canines with dogs exercised each day, and found the discs of the active animals undergoing long training to be better nourished than those of their sedentary counterparts [20]. In the course of everyday life the intervertebral disc is mechanically stimulated in different ways. While most researchers agree on the beneficial effects of movement on the intervertebral disc [23,31], the risk of injury is emphasized in certain movements. For example, Farfan et al. [14] indicated that extreme torsion of spinal motion segments may lead to disc injury, but Adams and Hutton [2] argued that torsion is unimportant in the etiology of disc degeneration and prolapse. Similarly Liu et al. [25] have shown that repetitive torsion over a limited range (± 1.5 degrees) can cause the annulus fibrosis to fail, whereas Shirazi-Adl et al. argued that torque by itself cannot cause the failure of disc fibers, but can enhance the vulnerability of those fibers when torque acts in combination with other types of loading, such as flexion [40]. During ambulation, the intervertebral disc experiences an axial torque in conjunction with lateral flexion as a result of the spine's coupled motion. In normal, ambulant subjects the lumbar spine is axially rotated at a frequency in the order of 50 cycles per minute [13]. Evans et al. [12] showed significant association between occupation and lumbar disc degeneration, as evidenced by ambulating females having no degenerative lumbar discs and sedentary females having a large number of degenerative discs. Based on Farfan's calculations of 50 cycles per minute during walking, Evans and co-workers calculated lumbar disc rotation cycles ranging from 160 million cycles in walking persons over a period of 50 years, to only 3 million cycles in sedentary subjects [12]. Our group found that walking can contribute to pain relief in LBP patients [8], and that rotary continuous passive motion (RCPM) of a seat pan in the horizontal plane caused significant pain relief in LBP patients while sitting [7]. In addition, during sitting an increase of spinal length was found versus a decrease when sitting without RCPM [9]. The amplitude of the RCPM in these latter studies was limited to 1.25 degrees while a frequency of 0.08 - 0.20 Hz was used. This would imply lower angular excursions at the segmental level than those used in previous *in vitro* studies showing the injury potential of torsion. The underlying mechanism of the beneficial effects of cyclic torsion was thought to be a 'pumping action' of the disc resulting from squeezing of the annulus and depressurization of the nucleus [10,11].

Therefore, we believe that back pain is positively influenced by daily axial rotations of the spine.

The aim of the present study was to measure the number of axial spinal rotations during common activities in healthy subjects, and secondary to relate the number of rotations to pain experience in LBP patients as recorded in an earlier study during the same activities [8].

MATERIALS AND METHODS

Five healthy male subjects without LBP participated in the study (Table 1) and followed each a scheme of: standing; sitting on a chair with slightly thoraco-lumbar flexion without a backrest and both arms supported by a desk; walking on a treadmill with a constant speed of 5 km/h; cycling on an ergonometric bicycle with a constant speed of 18 km/h; lying down on the side on a polyether mattress. All activities were performed during five minutes per activity. The spinal axial rotation data were continuously sampled and stored. Data acquisition and reconstruction calculations were performed post-session. The axial rotation data were compared with pain experience as recorded earlier in LBP patients [8].

subject	**age** (years)	**weight** (kg)	**height** (cm)
1	58	88	181
2	30	72	165
3	32	76	176
4	46	87	178
5	54	95	185

Table 1 : Data on the five male participants.

Measurement system

The subject's spinal variation as a consequence of the prescribed activities was measured with a 3-D opto-electric motion registration system.

The infrared light emitted by the four diodes (IREDs) attached to the subject's spine (for positioning see Figure 1) is received by two camera units each with two infrared cameras. The cameras were linked to a data acquisition system unit that combined the information of the two cameras, providing raw data sets. A computer attached to the data acquisition system translated the raw data sets into the co-ordinates of all the IREDs. The whole system was an OPTOTRAK 2010 (Northern Digital Inc., Waterloo, ON, Canada) 3-D opto-electric motion registration system. The angle between the two infrared cameras was set at 60 degrees. According to the specifications of the manufacturer, the reading of the emitter positions is optimal at this angle. The inaccuracy in this setting is 0.15 mm for the y-axis and 0.1 mm for the x- and z-axis. The sampling frequency rate of 10 Hz was high enough for the low frequency movements that we expected.

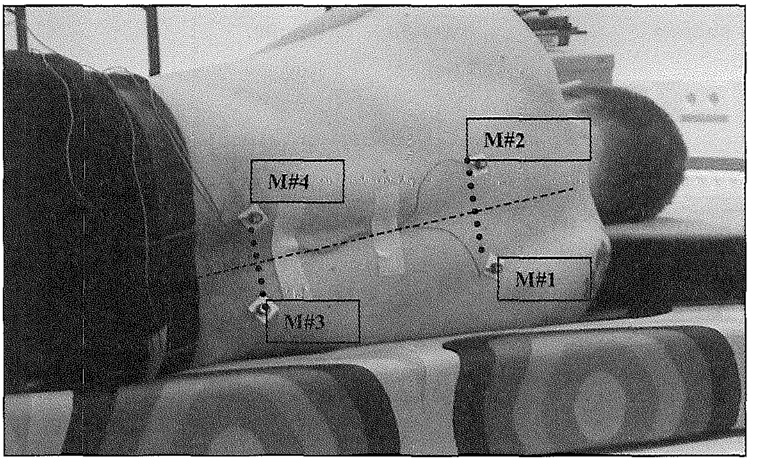

Figure 1: Position of the 4 markers on the spine of the subject. Markers 1 and 2 are attached on Th 8 level, approx. 8 cm to the left and right. Markers 3 and 4 are attached on level L4.

The calibration procedure uses a special cubic framework with 20 attached markers, with known positions. After calibration a 3-D reconstruction can be made of a maximum of 20 markers in space. The co-ordinate system of the Optotrack is given in Figure 2.

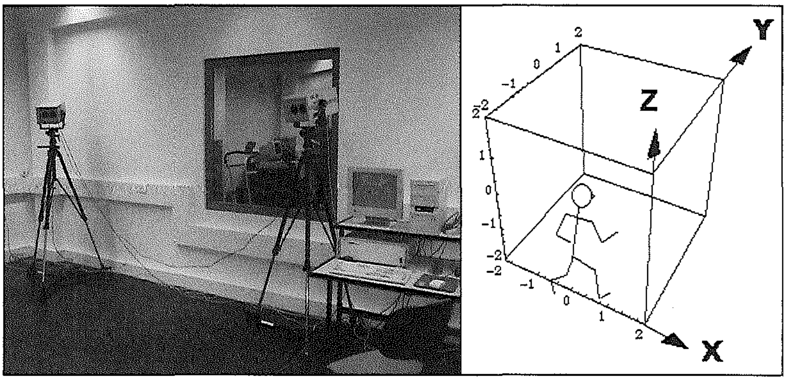

Figure 2: The 3-D opto-electric motion registration system (left); the co-ordinate system and definition of the x, y and z-axis (right).

Spinal axial rotation angle

For the definition of the angle of axial spinal rotation we observed the position of the virtual line between the upper two markers (M#1 and M#2 in Figure 1) compared with the line between the lower two markers (M#3 and M#4 in Figure 1).

Figure 3 shows the definition of the rotation angle α in the projected (x, y) plane. This definition is used for standing, sitting, walking and cycling. For lying down the projected (y, z) plane is used.

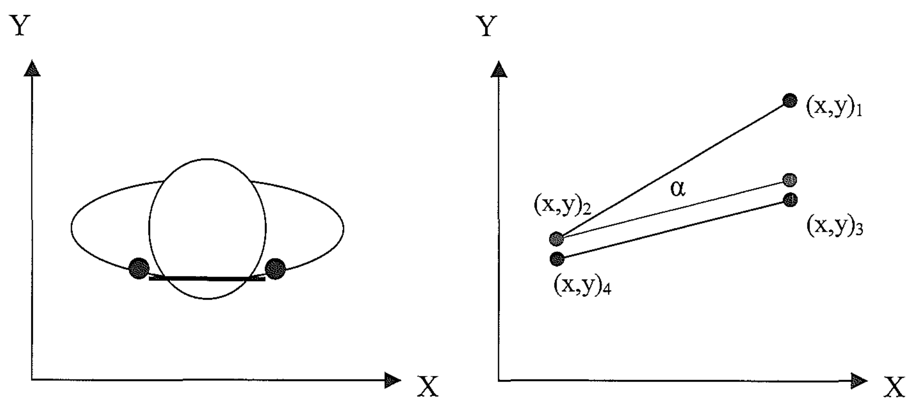

Figure 3: Definition of the rotation angle α in the projected (x, y) plane; this definition is used for standing, sitting, walking and cycling. For lying down the projected (y, z) plane is used.

The tangus of alpha is derived from the following equation:

$$\tan(\alpha) = \tan(\alpha_{12}) - \tan(\alpha_{34}) = \tan\frac{(y_1 - y_2)}{(x_1 - x_2)} - \tan\frac{(y_3 - y_4)}{(x_3 - x_4)} \qquad [1]$$

This means that

$$\alpha = [a\tan(\alpha_{12}) - a\tan(\alpha_{34})] \times \tfrac{360^0}{\pi} = [\ a\tan\frac{(y_1 - y_2)}{(x_1 - x_2)} - a\tan\frac{(y_3 - y_4)}{(x_3 - x_4)}\ ] \times \tfrac{360^0}{\pi}$$

This angle was calculated in the post-processing with the raw data set within each frame. Each subsequent measurement counted 300 seconds at a sample rate of 10 Hz. Thus, each array was a column of 3000 measurement points and stored for the (x,y,z) co-ordinates of the four markers.

Subsequently, variance of analysis for repeated measures on the number of rotations estimates were performed with amplitudes above one degree.
The (x,y,z) positions of the four markers were AD converted and stored at a sample rate of 10 Hz.

The data were low-pass filtered with a 2nd order Butterworth-algorithm (cut-off frequency 2 Hz.)
An algorithm transformed the data over a selected time interval, and counted these values according to: $\Sigma\ (\alpha_{mean} + 1^0) + (\alpha_{mean} - 1^0).$)

Statistical analysis was performed on these data: The inhomogeneous t-test was performed for frequency and activity variances, and for amplitude and activity variances. Inter- and intra-individual differences were measured for all subjects.

Pain experience during the same activities found in an earlier study [8] is showed in Figure 4.

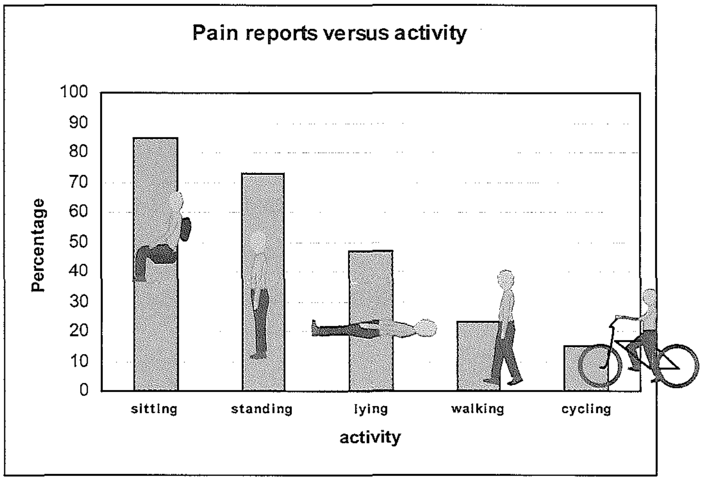

Figure 4 : Pain experience during five everyday activities in LBP patients (n=100)

RESULTS

Activity significantly affected the number of torsions made in a freely chosen time interval. The variation in activity was consistent within the five subjects measured. The number of axial spinal rotations increased in the following order of activities (Figure 5): sitting 0.13 (SD 0.04); standing 0.18 (SD 0.11); lying down 0.34 (SD 0.12); walking 0.77 (SD 0.07) and cycling 0.98 (SD 0.10).

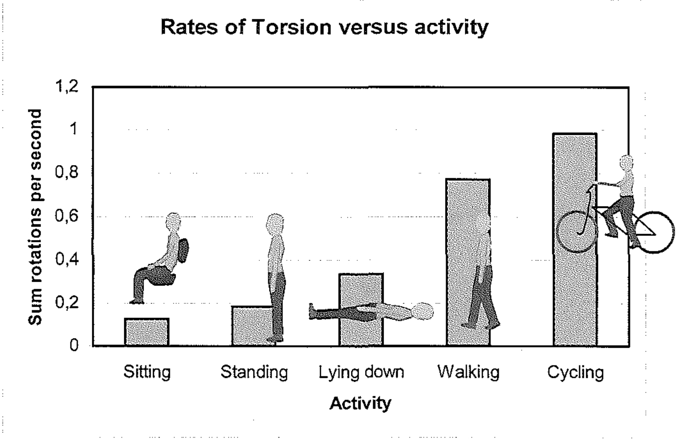

Figure 5 : Average number of rotations per second during five everyday activities

Figure 5 shows the average number of rotations of more than 1 degree per second during measurement of the five everyday activities for the five subjects. Comparison of this order with the order of pain experienced by LBP patients during the same activities reported earlier [8] shows a clear inverse proportional relationship (Figure 6).

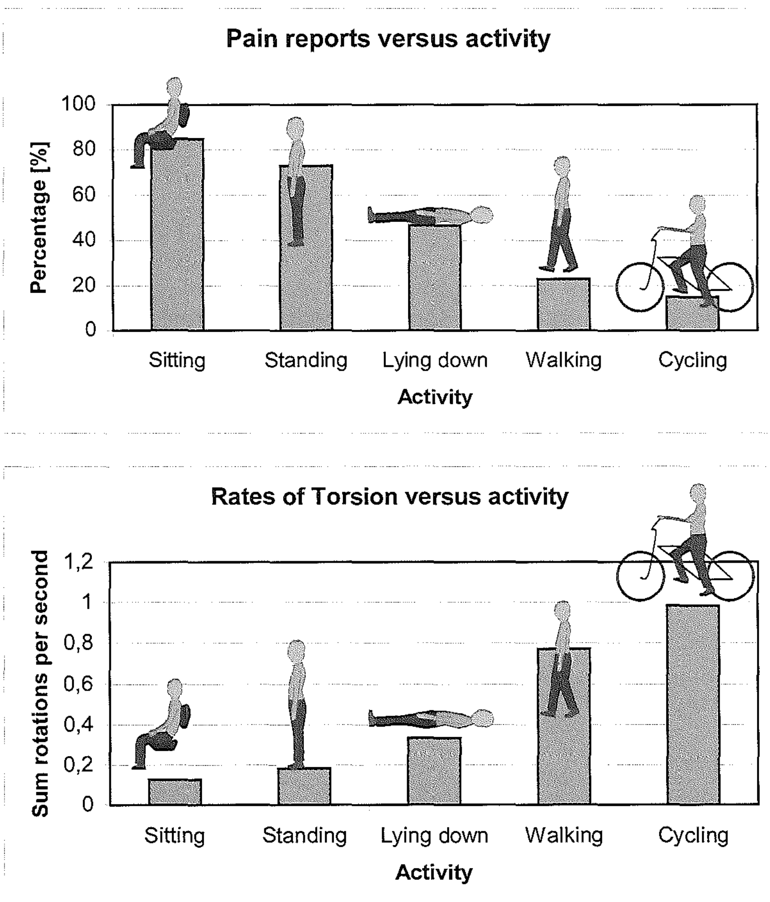

Figure 6: Comparison between pain experience in LBP patients and the number of axial rotations during the five everyday activities measured in the present study.

The one-tailed Student's t-test (Figure 7) was used to observe the between-activity dependency. All calculated p-values were smaller than 0.04, except that between sitting and standing which was 0.23 and therefore not significant.

Figure 7

One-tailed t-test					
	Sitting	Standing	Lying	Walking	Cycling
Sitting		0.23	0.009	0.000	0.000
Standing			0.04	0.000	0.000
Lying				0.001	0.000
Walking					0.002
Cycling					

DISCUSSION

This study assessed the number of axial spinal rotations for five everyday activities and related low back pain experience by LBP patients to this mechanical parameter. We found a striking relationship between pain experienced during sitting, standing, lying down, walking and cycling and the number of axial spinal rotations during these activities, i.e. most pain is experienced with the least axial spinal rotations. As far as we know, no basic study exists which substantiates that everyday activities should be promoted in LBP. This is the first in vivo study which supports the increasingly accepted practice to advocate activity in cases of LBP.

The relatively large number of axial rotations during walking and cycling is in sharp contrast to the very low number during sitting. Although most pain is experienced during sitting (Figure 4), it is difficult to achieve activity during sitting postures, particularly at work. This led us to add passive dynamic stimuli whilst sitting.

A normal office chair was provided with an electromotor that generated small rotatory movement of the seat pan in the horizontal plane. Rotation was limited to 1.25 degrees on both sides, and frequency ranged from 0.08 - 0.20 Hz. This resulted in significant pain relief in 120 patients [7]. The present study on axial rotation of the spine confirms this finding. However, we have no explanation why the optimal frequency for rotary continuous passive motion during sitting seems significantly lower than in walking and cycling. Furthermore, the underlying health promoting mechanism of axial rotation remains undefined. Possible mechanisms are nutrition and neuromuscular stimulation, and influences on metabolism. Nutrition of the disc may be promoted by small axial rotations of the spine, as suggested by van Deursen et al. who showed alternating increase of disc height and decrease of intradiscal pressure in an in vitro study [10]. These rotations were permitted within the free interspaces of the zygapophysial joints. Lack of spinal motion is believed to be a dominant factor in the development of LBP and limits the nutrition of the a-vascular intervertebral disc; although the type of motion was not specified [23,31]. Evans et al. studied axial rotation and reported an inverse relation between disc degeneration and the amount of rotation as counted for walking and sitting [12]. Apart from this latter study no other studies are known to us that relate rotary movements to daily life activities and to the occurrence of LBP.

Neuromuscular stimulation may also be promoted by axial spinal rotations, but this remains speculative. Weinstein indicated that mechanical activity can affect pain perception by influencing the metabolism of neurotransmitter substance P [45].

The relation between LBP and specific activities has previously been associated with intradiscal pressure height [3,4,17,32,33,34,39,46]. Nachemson found a higher intradiscal pressure in sitting than in standing and higher pressure in standing than in lying down [32,33,34]; this concurs in part with the pain recordings in Figure 4. However, the intradiscal pressure measurements reported by Nachemson were restricted to static situations and did not include walking and cycling. Wilke et al. measured intradiscal pressure in walking and found higher values than in standing [46]. So, this disturbs the earlier assumed relationship between intradiscal pressure and LBP. In contrast to intradiscal pressure, the present study indicates the importance of the amount of movement, especially axial rotations.

One limitation of the present study is the small number of subjects, although the inter-individual differences in the number of rotations were not significant. Also because we decided to count the number of rotations above one degree in order to eliminate noise, we do not know the influence of smaller excursions. The question arises whether patients with LBP make the same number of axial rotations during the measured activities as do healthy subjects. We do not exclude this but do not expect this to change the trend observed in this study. Therefore, we conclude that the mechanical parameter of axial spinal rotation could be a good explanation for the positive experience in LBP with the prescription of everyday activities in clinical practice.

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CHAPTER 5

Sitting and low back pain: the positive effect of rotatory dynamic stimuli during prolonged sitting

Eur Spine J (1999) 8: 187-193

L. L. van Deursen, J. Patijn, J.R. Durinck, R. Brouwer, J.R.van Erven-Sommers, B.J. Vortman

Abstract

In this study the effect of dynamic stimuli on low back pain during prolonged sitting was investigated. The pain experience of two groups of 60 subjects with aspecific low back pain was recorded. All subjects were investigated on pain behaviour by the Multidimensional Pain Inventory (MPI) and pain was measured on an open visual analogue scale (VAS). During sitting, one group received dynamic stimuli that were generated by alternating rotations in the horizontal plane of the seat of the chair, with back and arm rests in fixed position. Two different frequencies of rotation were applied in subgroups. The authors concluded that such stimuli, especially of the lower frequency, reduced pain in prolonged sitting.

Key words: Low back pain, sitting; Low back pain, rotatory dynamic stimuli; Low back pain, chair

Introduction

Sitting, especially prolonged sitting, is generally accepted as a risk factor in developing low back pain (LBP) [4,8,15,16]. Although much attention has been paid to the best ergonomic sitting posture, the problem has never really been resolved [2,3,20,26]. According to Jensen, one of the three factors responsible for the development of LBP in sitting is insufficient nutrition of the intervertebral discs due to the lack of spinal motion [14]. Lack of spinal motion as a provocative factor seems to correspond with what we found in an analysis of patients with LBP: 85% found pain was brought on by prolonged sitting, 73% by standing, but only 23% by walking and 15% by cycling [6].

For that reason we speculated that the introduction of a dynamic stimulus during prolonged sitting could reduce pain symptoms, especially in subjects with LBP. The simple introduction of the possibility for active movement, like on rocking chairs, balance chairs or chairs with tilt able seats, was proven to be insufficient [14]. We expected that a constant passive forced motion would be necessary. We decided to use a strictly rotatory dynamic stimulus, because rotation of the spine is independent of age, intervertebral disc degeneration and facet joint sclerosis [21]. Disc degeneration has an effect on flexion and extension, but not on lateral flexion and rotation [21]. Unless a rotation is combined with lateral flexion and/or flexion, a rotatory range of 1° - 2° does not endanger the disc [1,5,9,22]. For this reason we chose an angle of rotation of 1.25° to either side.

Our aim was to study the effect of strictly rotatory dynamic stimuli on LBP during prolonged sitting.

Material and methods

Population

120 LBP patients (72 female, 48 male) were included in this study. Neurological examination and X-rays of the lumbar spine were performed in all patients. All patients signed an informed consent.

The inclusion criteria were: (a) non-specific LBP longer than 6 weeks, and (b) lumbar pain and discomfort elicited by prolonged sitting. Patients with signs of lumbar radicular syndrome, systemic diseases, lysis and olisthesis and vertebral fractures or malignity were excluded.

Experimental set-up

The subjects were selected by four physicians working at our clinic. Subjects who were willing to take part were asked to make an appointment with the secretary for the trial. This trial was conducted by another co-worker. Subjects were divided, by the order in which they enrolled, into an index group A (n = 60) with dynamic stimuli, and a control group B (n = 60) without stimuli. Subjects were unaware of the different test conditions. They were told that their LBP could benefit from a "newly developed chair", but were given no further information about the technical characteristics of the chair. All test subjects were seated uninterrupted for 1h on the experimental chair. In index group A the male/female ratio was 23/37 with a mean age of 41.4 years (SD 8.0 years) and a mean duration of LBP of 68.3 months (SD 71.6 months). In control group B the male/female ratio was 25/35 with a mean age of 40.5 years (SD 8.2 years) and a mean duration of LBP of 72.5 months (SD 74.7 months).

As it was also not clear to us whether the frequency of the seat rotation influenced the extent of pain response, two different frequencies were applied in index group A. Two subgroups were formed by order of enrolment in index group A: subgroup A-high, with a high frequency of 0.2 Hz (n = 30), and a subgroup A-low, with a low frequency of 0.08 Hz (n = 30). Frequencies were related to the technical properties of the frequency adaptor. In the subgroup A-high the male/female ratio was 12/18 with a mean age of 40.9 years (SD 8.0 years) and a mean duration of LBP of 70.4 months (SD 72.9 months). In subgroup A-low the male/female ratio was 11/19 with a mean age of 41.9 years (SD 7.6 years) and duration of LBP of 63.2 months (SD 79.3 months).

Experimental chair

In the index group A, dynamic rotatory stimuli were produced by a "revolving seat" of a conventional office chair. The seat rotated horizontally and independently of the backrest and arm supports. A compact, small, worm-geared electromotor provide an alternating movement, which was set on an angle of 1.25º to either side. The centre of rotation was placed 10 cm from the back of the seat near to the axis of the spine. An adaptor was used for changing rotatory frequency. The height and inclination of the back rest were adapted to the individual needs of the subject. The same chair was used in all tests.

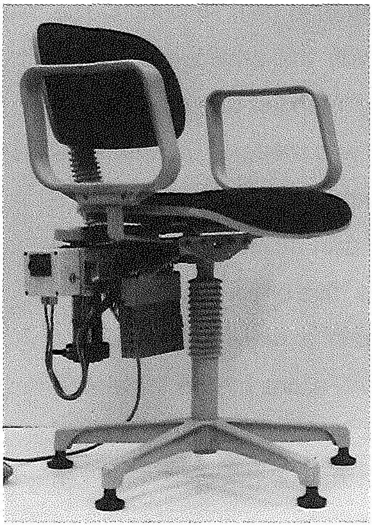

Figure 1: Experimental chair

Pain

Subjects were initially tested, and classified into five types for their pain behaviour and burden of illness by the Mulidimensional Pain Inventory- Dutch Language Version (MPI-DLV) [17,19,24], and the types were found to be equally distributed across all groups.

Although it is very difficult to measure pain, all subjects were asked to "score" their pain at the beginning of the test and then at intervals of 10 min. In this way, we obtained seven pain scores for each subject. Pain was recorded by an "open" visual analogue scale (VAS). The six successive time periods of 10 min seated were used as quantitative stimulus for the pain increment as applied to magnitude estimation procedures [25]. A quantitative analysis using the absolute length of the VAS scores was not applied, because it is unlikely that two subjects with the same pain in time will draw it the same on the VAS. The VAS score was considered as a position on an ordinal scale, which means that differences are only considered as "more"(pain) or "less" (pain), and do not refer to the absolute size of the VAS score. An arbitrary minimal difference of 0.5 cm in line-length between two successive VAS scores was considered as a real alteration in pain sensation. The subjects were able to compare their current VAS score with the previous scores so they did not draw their lines longer or shorter than they intended to by mistake.

A non-parametric analysis was made of the individual pain scores. We evaluated the number of VAS scores that had increased compared with the previous score. We distinguished six different pain increment scores, ranging from "no pain increment", "one pain increment" up to "five or six pain increments".

Secondly, in order to obtain a more quantitative approach, for every subject we divided each successive VAS score by the initial one (VAS-0), and defined it as the Relative Visual Analogue Scale (RVAS) score. The RVAS score indicates the multiplication factor that increased the initial pain score to the actual one, as a more or less objective individual pain factor".

Statistical analysis was performed using SPSS and the one-way Anova non-parametrical (Mann-Witney) test.

Results

There are no statistical differences in age, sex or duration of LBP between the index group A and control group B or between subgroup A-low and subgroup A-high.

X-rays were performed to exclude abnormalities and also to score possible differences in the frequencies of disc degeneration in both groups. No statistical differences between the two groups or the two subgroups were found. Index group A and control group B are also comparable regarding pain behaviour and burden of illness expressed by the MPI-DLV classification.

Table 1 shows the distribution of the five MPI-DLV pain behaviour types across the total population (n = 120), index group A, subgroups A-high and A-low and control group B.

MPI-DLV class		**1**	**2**	**3**	**4**	**5**
Total Population	**(n=120)**	**19**	**14**	**32**	**37**	**18**
Index group A	**(n= 60)**	**7**	**8**	**16**	**17**	**12**
Subgroup A-high	(n= 30)	3	4	8	9	6
Subgroup A-low	(n= 30)	4	4	8	8	6
Control group B	**(n= 60)**	**12**	**6**	**16**	**20**	**6**
***Median VAS-0**		**15.0 cm**	**7.5 cm**	**3.0 cm**	**6.0 cm**	**4.0cm**

Table 1. Distributiom of classes according MPI-DLV
* Median initial VAS-0 for different MPI-DLV classes

The five MPI- DLV types corresponded to:

1. Dysfunctional type
2. Interpersonally distressed type
3. Adaptive cooper type
4. Average type
5. Anomalous type

Seven subjects are classified as MPI-DLV 5, because they could not fill in answers to questions about partner-related data.

No differences exist between the MPI-DLV types with regard to sex, age and the duration of the LBP.

The median VAS-0 is high in the MPI-DLV type 1 "dysfunctional type" , at 15.0 cm, compared with the median VAS-0 values of the other types, which range from 3.0 cm to 7.5 cm. No relation is found between the VAS-0 and the characteristics of sex, age, duration of LBP and radiological diagnosis.

Although strictly speaking, pain as a phenomenon cannot be considered as measurable, there are indications that the amount of pain experienced is similar among individuals. Evidence for this point of view can be found by correlating the initial VAS scores of the subjects with the expression of pain as measured by the two pain intensity questions of the MPI-DLV questionnaire. In 118 subjects correlations of 0.21 ($p < 0.02$) and 0.39 ($p < 0.001$) respectively were found between initial VAS score and the questions of the MPI-DLV concerning actual pain and average pain experience during the preceding week.

Using a minimal difference of 0.5 cm between two successive VAS scores to define a real alteration in pain sensation resulted in 33.8% of the measurements showing no alteration and 66.2% showing an alteration, which indicates an acceptable sensitivity. Two subjects in control group B could not sustain the sitting procedure because of intolerable pain increase.

Table 2 shows the distribution of the pain increment scores of all subjects.

Pain increment scores		**0+**	**1+**	**2+**	**3+**	**4+**	**5/6+**
Group A	**(n=60)**	**13**	**18**	**9**	**8**	**7**	**5**
Group A-high	**(n=30)**	**5**	**9**	**3**	**4**	**5**	**4**
Group A-low	**(n=30)**	**8**	**9**	**6**	**4**	**2**	**1**
Control group B	**(n=60)**	**1**	**8**	**8**	**13**	**12**	**16**

Table 2. Distribution of the six different pain increment scores of all subjects

In the control group B, 47 of the remaining 58 subjects did have an increment of pain in the last VAS score compared to the initial one. There was "no progress" in 11 subjects, with 3 of these subjects showing "almost full relief", comparing the first with the last VAS score. In index group A, 30 out of 60 subjects showed "no progress" (13 of these showed "almost full relief").

The number of increased VAS scores is significantly lower ($p<0.01$, Chi-square and Kruskal & Wallis) in the index group A. The average number of increases in VAS score per subject is 3.3 in the control group B, 2.3 in subgroup A-high and 1.5 in subgroup A-low, reflecting a possible frequency effect in index group A.

As already mentioned, subjects can show one of six patterns, ranging from a pattern with no pain increment (0+) to a pattern with five ore six pain increments (5+/6+). A declining number of subjects with high scores is shown in the index group A, while the control group B shows an increasing number of subjects with high scores.
The number of subjects with no pain increment in their pattern is significantly ($p=0.01$) higher in the subgroup A-low than in the control group B. A weak indication for the same phenomenon also exists ($0.15<p<0.20$) between subgroup A-high and the control group B.
Semi-quantitative analysis using the mean RVAS scores is shown in Figure 1. There is a clear relation between the increase in the mean RVAS scores of the entire control group B, the MPI-DLV subtypes and the duration of sitting. Only type 5 shows a more pronounced increase in mean RVAS scores.

Figure 1 :

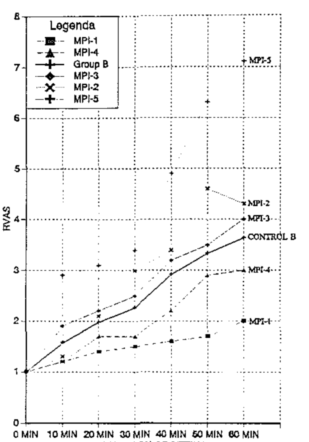

Figure 1. The RVAS-scores of control group B and the subdivision of control group B in MPI-DLV classes 1-5 with their RVAS-scores.

In the index group A the mean RVAS scores at the different measurement points are almost the same for MPI-DLV types 2-5. Only MPI-DLV type 1 showed a marked rise in the mean RVAS, at $t = 10$ min (Figure 2).

Figure 2.

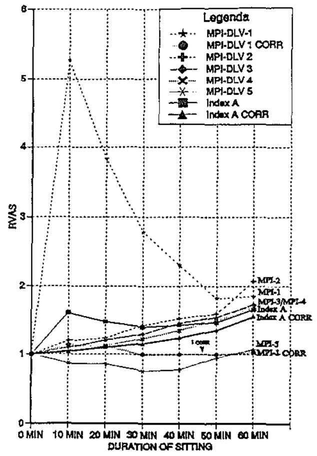

Figure 2. RVAS-scores of Index group A and subdivision of Index group A in MPI-DLV classes 1-5 with their RVAS-scores.

This suggests an MPI-DLV type effect on the mean RVAS scores in the index group A. Further analysis revealed that this effect was entirely due to the pain scores at $t =$ 10 min of one single subject (number 003). This subject had an initial open VAS score at $t = 0$ min of 5 cm and at $t = 10$ min an open VAS score of 171 cm, resulting in a RVAS of 34.2. Such an extravagant pain increment was observed only once in the entire population. Analysis of the mean RVAS scores in the different MPI-DLV types without the data of subject 003, illustrated by the curve marked MPI-1 Corr (Figure 2), shows the same slope as the curves of MPI-DLV types 2-5.

Figure 3.

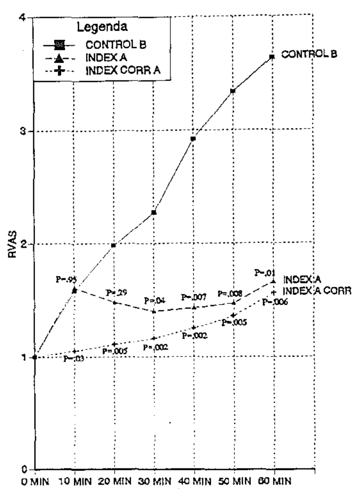

Figure 3. RVAS-scores of Index group A and the control group B.

Figure 3 shows the mean RVAS scores of the index group A and the control group B in relation to the duration of sitting. The p-values of the difference for the mean

RVAS scores between index group A and the control group B on the different measurement moments ($t = 10 - t = 60$) are added. Significant differences in mean RVAS score between index group A and control group B become clear after $t = 30$ min. From $t = 40$ min the mean RVAS increases slightly, but the difference with control group B remains significant till the end. Despite the dynamic stimuli in the first 10 min the mean RVAS at $t = 10$ min shows the same elevation as in the control group B, suggesting a lack of stimulus effect. This observation, again, was solely due to the pain scores of abovementioned subject 003. It is illustrated by the curve marked "Index A Corr", in which subject 003 was excluded from analysis. This curve shows considerable significant differences between groups A and B in the mean RVAS scores at all measurement moments. P-values for significance are indicated in the Figure.

Figure 4.

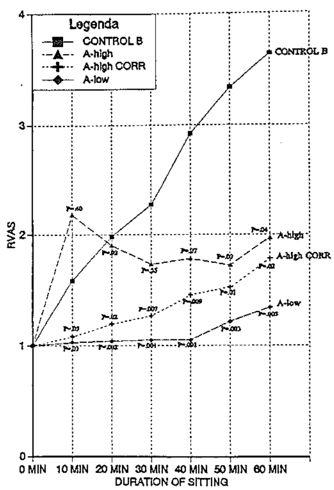

Figure 4. RVAS-scores of Index A-high and A-low versus control B

Figure 4 shows the mean RVAS scores of the subgroups A-high and A-low. P-values for differences with the control group B are also shown. No significant difference in mean RVAS scores exists between subgroup A-high and A-low. The first rise in the curve of subgroup A-high vanishes by excluding subject 003 from analysis (curve marked subgroup A-high Corr).

A probable frequency effect is illustrated by the observation that all p-values of subgroup A-low are smaller than those of subgroup A-high and A-high Corr.

Discussion

The clinical experience that "static load", such as during prolonged sitting, acts as a provocative factor for LBP [6] in patients with non-specific low back problems was confirmed by the findings of pain increment in our control group of patients who were sitting uninterrupted for 1 hour. We know of no previous study regarding the relation between prolonged sitting and increment of pain in a population of non-specific LBP patients. Because of the multidimensional aspects of pain, such as sensory, emotional and cognitive components, a pain questionnaire (MPI-DLV), classifying respondents into five types, was used to retrospectively ensure an equal distribution of burden of illness and pain behaviour in index group A and control group B.

We did not use a calibrated VAS score with fixed scale values, because it is unlikely that two subjects with the same pain in time will show an equal and a standardized VAS score increment. We preferred an "open" VAS score, as used in magnitude estimation procedures [25] because we were interested in time- and subject-dependent pain changes during six successive periods of 10 min of sitting, with or without a slightly moving seat. In our pain evaluation procedures, subjects could always check their previous open VAS score to estimate the alteration of pain due to the preceding 10 min of sitting, in order to help ensure the most accurate recording.

We obtained a more quantitative approach by dividing for each subject the successive VAS scores by the initial one (VAS-0), resulting in the so-called relative visual analogue scale (RVAS).

Strictly speaking, pain cannot be considered as a measurable quantity. Nevertheless, we found significant correlations between the initial VAS-0 scores and the two different pain intensity scores of the MPI-DLV questionnaire. This supported the application of a semi-quantitative analysis of pain by means of the RVAS score. The use of an RVAS score is restricted to pain evaluation procedures on an individual level and indicates the multiplication factor that increased the initial pain score to the actual one.

The qualitative non-parametric analysis of pain increment scores as well as the semi-quantitative analysis of the RVAS scores in the control group B confirmed the provocative effect of prolonged sitting on pain. In the control group, 47 out of 58 subjects had a final individual RVAS score of more than 1, which means a pain increase. Two subjects even had to give up because of intolerable pain increase.

The effect of dynamic stimuli during prolonged sitting in index group A was significant. No progress in pain levels was noted in 30 out of 60 in the index group A versus 11 out of 60 subjects in control group B.

On ethical and practical grounds we limited the sitting period to 1 hour; therefore, it is unknown whether the slight increment of pain at the end of this test procedure would continue. A possible relation between frequency of the seat rotation (high/low) and pain remission was noted. The low frequency application seems the more favourable.

Our test conditions and stimuli are in a way comparable with the experiments of Reinecke and Hazard, who also emphasize and recommend continuous passive motion as beneficial in sitting, and who introduced the "BackCycler" as a dynamic stimulus during sitting. In a study of patients with chronic, stable LBP who routinely drive motor vehicles for more than 2 h per day, the continuous passive motion (CPM) device clearly reduced LBP, stiffness, and fatigue [23]. It provides continuous lumbar spinal movement through greater and lesser degrees of lordosis, by inflating and deflating a lumbar support bladder in cycles of 2 min [12,23]. We could not find any reports of other investigations into pain in relation to prolonged sitting.

Williams et al. investigated effects of sitting posture on subjects with LBP, and found a centralization and reduction of the pain when sitting with a lordotic posture [26]. Other investigations were only performed on small groups of healthy subjects with ratings of spinal shrinkage, lumbar curvature and comfort, but no pain measurements [7,13,18,20]. We are not able to explain how the small alternating seat rotations in our study resulted in a beneficial effect on low back pain. We may refer to authors who suggest that lack of spinal motion causes insufficient nutrition of the disc [10,11,12,14,23]. On the other hand the angle of only 1.25° axial rotation seems too small for significant motion in all lumbar spinal segments. The more pronounced effect of low frequency dynamic stimuli in our study could correspond with calculations that showed little fluid flow to the centre of the disc when disc load fluctuates rapidly [2].

The present experiment shows pain reduction, but does not help to explain why the rotatory stimuli reduce pain, and it does not support the disc nutrition hypothesis any more than many other possible explanations. For example, the rotary movements may stimulate the back muscles and improve blood flow within them, or relax them. From the observed pain reduction in LBP patients, we conclude that application of small, low-frequency seat rotation in the horizontal plane is promising. The slight movement can hardly be felt and will not disturb labour. While we also support the idea of Reinecke et al. of using continuous passive motion during sitting [23], we are suggesting another kind of stimulation. In this study only subjects with pre-existing LBP were involved. It would be interesting to investigate whether application of rotatory stimuli can prevent LBP in populations at risk from mainly sedentary working conditions. This needs further investigation.

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CHAPTER 6

Low Back Pain caused by sitting is best relieved with low-frequency seat pan rotation

Submitted to European Spine Journal

LL van Deursen MD [1], DL van Deursen PhD [1], C J Snijders PhD[1], J Patijn MD PhD [2]

[1] Department of Biomedical Physics and Technology, Faculty of Medicine and Health Sciences, Erasmus University Rotterdam, the Netherlands

[2] Pain Management and Research Centre, Department Anaesthesiology, University Hospital Maastricht, the Netherlands

Summary / Abstract

Objective. To assess the influence of the frequency of rotary dynamic stimuli as used in a continuous passive motion (CPM) device for seating applications.
Background. In a former study a seating device with rotary CPM was successfully introduced to reduce the negative effects of a static posture (i.c. in sitting) on the development of low back pain. However, knowledge on the best motion pattern and the best frequency of CPM is lacking.
Methods. Pain experience was recorded during sitting for one hour in 180 patients with low back pain. Besides a control group of 60 patients, frequencies were applied at 0.20, 0.14, 0.08 and 0.04 Hz on 30 patients each.
Results. At all frequencies a reduction in pain was achieved but, unexpectedly, the lowest frequency proved to be the most effective.
Conclusion. In using rotary continuous passive motion in sitting, a frequency of 0.04 Hz proved to be the best.

Relevance

A seating device with rotary continuous passive motion was introduced with the aim to reduce the negative effects of sitting on the development of low back pain. Although a positive effect was proven, the use of an optimal frequency application was lacking.

Keywords: Sitting; Continuous Passive Motion; Low Back Pain.

Introduction

Because low back pain (LBP) is often reported in sitting, much attention is paid to the ergonomic aspects of a chair's design, particularly those used in offices and vehicles. Important factors include anthropometrics for individual fit and optimal support [3,9]. Despite the availability of good chairs, LBP is still experienced in prolonged sitting. This is attributed to the static nature of the sitting posture in for example, computer tasks [12]. Therefore, designers have introduced active dynamic seating concepts, such as tilt-able seats, sitting balloons, the "Balance chair" and chairs with synchron mechanisms.

Study of the (videotaped) number of movements of subjects sitting on chairs with and without tilt-able seats revealed no significant differences in either the number of movements or in comfort evaluation; the subjects did not prefer the tilt-able chair over the "ordinary" chair [12]. Comfort ratings have shown an overall preference for the conventional chair over the "Balance chair" [13]. Compared with a rigid chair, a decrease of spinal shrinkage, but no additional body movements were found while sitting on a "Balance chair" or a chair with synchron mechanism [14]. The lack of a positive dynamic effect from active dynamic devices is attributed to the desired fixation of posture during an instable situation when concentration is needed [2]. Subjects fix their body for a particular task performance, which overrules the invitation to movement of dynamic devices.

As an alternative to active dynamic seats, devices with continuous passive motion (CPM) have been introduced. One of the first was a lumbar support with alternating pressure [10,11,16,17]; a positive effect on both comfort and release of spinal stiffness awareness was demonstrated [16]. A car seat called "Active-seat", has two hydraulic bladders which produce alternating height (15 mm) below the left and right ischial tuberosities; to date, as far as we know no effect studies on this seat have been published.

Our group introduced a chair with rotary CPM (RCPM) based on cyclic moving of the seat pan in the horizontal plane, i.e. a small rotation of 1.25° to the left and 1.25° to the right about a vertical axis. The centre of the axis of rotation is located 10 cm in front of the backrest, thus below the spinal axis. A positive effect on pain experience in LBP patients has been shown [8].

One of the main problems in CPM is the probable dependency of the frequency. Initially, we applied a frequency comparable with normal walking or cycling speed, because most LBP patients experience decreased pain during this activity. However, pilot studies using frequencies of 30 rpm up to 60 rpm were judged as not comfortable, whereas lower frequencies were deemed agreeable. Therefore, we decided to investigate the lower frequencies. The aim of the present study was to determine the RCPM frequency which achieves the most pain relief in patients with low back pain.

Material and methods

Population

180 LBP patients (male /female ratio 77 /103 with a mean age of 40.9 years (SD 8.1 years) and a mean duration of LBP of 71.9 months) were included in this study and all gave written informed consent. Neurological examination and X-ray of the lumbar spine were performed in all patients. The inclusion criteria were: (a) non-specific LBP longer than 6 weeks, and (b) lumbar pain and discomfort elicited by prolonged sitting. Patients with signs of radicular syndrome, systemic diseases, lysis and olisthesis, vertebral fractures or malignity and pregnancy were excluded.

Experimental set-up

Patients were investigated in two cohorts. The investigation started with 120 LBP patients randomly divided into a control group of 60 patients and two groups of 30 patients each tested at a RCPM frequency of 0.2 Hz (group 1) and 0.08 Hz (group 2)[8]. Because this earlier study showed that the lowest frequency of 0.08 Hz was the most effective, an additional 60 patients were randomly divided into two additional groups of 30 patients each and tested at the frequencies of 0.14 Hz (group 3) and 0.04 Hz (group 4). All 120 test subjects were seated uninterrupted for one hour on the experimental chair with RCPM; they were allowed to read, to talk with the assistant or to do nothing. The 60 control subjects sat for one hour on the same experimental chair, but without RCPM.

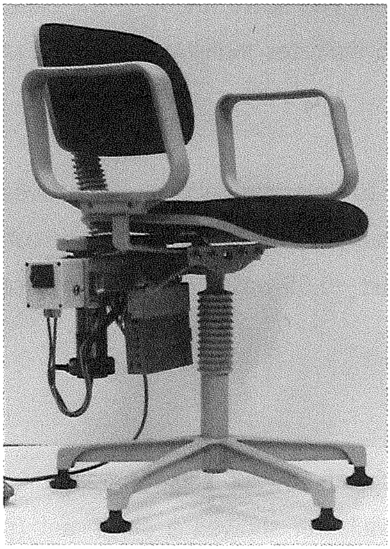

Figure 1: Experimental chair

Figure 1 shows the experimental chair which was used in all tests. RCPM was produced by a "revolving seat" of a conventional office chair. The seat rotated horizontally and independently of the backrest and arm supports. A compact, small, worm-geared electromotor provided an alternating movement, which was set at an angle of 1.25° on both sides. The centre of rotation was placed 10 cm anterior to the back of the seat. An adaptor was used to change the frequency. The height and inclination of the backrest were adapted to the individual's needs.

Pain

Pain was recorded by an "open" visual analogue scale (VAS), i.e. patients can draw a line as long as they wish to make it, in order to describe their pain. Subjects were asked to "score" their pain at the beginning of the test (baseline value) and then at intervals of 10 min during 1 hour; thus, seven pain scores were obtained for each subject. The subjects were able to compare their current VAS score with the previous scores so they did not inadvertently draw their lines longer or shorter than they intended. Dividing the 6 subsequent VAS score values by the baseline value gives the relative VAS (RVAS) score, which indicates individual's relative change in pain over time.

Statistical Analysis

Student's t-test (SPSS) was used to determine differences between the effect of the different frequencies between groups. In this analysis the two cohorts (n=180) were considered as one group. A p-value <0.05 was considered significant.

Results

Figure 2 shows the RVAS scores for all 180 subjects. Compared with the controls (no RCPM), the applied dynamic stimulation showed a significant ($p<0.001$) beneficial effect at all tested frequencies. Of the 180 subjects included in this study, 67 showed some improvement with the dynamic stimulation.

Figure 3 shows the percentage of patients with pain relief during sitting for 1 hour on a chair with RCPM at the 4 tested frequencies, compared with the control group.

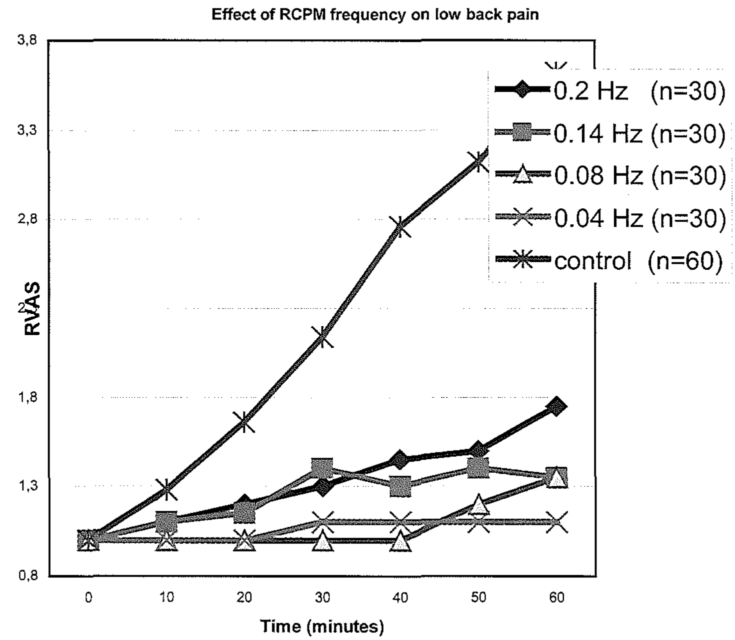

Figure 2: Effect of RCPM frequencies on low back pain

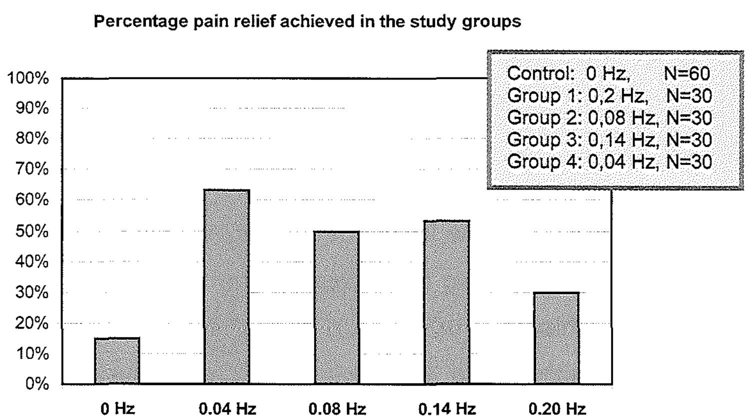

Figure 3: Percentage pain relief on different frequencies

Figure 4 shows the improvement on the patients' VAS score for the 4 frequencies.

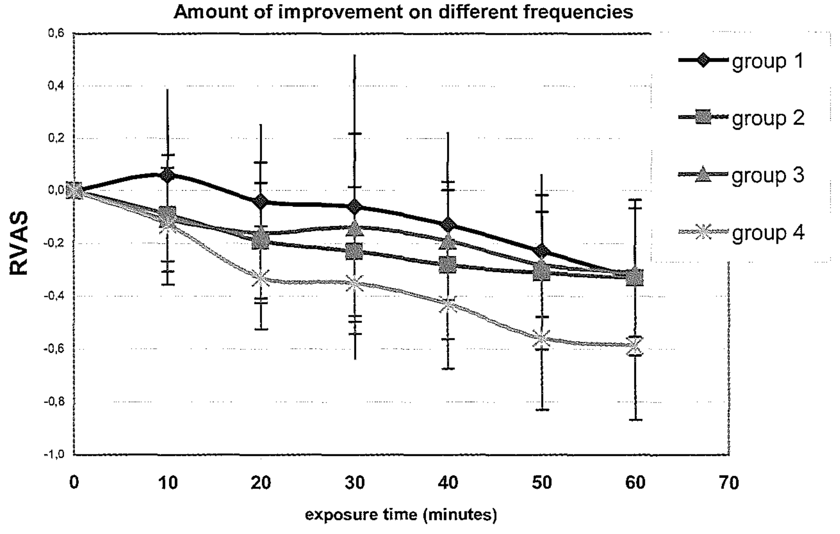

Figure 4: Pain improvement on different RCPM frequencies

Analysis of the group variance revealed that group 4 (0.04 Hz) showed a significant improvement ($p<0.022$) after 40 min, whereas there was no significant change between the 3 other groups tested with RCPM.

Discussion

The results of this study show that the lowest frequency tested (0.04 Hz) results in the least increase in pain during sitting for 1 hour. In the 120 patients tested with RCPM pain reduction was achieved in 48% versus 15% in the control group (n=60). Most pain relief was found in the group with the lowest tested frequency (63% of 30 patients). There is a possible bias effect for group 3 and group 4 because they were both part of the second cohort, and all were informed about the positive outcome of the first study [8]. Nevertheless, also in this cohort the lowest frequency proved to be the best. In another CPM study, Reinecke and Hazard found that a slow frequency of 0.008- 0.016 Hz was preferred to 0.25- 0.03 Hz ; they suggest that: "this low frequency effect is a result from spinal postural changes and not from whatever massage effect might result from fast CPM" [16,17]. Although the effect of massage on LBP relief remains debatable, we agree that the mechanical stimulation from RCPM is substantially different from the mechanics of massage. With respect to CPM in general and RCPM in particular, two problems exist: there is no clear explanation for its healthy effect, and the positive effect of lowering the frequency has not been elucidated. However, the positive effect of RCPM probably involves three main factors: neuron stimulation, postural improvement, and improvement of tissue conditioning.

Postural changes may result from muscle stimulation by RCPM. Improvement can be defined as assuming the neutral posture by means of muscle stimulation, as described by Cholewicki et al. [1]. A neutral posture implies minimal intrinsic spinal load.

Tissue condition can also be influenced by RCPM. The beneficial effect could be due to mobilisation of the facet joints, the alternating stretch of the spinal ligaments, and alternating torsion of the discs. These effects of pure axial rotation permitted within the free interspaces of the zygapophysial joints, are supported by a previous study which focused on nucleus pressure [6]. Cyclic torsion causes an alternating pressure gradient between the centre and periphery of the intervertebral disc (IVD), which promotes exchange of fluid. It may thus play a role in nutrition of the central area of the IVD, which remains devoid of nutrition when relying solely on diffusion [4,7,15]. The IVD could thus regain height over time. Indeed, increase of body height was found to occur in our previous RCPM study [5]. In an in vitro study, torsion of the disc, alternating 0.5- 2° and comparable with RCPM, resulted in an increase of disc height and a decrease of intradiscal pressure [6]; this suggests a pumping action, which could improve nutrition by fluid exchange. The RCPM frequency may influence disc nutrition by means of fluid exchange, which requires low-frequent pressure changes in the diffusion process. In the present study the lower frequencies tended to result in more pain relief. Although the results with RCPM are satisfactory, more studies are required to establish the optimal frequency.

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CHAPTER 7

General Discussion

Ever since Nachemson (1964) was the first to measure intradiscal pressure *in vivo,* the cause of low back pain (LBP) has mainly been attributed to intolerable high intradiscal pressure (Althoff 1992, Andersson GB 1981, Frymoyer 1980, Nachemson 1964, 1976, 1981, Sandover 1983, Wilke 1999). The work in this thesis contributes to the conclusion that the intradiscal pressure model may be a great misconception in the history of LBP.

This model seems not directly be related to pain. In fact, we know of no study that relates disc pressure to the level of pain experience. Moreover, intradiscal pressure can not be seen as a cause of degeneration or disc protrusion, because this has never been demonstrated in a biomechanical set-up. Hutton et al. (2000) showed that compression applied to the lumbar intervertebral discs of dogs for up to a year did not produce degeneration in any visible form, which add no credence to the commonly held belief that high compressive forces play a causative role in disc degeneration. Anderson and Chaffin (1985) calculated that a disc protrusion is unlikely under high disc pressure because such pressure results in an endplate fracture rather than in a failure of the annulus fibrosis. But, according to van Dieën (2001) even stress peaks cannot explain the occurrence of endplate fractures in non-degenerated discs. Although the risk of disc herniation is known to increase when the disc is loaded in flexed positions, the rate of loading appeared to have only a minor effect on the severity of damage induced in the discs, while the degree of flexion and the level of hydration are playing an important role. (Simunic 2001). Nevertheless, use of this pressure model persists and is often referred to for workload standards.

This thesis aims to contribute new hypotheses and new biomechanical models to help understand the phenomenon of low back pain.

A parallel of the intradiscal pressure model is the "spinal load model". Intradiscal pressure is generally related by means of calculations to spinal load and therefore to workload standards (Andersson 1981, Eklund 1984, Porter 1987, 1989, Stothart 2000, Tyrrell 1985). Helander (1990) used body shrinkage as a parameter to give advice on work-rest schedules in sedentary work. Measurement of body height and

body shrinkage as a method of assessing spinal load is widely accepted (Althoff 1992, Corlett 1987, van Dieën 1993, Eklund 1984, Helander 1990, Magnusson 1996, Tyrrell 1985).
General opinion seems to be that the lower this spinal load, the better it is for the spine, what has lead to the therapeutically strategy of bed rest as a first choice. Conversely, prolonged bed rest is an effective method to produce the severe disuse syndrome (Bortz 1984, Waddell 1993). It is also known that astronauts, although staying under conditions of microgravity, leading to a low spinal load, often return to earth with low back complaints (Nixon 1986).
The work in this thesis shows that the proposed relationship between body shrinkage and spinal load needs to be reconsidered. Although a simple linear relationship is suggested between body shrinkage and spinal load (Althoff 1992), which may apply to static loading, this procedure seems to fail in case of dynamic activities, as was also seen during sitting with rotary continuous passive motion (RCPM). Although spinal shrinkage is significantly different in sitting with or without dynamic impulses such as RCPM (van Deursen DL 2000) an explanation by the influence of a differing spinal load is very unlikely. Therefore, body shrinkage seems not only be related to the load on the intervertebral disc, but also to other intradiscal processes coupled with dynamics. Therefore, "spinal load" as an explanatory model for LBP seems to be inadequate.

Our clinical evaluation showed that static activities provoked more back pain than dynamic activities, suggesting that the LBP explanatory model should focus on the balance between statics and dynamics rather than on intradiscal pressure or spinal load. Mooney's (1987) statement that: "the disc lives by movement" suggests that LBP may be caused by a lack of spinal motion. Therefore, our study explored a static versus dynamic conceptual model of LBP.
We were the first to show a relationship by means of a mechanical parameter, i.e. axial spinal rotation, between the experience of low back complaints and everyday static and dynamic activities.
In a former study van Deursen et al. (2001) found that small rotary movement applied on the disc, leads to instantaneously disc height increase and intradiscal

pressure decrease, suggesting a pumping like action of the disc under rotation. This pumping like action could enhance a diffusion process. Our finding that low frequency had a better effect could correspond with calculations of Adams (1983) who showed little fluid flow to the centre of the disc when disc load fluctuates rapidly. Although a pumping mechanism could advocate a better diffusion effect under slow frequency, it is in contrast to our clinical experience that activities with higher frequencies of axial spinal rotation are leading to less back complaints. It is also unclear why an addition of RCPM in a frequency of 0.04 Hz has such a considerable influence on low back pain, where we found spontaneous axial rotations above 1 degree during sitting of 0.13 Hz. We can only speculate that a more regular sinusoidal rhythm is important. This could be in agreement with the still positive effect of RCPM on body shrinkage as found during sitting with stochastic impulses, simulating driving conditions (van Deursen DL 2000). Therefore more investigation has to be done.

The aim of this study was to relate clinical experience with biomechanical evidence. This resulted in a non-conventional approach. The intradiscal pressure theory seemed to be in agreement with pain experienced by LBP patients, but our study shows that this only holds for static activities. Nevertheless, this theory has resulted in the dramatic extrapolated conclusion of directly relating intradiscal pressure to the origin of LBP and therefore to a big mistake in thinking about therapy and avoidance of spinal load.

In 1987 Waddell received the Volvo Award on the conclusion that modern medicine has completely failed to cure the vast majority of patients with simple low back pain (Waddell 1987). A recent study of Rainville et al. (2000) showed that physicians' recommendations to patients with chronic back pain for activity and work vary widely and frequently are restrictive. Our research supports recommendations on activity promotion as done by therapy guidelines (Koes et al. 2001), but also suggests that some of the established biomechanical models seem to be obsolete and points to the need of studies based on dynamics.

Main conclusion of the present study is, that for low back pain risk, first the amount of activity, by means of axial rotation, is decisive and spinal load only affects in second place. Therefore we propose to use the dynamic model with axial rotations prior to the "intradiscal pressure" model. This "dynamic" model fits in the modern vision on LBP therapy: move and resume daily activities instead of bed rest. Especially cycling seems to be good for LBP patients and should be advised.

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SUMMARY

Low back pain (LBP) is a major problem in the industrialized world. The aetiology of LBP is multicausal: heavy physical workload, sedentary work, whole body vibration, smoking, as well as minimal influence over work conditions, poor social relations and psychological factors all play a dominant role (Thorbjörnsson et al. 2000).
Heavy physical workload is often cited as a primary factor, and is mostly related to an overload and high intradiscal pressure of the intervertebral discs. After Nachemson measured intervertebral disc pressure *in vivo* in 1964 and found higher disc pressure in sitting, lifting and bending than in standing and lying down, most physicians concluded that high intradiscal pressure, e.g. from heavy workload, should be avoided. Because of low intradiscal pressure during lying down, bed rest was the first choice in case of LBP, and recommendations for activities were restrictive.
It is now evident that bed rest for longer than two days is ineffective in case of LBP (Deyo et al. 1986) and even leads to chronicity and disuse (Waddell 1993; Bortz 1984); there is now worldwide consensus about the value of maintaining or resuming normal activities and doing exercises of any kind (Koes et al. 2001). However, even today, it is common in routine medical practice, that physicians still tend to restrict rather than encourage physical activity and work for patients with LBP (Rainville et al. 2000).

It is also remarkable that in daily practice it is not the extent of spinal load that may be most painful, but the lack of spinal motion. Most LBP patients say that: "I can easily do sports, cycling and walking, but sauntering, sitting and even lying down is painful". The controversy between the "spinal load" axiom and this clinical information from patients was the main incentive for the work presented in this thesis.

Chapter 2 presents data from 100 a-selective LBP patients who joined a study investigation whether or not they experience pain during several everyday activities.

It appeared that especially sitting, slightly bending (e.g. whilst vacuum cleaning, sweeping a floor, washing dishes and brushing teeth), standing and sauntering are highly likely to provoke pain, whereas walking and cycling generally do not. In other words, particularly static activities are pain provoking, while dynamic activities cause less pain, or may even lead to pain relief.

For static activities there is a high level of agreement between pain experience and intradiscal pressure height as measured by Nachemson. However, the question remains whether this relationship also applies to dynamic activities, because Nachemson did not measure intradiscal pressure for walking and cycling.

Chapter 3 investigates whether there is a direct relationship between spinal load and low back pain provocation during static and dynamic activities. Using spinal shrinkage as a measure, spinal load is measured during five everyday activities, including walking and cycling.

There is a circadian variation in body height due to shrinkage. Normal daily shrinkage accounts for approximately 1% of the total body height. Body shrinkage over time mainly depends on spinal loading and prior events. Measuring body height before and after one hour of activity, started immediately after rising from bed in the morning, allows to measure the spinal load for that particular activity. Body height was measured with a stadiometer, with an accuracy of 1 mm. Ten subjects performed five different everyday activities during different days. Shrinkage was found in the following descending order: walking (7.9 mm, SD 0.5); standing (7.4 mm, SD 0.5); sitting (5.0 mm, SD 0.6); cycling (3.7 mm, SD 0.4) and lying down (- 0.4 mm, SD 0.5). These values are comparable with intradiscal pressure values reported by Wilke et al. (1999), except for cycling which they did not measure. However, there is no relationship between these shrinkage values and pain experience as reported in Chapter 2, particularly not for the dynamic activities. In other words, there is no agreement between pain as experienced by LBP patients during everyday activities and the height of the spinal load or intradiscal pressure during these activities.

The fact that doubts exist about a relationship between the intradiscal pressure and pain provocation, especially for dynamic activities, the question remains whether another parameter may play a role.

Chapter 4 presents an analysis of the number of spontaneous axial spinal rotations during five different everyday activities in order to establish whether the outcome indicates a relationship between these activities and our clinical evaluation. Using four infrared cameras and 4 diodes, attached to the back of a test person, axial rotations were registered in the back between the low lumbar and the mid-thoracic level. Five subjects performed each of these five activities (standing, sitting, walking, cycling and lying down) for five minutes. Only rotations greater than 1 degree were filtered out. The average number of spontaneous axial rotations for these five subjects were: sitting 0.13 (SD 0.04); standing 0.18 (SD 0.11); lying down 0.34 (SD 0.12); walking 0.77 (SD 0.07); and cycling 0.98 (SD 0.10). With the exception of sitting and standing ($p=0.23$) the differences between the activities are significant ($p<0.04$).
This study shows a clear relationship between the number of spinal rotations and the experience of low back complaints, as was shown in Chapter 2. Activities with increasing axial spinal rotations lead to a decrease in pain.

Chapter 5 investigated the effect of rotary dynamic stimuli on low back pain during prolonged sitting in order to reconfirm the influence of axial rotations on pain experience. The pain experience of two groups of 60 subjects with non-specific low back pain was recorded. The pain behaviour of all subjects was studied using the Multidimensional Pain Inventory and pain was measured using an open visual analogue scale. During sitting, one group received dynamic stimuli generated by alternating rotations of 1.25 degrees to both sides, in the horizontal plane of the seat of the chair, with back and arm rests in fixed position. Two frequencies of rotation (0.2 Hz and 0.08 Hz) were applied in subgroups. It was concluded that such stimuli, especially at the lower frequency, reduced pain in prolonged sitting.

The results of this study confirm the findings reported in Chapter 4. Low back pain during sitting is significantly influenced by axial spinal rotation whereas there is minimal difference in the spinal load during sitting with or without rotary continuous passive motion.

This study also demonstrated that the lower frequency of rotary continuous passive motion of 0.08Hz is more effective in decreasing pain than the higher frequency of 0.2 Hz. This result raised the question as to whether or not there is an optimal frequency.

Chapter 6 studied two groups of 30 patients each in the same way as described in Chapter 5, but using the frequencies 0.14 Hz and 0.04 Hz. The results from this study were compared with the data from Chapter 5. It was found that although there were no significant differences, it is clear that the lowest frequency produced a more beneficial result.

Chapter 7 presents a summary of the main findings and conclusions of this thesis. Based on our clinical experience we have sought for a biomechanical explanation for the incidence of low back pain. For a long time medicine has maintained its belief in a relationship between spinal load and low back pain. We have demonstrated that this relationship is not correct and we were the first to show a relationship between the amount of axial spinal rotations and the experience of low back pain. Therefore we propose to use the dynamic model with axial rotations instead of the intradiscal pressure model. This dynamic model fits in the modern vision on LBP therapy to move and resume daily activities instead of bed rest. Bicycling has proven to be particularly beneficial for LBP and should be recommended more often.

SAMENVATTING

Lage rugklachten vormen een omvangrijk probleem in de geïndustrialiseerde wereld. De oorzaak van lage rugklachten is multifactorieel. Zware rugbelasting, zittend werk, trillingen, roken, maar ook het hebben van weinig invloed op werkomstandigheden, slechte sociale omstandigheden en psychogene factoren spelen een rol van betekenis (Thorbjörnsson et al. 2000).

Zware rugbelasting wordt vaak als eerste genoemd en hierbij wordt snel een relatie gelegd met overbelasting en hoge intradiscale druk. Toen Nachemson in 1964 als eerste de druk in de tussenwervelschijf *in vivo* bepaalde en vond dat bij zitten, tillen en bukken een hogere intradiscale druk bestond dan bij staan en liggen werd automatisch aangenomen dat deze hoge intradiscale druk vermeden diende te worden. Vanwege de lage druk bij liggen werd bedrust therapeutisch eerste keus bij lage rugklachten. Ten aanzien van activiteiten werd terughoudend geadviseerd.

Nu het duidelijk is dat bedrust langer dan 2 dagen niet zinvol is (Deyo et al. 1986) en kan leiden tot chronisch worden van de klachten, bestaat er wereldwijd consensus over dat snel hervatten van activiteiten en het doen van oefeningen van welke aard dan ook beter is (Koes et al. 2001). Navraag onder Britse artsen in 2000 liet echter zien dat de adviezen aan patiënten met rugklachten nog steeds sterk variëren en dat het hervatten van activiteiten en werk meestal nog ontraden wordt (Rainville et al. 2000).

In tegenspraak met het axioma dat de hoogte van de rugbelasting oorzaak van lage rugklachten is, is de dagelijkse praktijk, waarin het lijkt alsof niet de mate van belasting voor rugpatiënten belangrijk is, maar veeleer de mate van beweging.

De meeste rugpatiënten zeggen "Ik kan goed sporten, fietsen, tennissen en hardlopen, maar slenteren, zitten en zelfs liggen is pijnlijk". Vooral deze van het axioma afwijkende klinische informatie vormde de aanleiding voor dit onderzoek.

Hoofdstuk 2 laat de antwoorden zien van 100 niet geselecteerde rugpatiënten op de vraag of zij wél of géén last hebben bij een aantal met name genoemde dagelijkse

activiteiten. Vooral zitten, half gebukte houdingen (zoals tijdens stofzuigen, vegen, afwassen en tanden poetsen), staan en slenteren scoren hoog, terwijl bij lopen en fietsen veelal weinig klachten optreden. Met andere woorden, vooral statische bezigheden provoceren veel pijn, terwijl dynamische activiteiten minder pijn veroorzaken, integendeel, vaak zelfs pijn verlichtend werken.
Wat betreft de statische activiteiten komt deze score opvallend goed overeen met de hoogte van de intradiscale druk zoals deze door Nachemson gemeten werd. De vraag blijft echter of deze correlatie tussen de hoogte van de intradiscale druk en klachten ook bestaat voor dynamische activiteiten, want Nachemson heeft de intradiscale druk bij lopen en fietsen nooit gemeten.

In *Hoofdstuk 3* wordt onderzocht of het krijgen van rugklachten in een directe relatie staat met de rugbelasting zowel tijdens statische als tijdens dynamische activiteiten. Gebruik makend van de mate van lichaamskrimp wordt de rugbelasting gemeten, in het bijzonder ook voor een tweetal dynamische activiteiten als lopen en fietsen.
Het is bekend dat de rug in de loop van de dag inzakt, om vervolgens 's nachts weer langer te worden. We praten over ongeveer 1% van de totale lichaamslengte. De snelheid waarmee we krimpen, is mede afhankelijk van de mate van belasting. Hoe zwaarder de belasting hoe groter de mate van krimp over een bepaalde tijd. Door onmiddellijk na het opstaan een bepaalde activiteit gedurende één uur te laten uitvoeren, is het mogelijk om de bij deze belasting behorende krimpwaarde te bepalen. Met behulp van een stadiometer is de lichaamslengte tot op 1 mm nauwkeurig te meten. Aan de hand van 10 proefpersonen worden de krimpwaarden voor 5 verschillende activiteiten bepaald. Achtereenvolgens blijkt de meeste krimp op te treden voor: lopen (7.9 mm, SD 0.5) ; staan (7.4 mm, SD 0.5) ; zitten (5.0 mm, SD 0.6); fietsen (3.7 mm, SD 0.4) en liggen (- 0.4 mm, SD 0.5). De mate van krimp zoals hier vastgesteld komt redelijk overeen met de mate van intradiscale druk zoals gemeten door Wilke (1999), behoudens voor fietsen, wat niet door Wilke bepaald is. Echter, deze waarden staan totaal niet in verhouding tot de mate van pijn provocatie zoals gemeten in hoofdstuk 2, vooral niet waar het de dynamische activiteiten betreft. Met andere woorden: de mate waarin bij rugpatiënten pijn optreedt bij

bepaalde activiteiten is niet in overeenstemming met de mate van rugbelasting, noch met de bijbehorende intradiscale druk.

Nu de relatie tussen de intradiscale druk en provocatie van rugklachten, zeker met betrekking tot dynamische activiteiten in twijfel wordt getrokken, blijft de vraag of er mogelijk een andere parameter bestaat.

In *Hoofdstuk 4* wordt nagegaan hoeveel "spontane" axiale rotatiebewegingen er plaats vinden tijdens voornoemde vijf activiteiten, ten einde een mogelijke relatie tussen pijn provocatie en de mate van beweging na te gaan.
Met behulp van 4 infrarood diodes, welke op de rug van een proefpersoon worden gefixeerd, en 4 infrarood camera's worden de axiale rotatiebewegingen in de rug geregistreerd tussen het laag lumbale en het mid- thoracale niveau. Vijf proefpersonen voeren achtereenvolgens vijf activiteiten uit (staan, zitten, lopen, fietsen en liggen), elke activiteit gedurende vijf minuten. Uit de continue registratie worden de rotatie uitslagen groter dan 1 graad gefilterd en gemiddeld over de vijf proefpersonen. De volgende aantallen axiale rotatiebewegingen (boven 1 graad) per seconde worden hierbij geregistreerd: tijdens zitten 0.13 (SD 0.04); staan 0.18 (SD 0.11); liggen 0.34 (SD 0.12); lopen 0.77 (SD 0.07) en fietsen 0.98 (SD 0.10). Behalve tussen zitten en staan ($p=0.23$) bestaan er significante verschillen tussen alle activiteiten onderling ($p<0.04$).
Vergelijken we deze waarden met de pijnscore uit hoofdstuk 2, dan zien we een nagenoeg omgekeerd evenredig verloop: hoe meer rotatiebewegingen we maken, des te minder pijn we krijgen.

In *Hoofdstuk 5* wordt een onderzoek beschreven dat de bevinding uit hoofdstuk 4 wil toetsen. In deze studie wordt het effect gemeten van het toevoegen van axiale rotatiebeweging ofwel rotary continuous passive motion op lage rugklachten tijdens één uur zitten. De pijn welke optreedt bij twee groepen van elk 60 proefpersonen met aspecifieke lage rugklachten wordt geregistreerd. Alle proefpersonen worden tevens onderzocht op pijngedrag met behulp van de Multidimensional Pain Inventory en pijn wordt gemeten met behulp van een open visual analogue scale. Tijdens het

zitten krijgt één groep axiale rotatiebewegingen toegevoegd, terwijl de andere groep als controlegroep functioneert. De zitting van een experimentele kantoorstoel wordt in het horizontale vlak met behulp van een elektromotor in een continue heen en weer gaande draaibeweging gebracht, terwijl de rugleuning en de armleuningen stil staan. De hoekuitslag bedraagt hierbij 1.25° naar links en naar rechts. Er worden twee verschillende frequenties toegepast: 0.2 Hz (12 slagen per minuut) en 0.08 Hz (5 slagen per minuut).
Vastgesteld wordt dat deze dynamische axiale rotatiebewegingen het optreden van pijn tijdens langdurig zitten significant reduceren. Hierbij blijkt vooral de lage frequentie het meest effectief.

Met dit onderzoek wordt o.i. de waarneming uit hoofdstuk 4 bevestigd. Niet de drukbelasting, welke immers tijdens zitten met of zonder RCPM nauwelijks lijkt te veranderen, maar de mate van axiale rotatie beweging beïnvloedt het krijgen van pijn in de rug.

Voorgaand onderzoek roept wel vragen op met betrekking tot de invloed van de frequentie van rotary continuous passive motion tijdens zitten. Niet duidelijk is waarom de lage frequentie van 0.8 Hz een duidelijk beter effect heeft dan de iets hogere frequentie van 0.12 Hz. De vraag is tevens of er een optimale frequentie is.

In *Hoofdstuk 6* worden opnieuw twee groepen van 30 patiënten op soortgelijke wijze als in hoofdstuk 5 onderzocht bij twee andere frequenties, zijnde 0.14 Hz en 0.04 Hz. De uitslagen worden vergeleken met de uitslagen uit hoofdstuk 5. Ofschoon de onderlinge verschillen niet significant zijn is de tendens duidelijk dat hoe lager de frequentie des te beter het resultaat.

In *Hoofdstuk 7* wordt een samenvatting gegeven. Uitgaande van onze klinische ervaringen hebben we in deze thesis gezocht naar een biomechanische verklaring voor het optreden van lage rugpijn. Hierbij hebben we aangetoond dat er ten onrechte lange tijd is vastgehouden aan het primaire belang van de relatie tussen intradiscale druk (als maat voor rugbelasting) en lage rugpijn. Wij hebben kunnen vaststellen dat het aantal axiale rotatiebewegingen een passender parameter vormt.

In relatie tot lage rugpijn pleiten wij daarom voor het vervangen van het "intradiscale druk" model als maatgevend model door een "dynamisch" model. Dit dynamische model met axiale rotatie ondersteunt in hoge mate de moderne richtlijnen met betrekking tot de behandeling van lage rugklachten om in geval van rugklachten de dagelijkse activiteiten zo snel mogelijk te hervatten en om oefeningen te adviseren in plaats van bedrust. Uit ons onderzoek komt naar voren dat vooral fietsen erg goed is voor rugpatiënten en daarom met recht nog meer gestimuleerd zou mogen worden.

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Tot slot

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wesentlichen Beitrag zu RCPM geliefert und wirst das Thema "bewegtes Sitzen" in Deutschland sicher auch weiter vorantreiben. Es wäre schön, wenn dieser enge Kontakt uns weiter erhalten bleibt und wir noch Vieles gemeinsam "bewegen" können; Du würdest mir damit weiter eine große Freude machen.

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Dirk bedankt !

Curriculum Vitae

Leo van Deursen werd geboren op 8 juli 1944 in Geldrop, Nederland. Na het Gymnasium β gevolgd te hebben aan het Carolus Borromeus College te Helmond ging hij in 1964 medicijnen studeren aan de Katholieke Universiteit te Nijmegen. Na zijn afstuderen in 1972 vestigde hij zich als huisarts te Heeze, waar hij praktijk voerde tot 1982.

Vanaf 1982 heeft hij zich gespecialiseerd in de manuele geneeskunde en werkte tot 2001 op de polikliniek voor manuele geneeskunde van de SMG te Eindhoven. Gedurende diezelfde periode was hij tevens als docent verbonden aan de opleiding voor "arts manuele geneeskunde" en gaf hij daarbuiten regelmatig cursussen in onderzoek van het bewegingsapparaat aan huisartsen, met name in de regio Eindhoven. Sedert 2001 is hij actief in Ergodynamics Industries B.V. samen met zijn zoon Dirk, die in 2000 promoveerde op de mechanica van de tussenwervelschijf tijdens dynamisch zitten. Beiden houden zij zich momenteel bezig met de ontwikkeling van ergonomisch meubilair.

Tevens is hij parttime verbonden aan de onlangs opgerichte polikliniek voor manuele geneeskunde aan het Hertog Hendrik van Brabantplein 17 te Eindhoven.