Possible harmful effects of high intra-abdominal pressure on the pelvic girdle

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Accepted 13 January 2005

Abstract

The present study explores the hypothesis that a high intra-abdominal pressure (IAP) loads the ligaments of the pelvic girdle to such an extent that frequent periods of high IAP might cause pain and/or interfere with recovery of patients with pelvic girdle pain (PGP). In a theoretical model the size of the load of IAP on the pelvic girdle was computed. The diameters of abdomen and pelvis needed for the calculations were measured on MRI scans; the IAP values during activities were gained from literature. In slim, healthy subjects the calculated load on the pelvic ring during activities of daily living was 26.0–52.0 N with peaks to 135 N. During straining, vigorous work or heavy exercises the load could increase to values ranging from 104 to 520 N. The load is higher in subjects with pain or fatigue, or in case of a distended abdomen. When the load on the pelvic ring induced by IAP is larger than 100 N, the force exceeds the force at which a pelvic belt relieves complaints in PGP; at 90 N, the force is larger than the force at which isometric hip adduction provokes pain in PGP. We conclude that the size of the load induced by IAP on the pelvic girdle seems to be sufficient to cause pain in patients with PGP and might interfere with recovery. It seems worthwhile to give patients with PGP instructions to reduce IAP as much as possible during activities.

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Keywords: Low back pain; Intra-abdominal pressure; Biomechanics; Pelvic bones

1. Introduction

Although the influence of intra-abdominal pressure (IAP) on the lumbar spine has been extensively discussed, to our knowledge the influence of IAP on the pelvic girdle has not been studied. Bartelink (1957) was the first to study IAP in relation to low back pain. His measurements of IAP in healthy subjects during lifting showed that athletic subjects lifting 90 kg had an IAP of 1.85 N/cm², whereas in slightly built people the pressure was sometimes not more than 0.80 N/cm². If the body had been flexed without a weight being lifted, IAP was only slightly increased. The greater the lifted weight the greater the increase in pressure. Bartelink concluded that the increase in IAP should be marked as biomechanically beneficial for the lumbar spine, especially during heavy lifting. He estimated that the ‘abdominal balloon’ could provide a decrease of the spinal load by ‘several hundred pounds’.

Since the study of Bartelink many investigators have shown that the amount of load reduction by the pressured ‘abdominal balloon’ is less than has been suggested by Bartelink (Garg, 1992). Various calculations resulted in reductions ranging from 2.6% to 40%. However, one of the limitations of the calculations based on mathematical models, is the controversy that contraction of most of the muscles needed to produce the IAP results in compression of the spine. Direct measurements of the intradiscal pressure in healthy subjects during various tasks showed a positive correlation between IAP and intradiscal pressure (Schultz et al.,...
1982); however, the correlation was poor (0.36). Measurements of the intradiscal pressure in healthy subjects showed that performing the Valsalva maneuver (voluntary pressurization of the intra-abdominal cavity) raised the intradiscal pressure in four of the five tasks rather than decreasing lumbar spine compression (Nachemson et al., 1986). The idea of Bartelink that the pressured ‘abdominal balloon’ unloaded the spine by ‘several hundred pounds’ is now largely abandoned. Nevertheless, many investigators still believe that the pressured ‘abdominal balloon’ has an important function in stabilization of the spine (Garg, 1992; Marras and Mirka, 1996; Cholewicki et al., 1999a, b). It has been questioned whether IAP directly stabilizes the spine or whether the contraction of several muscles stabilizes the spine, and whether the increase in IAP is just a by-product of the contraction of those muscles (Marras and Mirka, 1996).

Reported harmful effects of IAP concern herniation of the borders of the ‘abdominal balloon’ (abdominal wall, diaphragm, vaginal and rectal prolapse) and urinary incontinence (Davis, 1959). Moreover, an increase of IAP brings about an increase of the pressure in blood vessels outside the ‘abdominal balloon’, producing headache and ruptures of blood vessels causing innocent haematomas, but which may be the cause of intra-ocular or cranial bleeding leading to blindness and even death (McGill et al., 1990; Narloch et al., 1994; Pool-Goudzwaard et al., 1998; Mens et al., 1999, 2001, 2002; Damen et al., 2002; Wu, 2004). Although the influence of IAP on the spine has been largely elucidated, the load on the pelvic girdle due to an increase in IAP is still a matter of investigation. In a pilot study in 53 patients with pregnancy-related PGP, 26%, 28% and 32% of the patients indicated pain on coughing, sneezing and straining, respectively (unpublished data). This latter study was performed in the group described below (see Section 2.1.4).

We hypothesize that a high IAP loads the ligaments of the pelvic girdle. Many patients with PGP feel relief when wearing a pelvic belt and feel (increase of) pain during isometric adduction of the hips. We assume that IAP overloads the ligaments of the pelvic ring when the load on the pelvic ring exceeds the force at which a pelvic belt relieves pain in patients with PGP, and at which the force of isometric adduction of the hips provokes pain in PGP.

The present study investigates the hypothesis that a high intra-abdominal pressure loads the ligaments of the pelvic girdle to such an extent that frequent periods of high IAP might cause pain and/or interfere with recovery of patients with PGP. First we computed the size of the load induced by the IAP on the pelvic ligaments during activities of daily living (ADL). Then we compared this force with the force at which a pelvic belt relieves pain or at which isometric hip adduction provokes pain in PGP. An additional aim was to gain information about the kind of instructions patients with PGP need to minimize the harmful effects of IAP.

2. Methods

2.1. Part I—Collecting data for calculations

2.1.1. Dimensions of the abdominal-pelvic cavity

The abdominal and pelvic cavities are two parts of the same ‘balloon’. The abdominal-pelvic cavity is surrounded by the diaphragm, the anterior part of the lumbar spine, the muscles of the abdominal wall and the pelvic floor. Arbitrarily, the horizontal plane through the most cranial point of the iliac crest was chosen as the border between the pelvic and abdominal part of the cavity. The size of the area \((A = \text{area})\) and circumfer-
ence ($C = \text{circumference}$) of the mid-sagittal plane of the cavities were measured by means of MRI scans in two female subjects (Fig. 1A–C). Subject A had a flat abdomen (not pregnant, nulliparous) and subject B had a distended abdomen (pregnancy 28 weeks). In addition, the height ($h$) of the pelvic part of the abdominal wall was measured (distance between the upper edge of the pubic symphysis and the cranial border of the pelvic cavity). In the transversal plane, at the level of the superior anterior iliac spine, the angle alpha was measured between the abdominal wall and the frontal plane (Fig. 2A–C).

2.1.2. IAP during activities

There are many studies on the influence of activities on IAP in patients with low back pain as well as in healthy subjects. A search was made in PubMed with the search terms IAP, intra abdominal pressure, back and measurement. The reference lists of those publications were also screened. Pressures were expressed in N/cm$^2$ (1 kPa = 0.1 N/cm$^2$ and 1 mmHg = 0.0133 N/cm$^2$).

2.1.3. Size of the protective force of a pelvic belt

A literature search was performed in PubMed with the search terms: pelvic, belt and sacroiliac. The reference lists of those publications were also screened.

2.1.4. Size of the provoking force of isometric hip adduction

During a 15-month period (1-9-1998 to 1-12-1999), patients with PGP were selected from an outpatient clinic specialized in rehabilitation of low back pain and PGP. Included were patients with pain, which started during pregnancy or within 3 weeks after delivery, with duration of at least 6 months and localized between the upper level of the iliac crests and the gluteal fold. Posterior pelvic pain provocation test was positive (Östgaard et al., 1994), the score on the Active Straight Leg Raise (ASLR) test was positive (score 3–10 on a scale ranging from 0 to 10) (Mens et al., 2001), a pelvic belt lowered the score on the ASLR test and pain could be provoked by isometric hip adduction. Patients were excluded in case of systemic diseases of the locomotor system.

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Fig. 1. Mid-sagittal plane: (A) MRI of subject A, with a flat abdomen, (B) MRI of subject B, with a distended abdomen and (C) drawing. For legends see Table 1.
system or with major psychological disorders. The method to measure (maximal) adduction strength was based on a former study (Meeteren et al., 1997). The measurement took place with a handheld dynamometer (Microfet, Hoggan Health Industries Inc., Draper, Utah, USA) in the supine position, the knees at 90° and the feet placed on the couch. Reliability of the strength measurement has been shown to be good (Meeteren et al., 1997; Mens et al., 2002).

2.2. Part II—Calculations

Using the principles of physics and mathematics the forces applied on the pelvic ring were calculated. The force by which the left and the right half of the abdominal and pelvic cavity are pushed apart (to ‘lateral’) is given by

\[ F_{\text{lateral}} = p \cdot A, \]  

where \( p \) is IAP and \( A \) is the area of the mid-sagittal plane of the abdominal-pelvic cavity (Fig. 1A–C). In accordance with Laplace’s law (Rhoades and Tanner, 1995), the tension \( T \) in the wall of the cavity is found by

\[ T = F_{\text{lateral}} / C, \]  

where \( C \) is the circumference of this plane. From (1) and (2), we conclude:

\[ T = (p \cdot A) / C. \]  

The tensed abdominal wall pulls both pelvic halves together (to ‘central’). The size of the force is

\[ F_{\text{central}} = T \cdot \cos \alpha, \]  

where \( h \) is the height of the pelvis, and \( \alpha \) the angle in the transversal plane between the abdominal wall and the frontal plane.

3. Results

3.1. Part I—Data for the calculations

3.1.1. Dimensions of the abdominal-pelvic cavity

The dimensions of both subjects are summarized in Table 1. The angle (alpha) between the abdominal wall and the frontal plane in subject A is about 0° indicating a flat abdomen (Fig. 2A–C).

3.1.2. IAP during activities

IAP increase has been established during many activities of daily living and during exercises (Table 2). The highest values were measured during lifting. IAP increased with the load and the amount of bending. IAP increase of patients with back pain is largely the same as in healthy controls as long as no pain has been provoked during the activities (Hemborg and Moritz, 1985). For a given task, IAP is higher as soon as subjects feel pain or fatigue (Fairbank et al., 1980; Davis, 1981; Williams and Lind, 1987).

Baty and Stubbs (1987) monitored the IAP level of healthy subjects during the 8-h working day of geriatric nurses. In total, 87% of the IAP peaks were between 0.27 and 0.53 N/cm² and 13% were higher than...
0.53 N/cm² with peaks to 1.33 N/cm². Nicholson et al. (1981) measured IAP peaks per professional activity in telecommunication engineers and assessed that in most of their tasks IAP was between 0.40 and 1.20 N/cm², but pressures between 1.20 and 2.00 N/cm² were not exceptional.

So, during ADL, most IAP peaks are between 0.25 and 0.50 N/cm²; a minor part of the peaks are between 0.50 and 1.30 N/cm². During straining, vigorous work, or heavy exercises IAP reaches peak values between 1 and 2 N/cm². In extremely powerful weightlifters IAP may reach values of 5 N/cm². The more muscle power a subject has, the higher the IAP levels can be reached during the performance of tasks.

3.1.3. Size of the protective force of a pelvic belt

Three studies have investigated the force induced by a pelvic belt (Vleeming et al., 1992; Mens et al., 1999; Damen et al., 2002). Vleeming et al. (1992) investigated the mobility of the sacroiliac joints in human cadavers and found a significant decrease of sacroiliac mobility when a pelvic belt had been applied with a tension of 50 and 100 N; the influence of a tension of 50 and 100 N were about the same. Mens et al. (1999) performed an in vivo study in patients with pregnancy-related PGP. The influence of various tensions of a pelvic belt was studied on the ability to perform an active straight leg raising maneuver. The tensed belt resulted in a significant improvement. A tension of about 50 N seemed to be sufficient. Damen et al. (2002) investigated the influence of a pelvic belt on the stability of the pelvic joint by means of Doppler Imaging of Vibrations (DIV). The signal of the DIV changed significantly when a pelvic belt was tensed around the pelvis. They concluded that a pelvic belt reduces the mobility of pelvic joints, and a tension of 100 N does not reduce mobility more than 50 N. Thus a tension of 50 N in a pelvic belt seems to be sufficient to protect the pelvic ring against (a part of the) pain during ADL.

3.1.4. Size of the provoking force of isometric hip adduction

A total of 53 patients with PGP with pain at isometric hip adduction were included. Mean age was 32.5 years (SD 3.8 years), height 170.5 cm (SD 6.6 cm) and weight 72.8 kg (SD 14.3 kg). Mean (maximal) strength at isometric hip adduction was 90 N (SD 48 N).

3.2. Part II—Calculations

(1a) Forces within the wall of the abdominal-pelvic cavity: Substitution in formula (3) of the data for area and circumference found for subject A (area = 261 cm² and circumference 94 cm) and subject B (area = 411 cm² and circumference 103 cm) results in the relation between the IAP and the tension T in the abdominal wall:

\[ T_{\text{subject A}} = 2.8 \text{ cm} \cdot \text{IAP}, \]

\[ T_{\text{subject B}} = 4.0 \text{ cm} \cdot \text{IAP}. \]
So in case of a given IAP, the load on the abdominal wall in the distended abdomen is 1.4 times as much as in the flat abdomen.

(1b) For subject B: Substitution in formula (1) of the data for area and circumference found for subject A (area = 131 cm²) and subject B (area = 176 cm²) results in the relation between the IAP and the force loading the pelvic part of the abdominal-pelvic cavity:

\[ F_{\text{lateral subject B}} = 131 \text{ cm}^2 \cdot \text{IAP}, \]  
\[ F_{\text{central subject B}} = 176 \text{ cm}^2 \cdot \text{IAP}. \]  

(1c) Protective forces induced by the abdominal wall: Substitution in formula (4) of the data for the height \( h \) of the pelvic part of the abdominal wall, cosines alpha and tension in the abdominal wall (formula (5) and (6)):

\[ F_{\text{central subject B}} = T \cdot h \cdot \cos \text{alpha}. \]  
For subject A:

\[ F_{\text{central subject A}} = 2.8 \text{ cm} \cdot \text{IAP} \cdot 9.8 \text{ cm} \cdot 1.0, \]  
\[ F_{\text{central subject A}} = 27 \text{ cm}^2 \cdot \text{IAP}. \]  
For subject B:

\[ F_{\text{central subject B}} = T_{\text{subject B}} \cdot h \cdot \cos \text{alpha}, \]  
\[ F_{\text{central subject B}} = 4.0 \text{ cm} \cdot \text{IAP} \cdot 12.7 \text{ cm} \cdot 0.93, \]  
\[ F_{\text{central subject B}} = 47 \text{ cm}^2 \cdot \text{IAP}. \]  

So, in subject A, the force loaded by the IAP \((F_{\text{lateral}})\) is about 4.9 times (131/27) the size of the protective force provided by the abdominal wall \((F_{\text{central}})\). In subject B this ratio is 3.7 (176/47).

(1d) Net load induced by IAP: The negative influence of the force induced by the IAP \((F_{\text{lateral}})\) will partially be compensated by the increase of the protective force by the increased tension in the abdominal wall \((F_{\text{central}})\). The net load on the pelvic ring induced by IAP is

\[ \text{Load} = F_{\text{lateral}} - F_{\text{central}}. \]  
For subject A:

\[ \text{Load}_{\text{subject A}} = (131-27) \text{ cm}^2 \cdot \text{IAP}, \]  
\[ \text{Load}_{\text{subject A}} = 104 \text{ cm}^2 \cdot \text{IAP}. \]  
For subject B:

\[ \text{Load}_{\text{subject B}} = (176-47) \text{ cm}^2 \cdot \text{IAP}, \]  
\[ \text{Load}_{\text{subject B}} = 129 \text{ cm}^2 \cdot \text{IAP}. \]  

3.2.2. Protective force induced by a pelvic belt

With the assumption that 50 N tension in a pelvic belt seems to be sufficient to protect the pelvic girdle against (a part of) the pain, (the compressive) force induced by a pelvic belt works as well as at the anterior as at the posterior side of the pelvis, so the force is \( 2 \times 50 = 100 \text{ N} \). It should be noted that it is theoretically possible to increase the tension in the belt to protect the pelvis against higher loads.

The IAP at which the protective force of the pelvic belt will be exceeded by the load of IAP will be computed with the formula:

\[ F_{\text{belt}} < \text{Load}. \]  
Substitution in formula (15) of the formula for load ((13) and (14)):

For subject A:

\[ F_{\text{belt}} < \text{Load}_{\text{subject A}}, \]  
\[ 100 \text{ N} < 104 \text{ cm}^2 \cdot \text{IAP}, \]  
\[ \text{IAP} > 100/104 \text{ N/cm}^2, \]  
\[ \text{IAP} > 0.96 \text{ N/cm}^2. \]  
For subject B:

\[ F_{\text{belt}} < \text{Load}_{\text{subject B}}, \]  
\[ 100 \text{ N} < 129 \text{ cm}^2 \cdot \text{IAP}, \]  
\[ \text{IAP} > 100/129 \text{ N/cm}^2, \]  
\[ \text{IAP} > 0.78 \text{ N/cm}^2. \]  

So the protective force of the pelvic belt will be exceeded by the load of IAP at values of IAP higher than 0.96 N/cm² in a flat abdomen and higher than 0.78 N/cm² in a distended abdomen.

3.2.3. Size of the provoking force of isometric hip adduction

During isometric measurement the force of the adductors must be compensated by the connections between both pelvic halves. In other words the adductors load the pelvic ring with the same force as is measured between the knees. Adduction strength was on average 90 N. Most of the PGP patients felt pain at a lower tension of the adductors and increased the tension irrespective of the pain. It is uncertain how many of them increased the IAP during their attempts.

The IAP at which the provoking influence of IAP will exceed the provoking force of isometric hip adduction
will be computed with the formula:
\[
\text{Load} > F\text{ adductors.}
\] (18)
Substitution in formula (18) of the formula for load ((13) and (14)):
For subject A:
\[
\text{Load}_{\text{subject A}} > 90 \text{ N,}
\]
\[
104 \text{ cm}^2 \cdot \text{IAP} > 90 \text{ N,}
\]
\[
\text{IAP} > 0.87 \text{ N/cm}^2.
\] (19)
For subject B:
\[
\text{Load}_{\text{subject B}} > 90 \text{ N,}
\]
\[
129 \text{ cm}^2 \cdot \text{IAP} > 90 \text{ N,}
\]
\[
\text{IAP} > 0.70 \text{ N/cm}^2.
\] (20)
So the provoking influence of IAP will exceed the provoking force of isometric hip adduction with values of IAP higher than 0.87 N/cm² in a flat abdomen and higher than 0.70 N/cm² in a distended abdomen.

4. Discussion

The load induced by the IAP on the pelvic girdle is calculated as 131–176 cm² IAP. This force will be partially compensated by increased tension in the abdominal wall and the pelvic floor. The load on the pelvic ring during ADL ranges from 26.0 to 52.0 N with peaks to 135 N in a flat abdomen and from 32.3 to 65.0 N with peaks to 168 N in a distended abdomen. During straining, vigorous work or heavy exercises the load is 104–520 N in a flat abdomen and 129–645 N in a distended abdomen. Thus, during many situations, the load on the pelvic ring induced by IAP is of the same size, or even higher than the force at which a pelvic belt relieves pain (100 N) or isometric hip adduction provokes pain (90 N). The harmful influence of IAP increases with the size of the abdomen. So the load induced by IAP on the pelvic girdle is sufficient to cause pain in patients with PGP and might interfere with recovery.

A pelvic belt is frequently advised in the treatment of PGP (Wu, 2004). Theoretically the use of a belt seems to be justified, because the parts of the pelvic girdle will be compressed together by the belt. However, as a side effect of this wanted effect, IAP may increase by decreasing the volume of the abdominal–pelvic cavity. Poppel et al. (2000) showed that lumbar supports do not influence IAP. The influence of pelvic belts on IAP had never been studied, but when large lumbar supports do not increase IAP, it may be assumed that neither will a pelvic belt of 6 cm wide placed over the lower part of the abdomen.

Another popular treatment for PGP is instruction on how to contract the transversus abdominis (TA) and the pelvic floor muscles (Pool-Goudzwaard et al., 1998; Richardson et al., 2002; Wu, 2004; Stuge et al., 2004). The theoretical background is the same as for the use of a pelvic belt: compression of the parts of the pelvic girdle together. In many situations the TA will also contract when subjects make an effort to contract the pelvic floor muscles (Sapsford et al., 2001; Neumann and Gill, 2002). Increase of IAP during the co-contraction of TA and pelvic floor is only 0.08–0.12 N/cm² (Neumann and Gill, 2002).

We may conclude that the popular methods to treat PGP (a pelvic belt, tensing TA and the pelvic floor muscles) do not increase IAP; this fact supports the idea that effective measures for PGP should not increase IAP.

In the present study the assumption had been made that IAP overloads the ligaments of the pelvic ring when the load on the pelvic ring exceeds the force at which a pelvic belt relieves pain in patients with PGP. It is not logical to think that the distribution of the load generated by the IAP over the various parts of the wall of the cavity is exactly the same as the distribution of the load induced by isometric hip adduction or by a pelvic belt. The load during isometric adduction will act as a separating force on the pelvis, but will also induce a torque moment. The consequence is that isometric adduction loads especially the anterior parts of the pelvic ring: the ligaments around the pubic symphysis and the anterior parts of the sacroiliac joints. This is in line with the experience that pain during isometric adduction is mostly localized around the symphysis pubis. Thus the influences of IAP, of a pelvic belt and of isometric hip adduction are not exactly focused on the same structure. The most important conclusion of the present study is that the size of the three forces is of the same class.

One of the limitations of the study is that we did not ask the patients with PGP to perform a Valsalva maneuver to verify if an increase in IAP would result in provocation of pain and if this pain could have been reduced by means of a pelvic belt. The results could have given extra support to the presented theory.

It seems that almost everyone has the tendency to strain when having to perform a difficult task. Bartelink believed that, during weight lifting, subjects had a ‘reflex contraction of the abdominal wall’ in combination with ‘a (subconscious) voluntary contraction’ (Bartelink, 1957). It seems possible to instruct a person to change this habit (Hemborg et al., 1985; McGill et al., 1990). The IAP during exhalation was about 0.20 N/cm² less than with breath held (McGill et al., 1990). If we assume that IAP loads the pelvic ring it seems worthwhile to investigate the possibility to reduce IAP by special instructions during peak tasks. Another way to reduce
IAP seems to avoid maximal performance of a subject, to prevent serious provocation of pain and to prevent fatigue during exercises (O’Sullivan et al., 2002; Williams and Lind, 1987).

Acknowledgements

The study was funded by a grant of the Stichting Algesiologie, project 98–0503.

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