

INTRA-ABDOMINAL PRESSURE MEASUREMENTS USING A WIRELESS RADIO PRESSURE PILL AND TWO WIRE CONNECTED PRESSURE TRANSDUCERS: A COMPARISON

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ABSTRACT. Intra-abdominal pressures were measured simultaneously with a wireless radio pill and two wire-connected pressure transducers introduced orally and rectally respectively. Measurements were made on 8 men during common postures, simple activities and static and dynamic lifting. An acceptable correspondence was found in wave forms of the generated pressure curves in time and shape. The three systems showed, however, a less good agreement in recorded peak differences, i.e. highest and lowest pressure responses to each task. The radio pill is simple to use, but more difficult to calibrate and expensive, compared to the wire-connected methods, which however are less attractive for use in the work environment.

Key words: Intra-abdominal pressure measurements, lifting, lumbar spine, radio pressure pill, wire-connected pressure transducers

Intra-abdominal pressure measurements have been used extensively to analyse trunk stresses. Several studies have documented that the pressures within the trunk cavities increase when heavy weights were lifted (2, 3, 4, 5, 10, 11, 12, 14, 15, 17, 18). Large increases in intra-abdominal pressure frequently occurred when subjects lifted with straight legs and deep forward bending of the spine. Increases were smaller when subjects maintained an upright position of the trunk while lifting. Andersson et al. and Örtengren et al. found that the intra-abdominal pressures during static lift were proportional to the magnitude of the trunk moments (1, 19). The increase in intra-abdominal pressure is due to contractions mainly of the abdominal muscles, but the diaphragm and the muscles of the pelvic floor will also contribute. Little is known about the way in which these muscles are called upon to act (13, 16).

The aim of the present study was to compare values for intrabdominal pressure measured simultaneously with a wireless radio pill and two wire-connected pressure transducers during common

postures, simple activities, and static and dynamic lifting.

MATERIALS, METHODS AND PROCEDURES

Subjects

Eight male volunteers were studied. All were free from back pain. The subjects ranged in age from 22 years to 27 years (mean 26.5 years). Their heights varied between 170 cm and 200 cm (mean 185 cm), and their weights ranged from 67 kg to 91 kg (mean 76.9 kg).

Measurement of intra-abdominal pressure

A Rigel model 7014 pressure-sensitive radio pill (Rigel Research Ltd., 99 Gander Green Lane, Sutton, Surrey, UK) was used as one means of measuring intra-abdominal pressure (Fig. 1). These are small radio transmitters specially designed for pressure measurement in the gastrointestinal tract. They transmit at a central frequency of approximately 400 kHz. Depending on the accuracy of adjustment, pressure variation alters the frequency of transmission; this alteration is between 10 and 40 kHz for a pressure change of about 10 kPa (75.2 mmHg). The pill consists of a transistor oscillator, the frequency of which is controlled by a diaphragm-operated variable inductor. A miniature silver battery is used as a power source. The pill signals are detected by a uni-directional antenna placed on the subject's abdomen in an optimal position indicated by a signal strength meter on the receiver. This meter was monitored periodically, and the antenna was repositioned when necessary.

The second and third means of measuring intra-abdominal pressures were one orally and one rectally introduced wire connected transducers (Miniature pressure transducer, AE 800, Sentralinstitutt for Industriell Forskning, Forskningsvågen 1, P. B. 350 Blindern, Oslo 3, Norway). The transducers consist of a silicon bar with diffused resistors on each side of the bar mounted in a special "header". A miniature diaphragm is mounted on the bar and pressure variations cause the diaphragm to deflect the bar. The miniature transducer element converts mechanical positions to an electrical signal.

To facilitate insertion of the rectally transducer and the soft connecting cord, these were placed inside a larger plastic catheter which was withdrawn after insertion. The catheter was inserted 12-15 cm so that the transducer

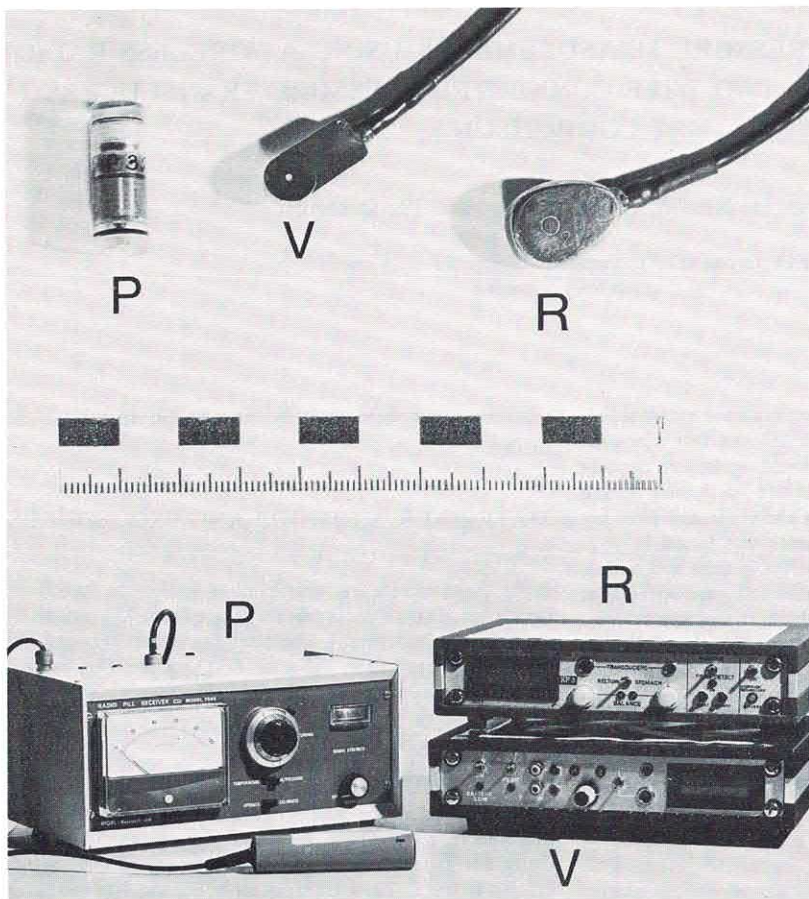


Fig. 1. Intra-abdominal wireless pressure-sensitive radio pill (P), orally (V) and rectally (R) wire-connected pressure transducers.

would be well within the abdominal cavity. The orally introduced transducer was inserted 45–55 cm. The exact length of insertion of the transducers varied with the height of the subjects.

The signals from the radio pill and the two transducers were graphically displayed simultaneously on an ink recorder. Traces produced by the pressurized inking system of the analog recorder are uniform in width. Pen motion is rectilinear. Pen positions were adjusted at the time of calibration. Built in solid state amplifiers provide a large input range. Depending on the task performed the sensitivity of the recorder was set at 1, 2, 5, 10, 20 or 50 mV/division. Chart speed, which was also adjusted according to the task, varied between 2 mm/sec and 25 mm/sec.

Calibration

Two radio pills were used. The pills and the two transducers were first calibrated simultaneously against a mercury manometer in a specially built plastic jar, filled with water and heated to a temperature of 35 to 39°C. To estimate any difference in temperature drift the three systems were tested at each degree between 35° and 39°C at 25 and 50 mm Hg (3.3 and 6.7 kPa). The three systems were thereafter calibrated simultaneously at 37°C and

with pressures 0, 25, 50, 100 mm Hg (0.3, 3, 6, 7, 13.3 kPa) before each test was performed. All three systems were found to be linear up to at least 200 mm Hg (26.6 kPa). They were then routinely recalibrated at 37°C as soon as the radio pill was regained.

Technical factors influencing the measurements are: calibration of the measurement systems, the ink recorder, manometer and graph reading. Previous temperature calibration at 50 mm Hg (6.7 kPa) of the systems at 35 to 39°C had shown a thermal drift for the oral transducer, the rectal transducer and the radio pill of 0.5, 0.1, 1.2 kilo pascals per degree Celsius respectively. Davis et al. report the pill to become accurate to 3% over the range of 35 to 40.5°C (8). Our two radio pills showed a variation of 20% over the range of 35 to 39°C. The oral and the rectal transducers were accurate to 8 and 2% respectively for the same temperature variations. As constant temperature of 37°C is probable in the intra-abdominal cavity, the three systems were calibrated before each testing at a temperature of about 37°C. The radio pill, the oral and the rectal transducers were accurate to 10%, 4% and 2% respectively. The accuracy of the ink recorder is given by the manufacturer to be 2%. The accuracy in manometer reading is estimated to ± 0.5 mm Hg (± 0.07 kPa) equal to

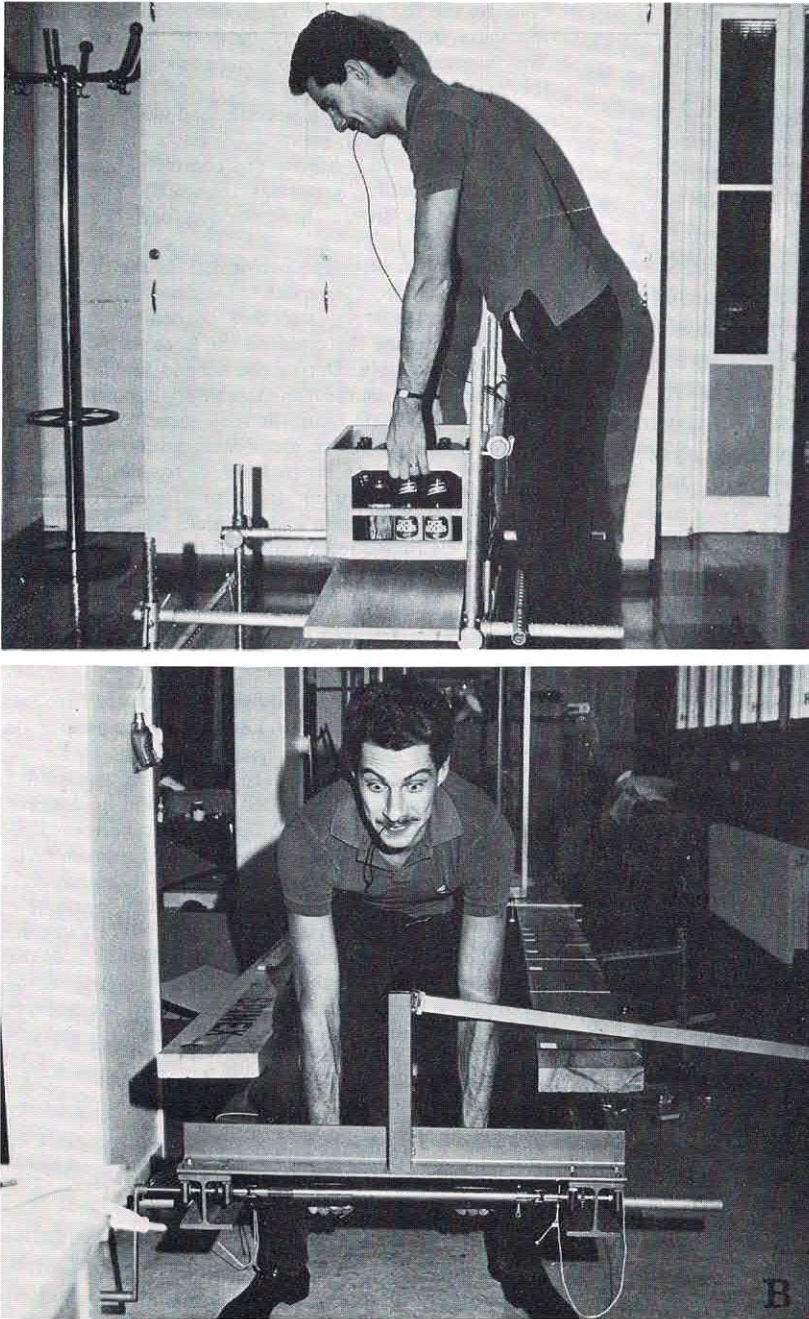


Fig. 2. Lifting. (A) Static lift of a crate (18 kg) a few centimeters above "trunk" floor. (B) Maximal static lift with the trunk in a deep forward bent position.

2%. Graph reading can be misinterpreted to about 1% (0.5 mm Hg, 0.07 kPa). Thus the maximal error is estimated to be 15%, 9% and 7% for the radio pill, the oral and the rectal transducer respectively.

Test procedures

Each subject participated in two measurement sessions in which the very same tasks were performed.

The first session was held in the morning immediately after the subject had swallowed the radio pill. The second session was held five to seven hours later, when the subjects reinserted the oral and the rectal transducers. This second measurement session was conducted to detect any changes in intra-abdominal pressure with the movement of the radio pill further along in the gastrointestinal tract.

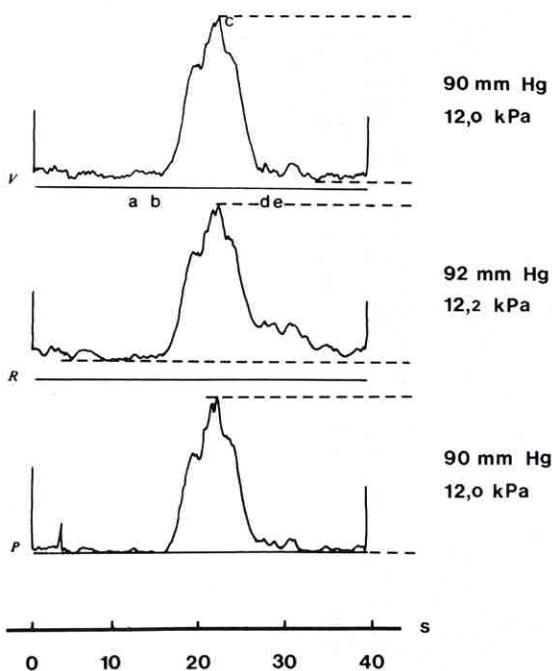


Fig. 3. Simultaneous recording of intra-abdominal pressure variations with radio pill (P), orally (V) and rectally (R) introduced transducers. The subject lifted a crate from a simulated trunk floor of a car (a). After reaching an erect position (b) the subject brought out the crate from the body until the arms were extended (c). The crate is brought back close to the upper body in upright standing position (d) and put back into the simulated trunk (e).

Intra-abdominal pressure variations were measured in all subjects while they assumed a variety of common postures, carried out several simple activities, and performed static and dynamic lifts.

The postures included: Standing relaxed, sitting down and lying supine. Six activities were studied: straining maximally "at stools" while standing, maximal coughing, laughing, slow flexion of the trunk to full flexion, an then rising again to an upright posture and jumping up and down on both feet.

The lifting tasks were performed using a wood and metal frame that was constructed to simulate the actual measurements of the boot and bumper of a car (Volvo 760, 1982 model). The object lifted was a plastic crate filled with bottles.

The following static "lifts" were performed:

1. Lifting the crate a few centimeters above the "trunk" floor (lift 1) (Fig. 2 A).
2. Lifting the crate straight up until the bottom of the crate was flush with the "trunk" threshold (lift 2).
3. Performing lift 1 with the upper body rotated about 45 degrees.
4. Performing lift 2 with the upper body rotated about 45 degrees.

Before lifting, the subjects were instructed to grip the

crate by the top rungs on each side of the crate and to distribute the weight evenly between their two hands. They were also instructed to stand as close as possible to the bumper.

In addition a maximum possible load was "lifted" from a deep forward bent position. Using a free style, the subjects attempted to lift one end of a metal frame weighing several hundred kilograms (Fig. 2 B). The subjects were asked to "freeze" their position for 5-15 sec during each static lift.

Two dynamic lifts were performed. In the first lift the crate was lifted from the trunk to the floor. They were told to lift the crate in any way they wished but to turn 90 degrees and place the crate on the floor as close to the bumper as possible. During the second lift the subjects lifted the crate from the trunk to an upright position. They then extended their arms, thereby increasing the trunk flexion moment. Before the dynamic lifts the subjects were given the same instructions as for the static lifts, except that they were not asked to "freeze" their position. During both static and dynamic lifts, the subjects were not instructed to lift with any particular lifting technique. To avoid fatigue a one-minute rest period was allowed between each task, longer if fatigue was indicated.

Analysis of data

The recorded data for the three systems were first analyzed in terms of waveform, i.e. start of increase or decrease in intra-abdominal pressure variations.

The data were then analyzed in terms of peak differences, i.e. graphically recorded highest and lowest pressure values in each task. The peak differences obtained were then compared for each system and measurement. One system was considered "reliable" if it did not differ in recorded peak difference more than 10% from one or both of the two other systems. This level was chosen due to the estimated maximal errors at calibration. In the interval of 37 to 38°C the thermal drift was 10% for the radio pill, 4% for the oral transducer and 2% for the rectal transducer. A peak difference greater than 10% was con-

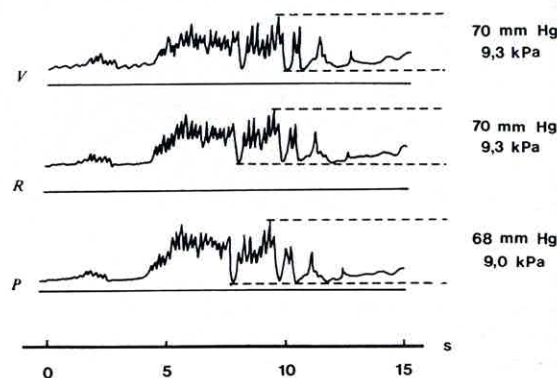


Fig. 4. Simultaneous recording of intra-abdominal pressure variations with radio pill (P), orally (V) and rectally (R) introduced transducers, during moderate laughing.

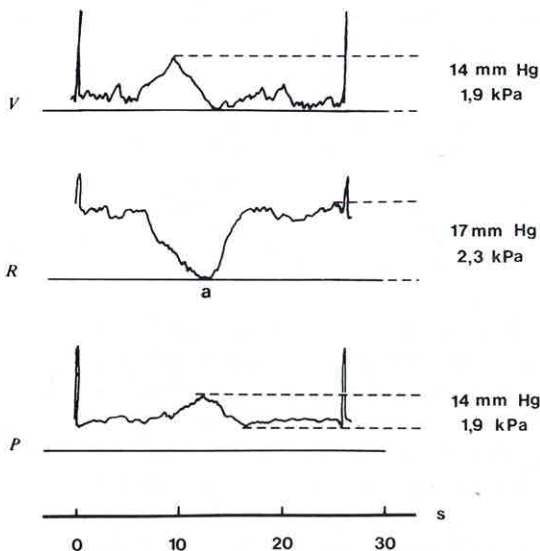


Fig. 5. Simultaneous recording of intra-abdominal pressure variations with radio pill (P), orally (V) and rectally (R) introduced transducer (R) responds in an opposite direction when deep forward flexion occurs (a).

sidered to have a biological explanation rather than a technical. Mean values (SD) were calculated for the data obtained.

RESULTS

The three different methods showed an acceptable correspondence in terms of waveforms except when maximal deep forward flexion of the trunk was performed. A less good correspondence was found in terms of peak differences.

Fig. 3 shows simultaneously the three methods graphically recorded when one subject lifted the crate from the simulated trunk floor. After reaching an erect posture the subject moved the crate away from the body. Fig. 4 shows the graphs recorded during moderate laughing of another subject. An almost perfect correspondence was found in the wave forms between the three methods in both experiments. The methods differed in waveform, however, in tasks which involved deep flexion of the trunk either as a single activity or when lifting the crate from the car trunk to the floor with straight knees and bent back (Fig. 5). The waveforms of the orally introduced transducer and the radio pill are similar, but the rectally introduced transducer responded to the intra-abdominal pressure changes in an opposite direction. This differ-

ence in pattern occurred in about one third of the measurements involving deep forward flexion of the trunk.

The three systems corresponded in peak values in 4% of the 169 measurements, while in 37% of the measurements a greater than 10% difference was found. In 59% of the measurements performed one system was in agreement with one of the two other systems. These percentages did not change when the mean values over morning and afternoon testing sessions were compared for all measurements and all subjects.

The orally introduced transducer corresponded with the rectally introduced transducer and with the radio pressure pill in 24% and 14% of all measurements, respectively, while the rectally introduced transducer corresponded in amplitude to the radio pressure pill in 13% of the recorded tasks. There were no significant differences in peak values or waveforms in the static lifts performed with the upper body in a rotated and flexed position compared with the upper body in a flexed and straight position.

A further analysis was made of the four heaviest tasks where maximal recorded amplitudes occurred; maximal straining, maximal static lifting, coughing and lifting a crate from the automobile trunk and extending the arms. An excellent agree-

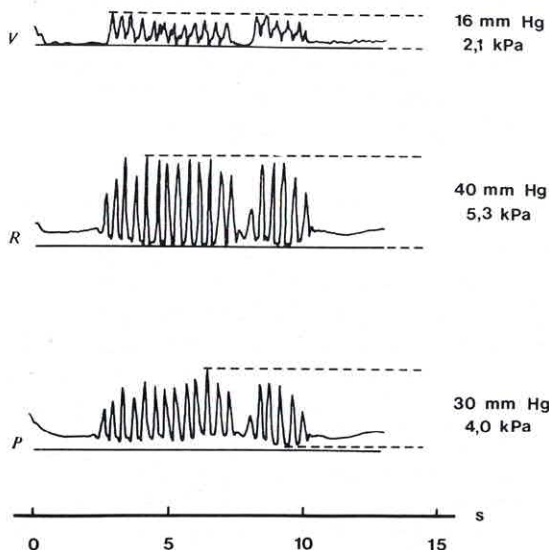


Fig. 6. Simultaneous recording of intra-abdominal pressure variations with radio pill (P), orally (V) and rectally (R) introduced transducers when jumping.

Table 1. Mean values (SD) in kPa during the performance of 2 testing sessions (morning and afternoon) Radio pressure pill (P), orally (V) and rectally (R) introduced transducers

Intra-abdominal pressure (kPa)			
Maximal straining (n=8)	26.9 (7.01)	24.9 (4.25)	25.2 (5.12)
Maximal lifting/trunk flexed (n=8)	17.4 (6.98)	18.5 (5.14)	16.7 (5.27)
Maximal coughing (n=7)	16.2 (7.25)	17.3 (8.75)	17.1 (7.99)
Lifting a crate (17 kg) (n=6)	5.4 (3.92)	5.8 (4.30)	5.2 (3.90)

ment in wave forms was found in all 58 measurements and the peak amplitude values corresponded in all three systems in 28%. In the remaining 72% one system always agreed with one of the other systems. In the lighter tasks performed the correspondence in amplitude was less and the least correspondence in peak differences was found when jumping (Fig. 6). But, the waveforms were still in agreement, although the oral transducer measurements were somewhat delayed.

The values for each subject obtained in the morning and in the afternoon testing sessions were similar in waveforms and in peak values.

The overall highest amplitudes of intra-abdominal pressure values were recorded when the subjects performed maximal straining. The mean values over two testing sessions ranged from 17 to 39 kPa. High intra-abdominal pressures were also found in the two following activities; maximal lifting with the trunk in a forward flexed position (values ranging from 8 to 29 kPa) and maximal coughing (values ranging from 8 to 33 kPa). Lifting of the crate and thereafter extending the arms resulted in measured values from 1 to 12 kPa. Mean values (SD) for these four tasks are presented in Table I.

DISCUSSION

The comparison shows a good correspondence in wave form of the generated curves in terms of start of decrease/increase of intra-abdominal pressure, both in time and shape, except when deep forward flexion of the trunk was involved. In that activity only 2/3 of the measurements corresponded in waveforms, while the rectally introduced transducer showed diverged waveforms: the rectally recorded pressure decreased when the two other systems showed an increase. One explanation can be that the rectal transducer slid away from its position. Another is that there are differences in pressure within the cavity, which would seem less likely

as the subjects in these experiments did not exceed a forward bending of the trunk of 90 degrees.

The three systems show a somewhat less good agreement in recorded peak differences i.e. highest and lowest pressure values in each task. The differences can be due to biological and/or technical factors.

Some biological factors influencing the peak values are different locations, environments and temperatures within the abdominal cavity. The oral transducer was inserted to be located distal to the upper orifice of the stomach and remained in that position, and the rectal transducer was introduced 12–15 cm into the rectum. A difference in hydrostatic pressure of about 20 cm column of water (14.7 mm Hg, or 1.9 kPa) exists between the location of the oral transducer and the location of the rectal transducer. This difference is less than the estimated maximal errors of the three systems and is therefore not taken into account. The location of the radio pill varied with time as it passed through the intestinal tract. One can tell if the pill has passed into the small intestine by having the subject take a sip of cool water. Because of the temperature sensitivity of the radio transmitter, there will be a shift in the recorded base line if the pill is still in the ventricle. During the first part of the morning testing sessions the pill was located in the stomach, whereafter the pill slowly worked its way through the intestinal tract. At the afternoon testing sessions no temperature reaction of the transmitter was found when the subjects drank. The peak values recorded with the radio pill and the oral transducer can also have been influenced by the peristaltic contractions. Normally about 3 contractions take place each minute. However, the amplitude of these pressure variations were noticed to be minimal (about 1–2 mm Hg=0.13–0.26 kPa). The higher recorded amplitude in peak values can thus only partly be explained by the influence of the peristaltic contractions.

All subjects were fasting at time of testing. The effect of different environments and differences in temperature can therefore be only marginal and is excluded in further discussion.

In industrial settings it is necessary to use a non-invasive method. Closest to a non-invasive method is the radio pill. As discussed previously by Davis et al. it would be preferable if "the present pill could be made smaller and cheap enough to be considered disposable" (8). None of our subjects reported difficulties in swallowing the pill, but the recovery of the pill was to some extent inconvenient especially for those subjects with a slow passage of 3-7 days. The present cost of the pills (about \$200 in Sweden) make them also too expensive to be disposable. The rectally introduced catheter is easy to apply, easy to calibrate, very stable when measuring and very easy to clean. While measuring we used a plastic top covering the transducer. The top was removed by the subject and the transducer and the wire were easily disinfected. The radio pill needs thorough and time consuming cleaning. The orally introduced catheter is well suited for laboratory testing but will not suit an industrial setting because of the discomfort produced of vomiting reflexes while introducing the transducer and even during testing.

Interestingly the highest values were recorded during maximal straining, maximal static lifting and coughing. Davis & Stubbs reported "that occupations in which peak intra-abdominal values in excess of 100 mm Hg (13 kPa) or more are induced, had an increased liability to reportable back injuries. Thus it seems likely that if pressure peak of this order can be avoided so can many back injuries" (6, 7, 9). With the simple tasks performed in this study, where all the measurements of maximal straining and coughing exceeded 13 kPa the following question can be put; Can intra-abdominal pressure alone be used as an indicator of safe spine loads? While intra-abdominal pressure may reflect the trunk moment, it can also rise to very high levels indeed in situations where the trunk moment is low. What loads are then placed on the spine, and what is the importance of such factors as constipation, sneezing and coughing on the occurrence of back pain (4)?

CONCLUSIONS

Three systems were used to measure intra-abdominal pressure responses to loads: a wireless radio

pressure pill and two wire-connected pressure transducers, one introduced orally and the other introduced rectally. Simultaneous measurements with the three systems showed a good to excellent correspondence in waveforms of the generated curves, i.e. in terms of start of decrease/increase of intra-abdominal pressure variations both in time and shape. A less good agreement was found in recorded peak differences, i.e. highest and lowest pressure response in the tasks performed.

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