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Noninvasive Assessment of Intra-Abdominal Pressure by Measurement of Abdominal Wall Tension[1]

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Background. **Sustained increased intra-abdominal pressure (IAP) has negative effects. Noninvasive IAP measurement could be beneficial to improve monitoring of patients at risk and in whom IAP measurements might be unreliable. We assessed the relation between IAP and abdominal wall tension (AWT) *in vitro* and *in vivo*.**

Materials and Methods. **The abdomens of 14 corpses were insufflated with air. IAP was measured at intervals up to 20 mm Hg. At each interval, AWT was measured five times at six points. In 42 volunteers, AWT was measured at five points in supine, sitting, and standing positions during various respiratory manoeuvres. Series were repeated in 14 volunteers to measure reproducibility by calculating coefficients of variation (CV). ANOVA was used for analyses.**

Results. **In corpses, all points showed significant correlations between IAP and AWT ($P < 0.001$ for points 1–4 in the upper abdomen, $P = 0.017$ for point 5 and $P = 0.008$ for point 6 in the lower abdomen). Mean slopes were greatest at points across the epigastric region (points 1–3). *In vivo* measurements showed that AWT was on average 31% higher in men compared to women ($P < 0.001$), and increased from expiration to inspiration to Valsalva's manoeuvre (all $P < 0.001$). AWT was highest at points 1 and 2 and in standing position, followed by supine and sitting positions. BMI did not influence AWT. Mean CV of repeated measurements was 14%.**

Conclusions. **AWT reflects IAP. The epigastric region appears most suitable for AWT measurements. Further longitudinal clinical studies are needed to assess usefulness of AWT measurements for monitoring of IAP.**

Key Words: **intra-abdominal pressure; abdominal wall tension; abdominal hypertension; compartment syndrome; measurement; noninvasive; surgery; trauma; complications; bladder pressure.**

INTRODUCTION

Intra-abdominal hypertension (IAH) is a condition in which intra-abdominal pressure (IAP) is consistently raised over 12 mm Hg. IAH can lead to the development of the abdominal compartment syndrome (ACS), which has been recognized as a significant cause of morbidity and mortality in intensive care unit (ICU) patients [1, 2]. IAH occurs in approximately 50% of the populations of general specialized adult intensive care units [3, 4]. Raised IAP (over 20 mm Hg) causes severe organ dysfunction and leads to a vicious circle, resulting into multiple organ failure, and finally, death [2, 3, 5–7]. In case of ACS, these serious complications can only be averted by surgical decompression if conservative medical treatment has failed [8]. Early diagnosis is therefore essential for adequate intervention and damage control.

IAP can by estimated by performing measurements *via* the bladder, but also *via* uterus, rectum and stomach [9]. The intravesical pressure measurement using a Foley catheter has been validated and has remained the accepted gold standard measurement of IAP for clinical use. This measurement, however, can be

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FIG. 1. Device for AWT measurements.

unreliable in case of low intrinsic bladder compliance, bladder trauma, or pelvic haematoma, which may compress the bladder. In addition, routine measurements are thought to be performed only in a minority of patients at risk [10–12]. This supports the use of an easy measuring method to quickly monitor admitted patients.

With the increase of IAP, the abdomen expands, acting like a balloon. This expansion results in increase of abdominal wall tension (AWT), and is directly correlated with IAP. A previous study in two fresh human corpses has shown that a relationship exists between AWT and IAP [13]. Noninvasive measurement of IAP, if feasible, could be useful for fast, easy, cheap, and patient-friendly screening, and monitoring of patients at risk of developing IAH and ACS in whom intravesical measurements are unreliable or undesired for other reasons. The aim of this study was to test the hypothesis that AWT and IAP are correlated. This hypothesis was tested in a group of 14 fresh human corpses, thereby allowing for a degree of intersubject variation. We also obtained AWT values in healthy volunteers during a variety of physiologic actions, similar to the studies performed by Iqbal *et al.* and Cobb *et al.* [14, 15]. In the latter study, normal range values for IAP in healthy subjects were measured during typical activities of daily life, e.g., in supine position, standing, sitting, and whilst performing an abdominal crunch [15].

MATERIALS AND METHODS

The prototype used for measuring AWT consisted of a built-in force and distance sensor, attached to a handheld personal digital assistant (PDA, HP IPAQ) (Fig. 1). The diameter of the circle-shaped base of the device is 72 mm. The tip of the instrument is shaped like one-half of a sphere and has a diameter of 18 mm, with a total surface area of approx. 5.1 cm^2. The shape of the tip was chosen due to the extensive use of this shape in industrial hardness measurements of materials. The size of the tip was chosen due to its comparability to the conventional instrument by which abdominal tension is estimated, which is the human finger. This device can measure the amount of force (N) needed to indent a certain distance (mm), which is then visualized on the PDA in graphics. Thereafter, a line is fit by means of method of least squares, and the resulting slope (RC) of this line is expressed in N/mm (AWT), as previously described [13].

Human Corpses

Fresh human corpses (up to 1 wk **post mortem** and adequately cooled) were included in this study. Exclusion criteria were visible abdominal scars (indicative of prior abdominal surgery) or signs of tissue necrosis (suggesting progressed stages of decay). Six points, derived from anatomical structures, were marked on each abdominal wall: 5 cm caudal to the xiphoid bone (point 1), 5 cm cranial to the umbilicus (point 2), 5 cm left to point 2 (point 3), 10 cm left to point 2 (point 4), 5 cm cranial to the pubic bone (point 5), and an extra point, 5 cm left to point 5 (point 6) (Fig. 1). The abdomens were then insufflated with air by means of a laparoscopic set-up, using a Veress needle. The insufflator (IHU-3; Olympus, Tokyo, Japan) displayed set input and achieved IAP (usually 1 mm Hg less than the set input). By insufflating intraperitoneally up to 3 mm Hg after positioning of the Veress needle, the proper position of the needle was checked. Baseline measurements were performed. At pressures below 4 mm Hg, immediate contact existed between the tip of the instrument and the vertebrae, thereby hindering measurements. Baseline measurements below 4 mm Hg were considered impaired and excluded from the analyses. The group of measurements were performed at the set input of 5 mm Hg; IAP was increased and measured at intervals of 5 mm Hg up to 20 mm Hg. At each interval, achieved IAP was noted and AWT was measured five times at each of the marked points. The mean value of these five measurements was used in analyses. Mixed model ANOVA (random coefficient models allowing for inter-individual differences in intercepts and slopes) was used to assess relations between measured tensions *versus* achieved IAPs per anatomical point.

Healthy Volunteers

Healthy students were asked to volunteer for the *in vivo* study. Procedures were followed in accordance with the ethical standards of the medical ethics committee at our institution. Exclusion criteria were history of abdominal surgery and current or past pregnancy. Gender (male, female), height (m), weight (kg), and waist (cm) were measured in each subject, and body mass index (BMI) was calculated. It was attempted to recruit students from all ranges of BMI. The first five points as described in the section 'Human Corpses' were marked on the abdomen as shown in Fig. 2.

Short series of test measurements were performed to familiarize subjects with the measurement technique. For the actual series, subjects were first measured in supine position during late expiration, inspiration, and Valsalva manoeuvre (straining against a closed epiglottis). During each respiratory movement, measurements were performed on the five points mentioned above. Measurements were repeated in sitting and standing positions and the order was kept identical for each subject. This resulted in 15 measurements in each position (five for each respiratory movement) and a total of 45 measurements in each subject. In 14 volunteers the entire series were repeated in order to measure reproducibility of measurements by calculating coefficients of variation (CV). Volunteers were not allowed to empty their bladders, eat, or drink between the two series of measurements. Repeated measurements ANOVA were used to assess relations between measured AWT and other variables (respiratory manoeuvre, gender, BMI, and position). In these analyses, RCs were transformed logarithmically in order to obtain approximate normal distributions. Two-sided P values below 0.05 were considered significant in all analyses.

RESULTS

The abdomens of 14 human corpses (8 female, 6 male, mean age 83 years at death) were insufflated with air