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ORIGINAL ARTICLE

Intra-abdominal Pressure Monitoring in Open Abdomen Management with Dynamic Abdominal Closure

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Abstract The importance of elevated intra-abdominal pressure (IAP) and abdominal compartment syndrome (ACS) have been recognized in critical care for its potential damaging effects. But, quantification of IAP values may be useful as a clinical tool for determining efficacy of coughing and straining for functional recovery of OA patients. We would like to evaluate IAP generated in an OA patient and the effect of negative pressure therapy (NPT) and dynamic abdominal closure systems (ABRA) on the IAP values at rest and during coughing and straining and compare those with IAP measurements of closed abdomen after standard open elective colorectal surgery (non-OA). Eight OA and eight non-OA patients were included in this study. OA patient with NPT and ABRA (OA + NA), OA patient without NPT and ABRA completely unbraced (OA-NA) (NA stands for NPT and ABRA), and non-OA patients underwent IAP measurements at rest, during coughing, and during straining via transurethral catheter. There was no difference in the mean of IAP measurement at rest in OA-NA (6.1 mmHg), OA + NA (6.5 mmHg), and non-OA (6.0 mmHg) patients. During coughing, IAP of OA-NA, OA + NA, and non-OA patients were 11.5, 19.1, and 22.0 mmHg and during straining, IAP of OA-NA, OA + NA, and non-OA patients were 11.5, 17.5, and 23.5 mmHg, respectively. Application of NPT in conjunction with ABRA did not increase IAP at rest but provided significant IAP increase in OA + NA patients, when compared to OA-NA patients during coughing and straining. NPT in conjunction with ABRA offers the advantage of increase of IAP during coughing and straining.

Keywords Open abdomen · Intra-abdominal pressure · Negative pressure system · Dynamic abdominal closure · Coughing · Straining

Introduction

The importance of elevated intra-abdominal pressure (IAP) and abdominal compartment syndrome (ACS) has been recognized in the trauma and critical care literature for its potential damaging effects [1, 2]. Elevated IAP also has an impact on distant organ function [1]. Elevations in IAP can have several harmful effects such as decrease in cardiac output due to reduced venous return, reduced splanchnic and hepatic perfusion, and decreased renal blood flow and glomerular filtration rate [2]. The importance of quantification of IAP in critically injured patient is well defined for diagnosis and management of intra-abdominal hypertension (IAH) and ACS. Open abdomen (OA) management has become the treatment of choice in recent years in patients with ACS, intra-abdominal sepsis to decrease elevated IAP, and in damage control surgery [1].

OA management is a challenging phenomenon with high morbidity and mortality [3, 4]. Survival of OA patients are dramatically increased because of improvements

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in OA management strategies, and ICU care facilities [5, 6]. While IAP increase leading to ACS may be an indication for OA, IAP increase during physiologic activities like coughing for respiratory system clearance and straining for defecation may be clinically important and play a critical role in functional recovery of these patients.

Coughing and straining are some major parts of the daily care in an OA patient. During coughing and straining, abdominal wall play a very important role [7, 8]. Increased IAP is necessary for functional coughing and defecation. Coughing is based on coordinated contractions of thoracic, abdominal, and pelvic muscles, providing neurophysiological protection of the upper airway. Cough and expectoration maintains airway patency by removing excessive secretions from the airway passages and spitting out the material produced in the respiratory tract [7]. Evacuation of feces is aided by increased IAP created by straining or the Valsalva maneuver which involves the simultaneous closure of the glottis and contraction of the abdominal muscles. Quantification of IAP values may be useful as a clinical tool for determining efficacy of neurophysiological airway protection and straining for functional recovery of OA patients. There are a few studies in the literature about the IAP measurement during voluntary and reflex cough and other daily activities [7–9].

According to our knowledge, there is no any data about IAP measurement during daily activities like coughing and straining in OA patients. We would like to evaluate changes in IAP generated in an OA patient and the effect of negative pressure therapy (NPT) and dynamic abdominal closure systems (ABRA) on the IAP values at rest and during typical activities of daily living such as voluntary coughing and straining and compare them with IAP measurements from the patients undergoing open elective colorectal surgery.

Materials and Method

After informed consent was obtained, eight OA patients and eight open colectomy (non-OA) patients were enrolled into the study. The conscious patients greater than 18 years old, without any neurological impairment, were included. IAP measurements of OA patients were performed in the operating room before anesthesia induction. IAP measurements of eight non-OA patients were obtained 24 h after surgery. OA patient with NPT and ABRA (OA + NA) (NA stands for NPT and ABRA) underwent IAP measurement before NPT was taken off and ABRA was braced (Fig. 1a). IAP measurements were obtained at rest, during coughing, and during straining. OA-NA patient underwent IAP measurement after NPT was taken off and ABRA was completely unbraced (Fig. 1b). IAP measurements were obtained at rest, during coughing, and during straining. From the same patient, repetitive measures were taken, when they underwent NPT change following times. A total of six measurements were obtained for each OA patient during each NPT change. IAP measurements of eight non-OA patients were obtained at rest, during coughing, and during straining to compare with the ones of OA patients. Measurements were repeated three times with 8-h intervals.

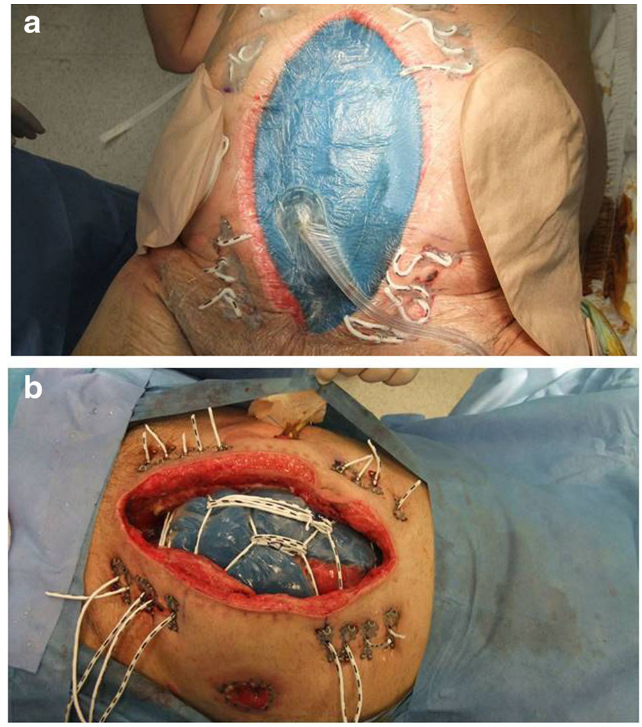

Fig. 1 **a** View of the OA + NA patient; applied form of NPT and ABRA on open abdomen. **b**)View of the OA-NA patient; NPT was taken of and ABRA was completely unbraced on the open abdomen

Intra-abdominal Pressure Measurement

The bladder was filled with 25-ml sterile water. The hydrostatic pressure in the bladder was obtained by abdopressure while the patient was supine. Unpack UnoMeter™ Abdo-Pressure™ system was connected to Foley catheter. The tube was lifted and zero point was placed at patient's mid-axillary line. The height of the fluid column was measured in the manometer tubing, and IAP results were documented. All measurements from all patients were taken at supine position. For measurement of IAP during coughing, the patients were asked to deeply inhale and perform strong voluntary coughs, and IAP's were obtained at that time point. For measurement of IAP during straining, the patients were asked to deeply inhale and perform voluntary strain forcefully, and IAP was measured at that time. Before the measurements, VAS score of all patients was <3. If it was ≥3, all patients received nonopioid analgesics for treatment of pain routinely. As rescue analgesics, tramadol and or morphine was administered. Demographical values of all patients, diameter of OA, Björck scores, APACHE II, and MPI scores of OA patients at first NPT application were recorded.

The Technique of NPT

After debridement and irrigation of all quadrants of abdomen with warm saline, a perforated polyethylene sheet was placed over the bowel under the fascia. Sponge was placed over the silicone sheet. Suction tubing was applied and sponge shrank. Negative pressure of NPT was adjusted between (−50 and 125 mmHg) intermittently, 4 or 7 min of high negative pressure was followed by 1 or 2 min of low negative pressure, respectively. The dressing is changed every 2 to 5 days.

The Technique of ABRA System

After debridement of surgical wound, a series of midline crossing elastomers are surgically inserted through the full thickness of the abdominal wall at a distance of approximately 5 cm from the medial fascial edge, with each elastomer. A perforated silicone sheet was inserted between the abdominal wall and its contents and treated with NPT dressing. The optimal tension was obtained by stretching the elastomers 1.5–2 their tension free length. Tension of ABRA was adjusted when NPT dressing was changed. If tension decreased to less than 1.25X, it was tightened again to a maximum of 2X stretch. When all the wound edges came across completely, fascia was sutured one by one with PDS 1/0.

Statistical Analysis

Data were analyzed using standard statistical methods. SPSS 22 version was used. Descriptive statistics including means, median, minimum, maximum, and standard deviations were used to describe the maximum IAP measurement for each measurement for each activity and rest. To evaluate the normality of variables, the Shapiro-Wilk test was used. Mann-Whitney *U* test was used to compare two nonparametric values between two groups. Fisher's exact test was used to compare ratio between two groups. Multivariate ANOVA test was used to evaluate independent variable. One-way repeated measurement of variant analyses was conducted to evaluate the dependent results of repetitive measurements in the same group. *P* value <0.05 was accepted as statistically significant.

Results

Eight OA and eight non-OA patients were enrolled into the study. Then, 138 IAP measurements (69 IAP measurements during OA-NA and 69 IAP measurements for OA + NA) of OA patients were obtained during 23 NPT change. Totally, 69 measurements were obtained in non-OA patients. Median age of OA and non-OA patients were 59 (22–79) and 54 (38–67) years, respectively. Median BMI of OA and non-OA patient were 26.5 (16–46) and 24.5 (17–38), respectively. Three of the OA patients and four of the non-OA patients were female. There were no statistical difference between OA and non-OA patients on the base of age, sex ratio, and BMI. For OA patients, median value of APACHE II, MPI, Björck score, width, and length of OA wound at first NPT application were given in Table 1. The mean, SD, minimum, and maximum values of IAP measurements of OA-NA, OA + NA, and non-OA patients during resting, straining, and coughing were demonstrated in Table 2. There was no difference between the IAP measurements of OA + NA, OA-NA, and non-OA patients at rest, and there was a significant difference between IAP measurements of OA + NA and OA-NA patients during both coughing and straining (Table 3). While the mean of IAP measurements of OA-NA patients increased to 11.5 mmHg and the mean of IAP measurements of OA + NA patients to 17.5 mmHg during straining, application of NPT and ABRA provided an average of 6.0 mmHg more increment in the mean of IAP measurements during straining (CI 95 % 8.6/3.3) (Table 3). While the mean of IAP measurements of OA-NA patients increased to 11.5 mmHg and the mean of IAP measurements of OA + NA patients to 19.1 mmHg during coughing, application of NPT and ABRA provided 7.7 mmHg more increment in the mean of IAP measurements during coughing (CI 95 %, 10.2/5.06) (Table 3). Mean of IAP measurements of non-OA patients during straining and coughing was significantly different from mean of IAP measurements of both OA-NA and OA + NA patients. Mean of IAP of OA + NA patients was closer to the mean of IAP measurements of non-OA patients, compared to mean of

Table 1 Median of the APACHE II, MPI, and Björck score

	APACHE II	MPI	Björck	Length of OA wound	Width of OA wound
Median	25.5	37	3.5	23	14.5
Minimum	18	28	2	16	12
Maximum	28	43	4	42	50

Table 2 Mean, standard deviation, minimum and maximum value of IAP of OA-NA, OA + NA, and non-OA patients

		Mean IAP (mmHg)	Std. deviation	Minimum	Maximum
Resting	OA-NA	6.1	1.2	4.4	8.8
	OA + NA	6.5	0.8	5.2	8.1
	Non-OA	6.0	1.4	2.9	9.0
Straining	OA-NA	11.5	1,5	9,6	14,3
	OA + NA	17.5	3.4	11.0	22.0
	Non-OA	23.5	5.2	15.4	33.8
Coughing	OA-NA	11.5	1.1	9.6	14.5
	OA + NA	19.1	4.1	11.4	25.0
	Non-OA	22.0	4.2	15.4	30.8

IAP measurements of OA-NA patients during straining and coughing (Table 3) (Fig. 2).

Discussion

IAP during daily activities has not been evaluated in OA patients so far. As far as we are concerned, this is the first report evaluating IAP increase during coughing and straining in OA patients managed by NPT and ABRA application. There was no difference in the mean of IAP measurement at rest in OA-NA, OA + NA, and non-OA patients. Application of NPT in conjunction with ABRA did not increase IAP at rest but provided significant IAP increase in OA + NA patients when compared to OA-NA patients during coughing and straining, but lesser than the IAP values of non-OA patients.

Coughing and straining are critical functions for OA patients like in the other critically ill patients in ICU. While these OA strategies (NPT and ABRA) prevent resting IAP increase to cause ACS, they might also offer some secondary advantages to OA patients living on a knife edge as a daily struggle of coping with ICU care themes by providing IAP increase in some daily activities such as coughing and straining.

Cobb et al. have found in their study including 20 healthy young adults with no prior history of abdominal surgery that the maximum IAP was 127 mmHg during coughing at sitting position and 141 mmHg at standing. A pressure as high as 252 mmHg was obtained while one jumped in place. For valsalva in this healthy adult population, the maximum pressures were 64 mmHg at sitting and 116 mmHg at standing [8]. Since we obtained all IAP measurements after intra-abdominal surgery in both OA and non-OA patients at supine position, the value of IAP measurements during coughing and straining were different than the other studies. It should be anticipated that there is a wide range of factors in ensuring the effectivity of coughing and straining in such a complex critically ill patient population; in order to get homogeneity, we obtained IAP measurements preferably at supine position. In our study, due to the invasiveness of direct IAP measurement, the measurement of urinary bladder pressure via a bladder catheter has been used as an indirect method of determining

Table 3 Statistical analyses of IAP measurement of OA-NA, OA + NA, and non OA patients at rest and during coughing and straining

	A	B	Mean difference (A-B)	*P*	95 % Confidence interval for difference	
					Lower bound	Upper bound
Resting	OA-NA	OA + NA	−0.448	0.598	−1.296	0.401
	OA + NA	Non-OA	0.511	0.431	−0.337	1.359
	Non-OA	OA-NA	−0.063	1.000	−0.912	0.785
Straining	OA-NA	OA + NA	−5.998	***0.000***	−8.652	−3.345
	OA + NA	Non-OA	−5.967	0.000	−8.621	−3.313
	Non-OA	OA-NA	11.966	***0.000***	9.312	14.620
Coughing	OA-NA	OA + NA	−7.651	***0.000***	−10.247	−5.055
	OA + NA	Non-OA	−2.913	***0.023***	−5.509	−0.317
	Non-OA	OA-NA	10.563	***0.000***	7.967	13.159

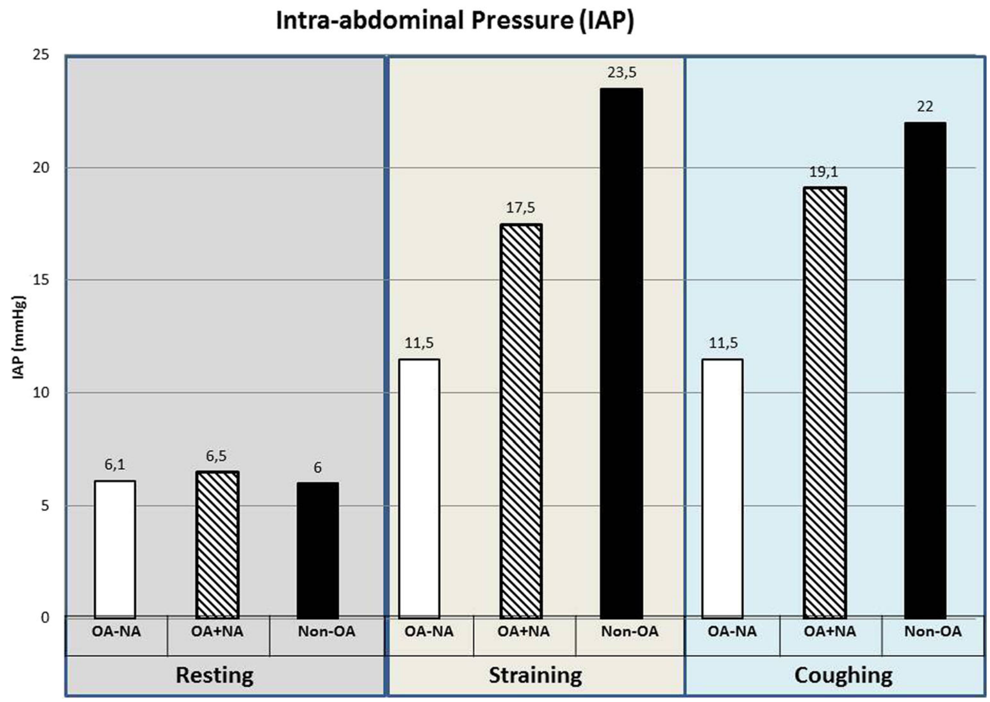

Fig. 2 Means of IAP of OA-NA, OA + NA, and non-OA patients

IAP, which is strongly recommended by the WSACS consensus conference in 2013 [1].

Stokes et al. have emphasized that antagonistic activation of abdominal muscles and intra-abdominal pressurization produces spinal unloading, that is lesser magnitude of spinal compression with higher IAP [10]. They have stated that curved abdominal muscles are required to contain intra-abdominal pressure; 111 symmetrical muscle strips are formed by 77 pairs of dorsal muscle slips including psoas, 11 pairs each of internal oblique, external oblique, and transversus abdominis; 1 pair representing rectus abdominis and 5 lumbar vertebrae linked by intervertebral joints [10]. In OA patients, some of these muscles cannot work properly, and there was no closed intra-abdominal space in which IAP increment could be provided during coughing and straining. Application of NPT in conjunction with ABRA to OA patient by providing abdominal domain partially offers the advantage of some of the necessary increment of IAP during coughing and straining.

Decrease in bowel edema, removal of cytokine-rich peritoneal fluid, improvement in granulation tissue formation, and minimizing heat and fluid loss are the key elements for NPT in the management of septic OA patients [11–14]. It has been shown that formation of granulation tissue is better with cyclic application of NPT by increasing rate of cell division and proangiogenic growth factors [13].

When NPT was combined with the strategies allowing reapproximation of the fascial edges, high closure rates can be achieved [15]. Use of mesh-mediated fascial traction methods may be more suitable in non-infected OA patients, whereas ABRA might be used in the severely infected OA patients in conjunction with NPT [16]. Dynamic traction adjusted continuously with ABRA in conjunction with NPT prevents fascial retraction, subscribes improvement in granulation tissue, allowing expansion and retraction during spontaneous respiratory cycle [3, 4, 17]. The stoma-related complications are more common following OA management [18]. NPT and ABRA do not worsen these complications.

Some small pieces of this big puzzle come into consideration for intensivists for a whole and thorough understanding and covering the territory of patient care in OA patients [19]. The increment in IAP may contribute to effectiveness of pulmonary physiotherapy and more powerful straining for starting defecation, all of which have unequivocal importance for patient care in OA patients.

A paradigm shift in management of OA with NPT in conjunction with ABRA is one of the pivotal points in coughing and straining of OA patient, besides being a cornerstone in steps of source control and delayed closure during management of OA [20].

There are several limitations of our study. Since we included those OA patients who are extubated and oriented with more than 10 cm width OA wound are scarcely found, we get recurrent IAP measurements from the same patient at different times. We did not use an anal manometer and spirometer in this study.

Conclusion

NPT application in conjunction with ABRA in OA management offers the advantage of increase of IAP which is the surrogate marker of critical daily care activities such as coughing and straining in addition to IAP decrease at rest.

Compliance with Ethical Standards

Conflict of Interest We have no conflict of interest.

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