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ORIGINAL ARTICLE

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Intra-abdominal pressure: a reliable criterion for laparostomy closure?

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Abstract *Background.* Laparostomy is frequently performed in the surgical therapy of mechanical obstruction, peritonitis, or trauma to prevent abdominal compartment syndrome (ACS). Extended incisional hernia is inevitable when fascial closure is missed (up to 90% of cases). Intra-abdominal pressure (IAP) has not yet been evaluated as a criterion for the feasibility of fascial closure.
Patients and methods. Over 12 months laparostomy was carried out in 40 patients. Definitive closure of the abdomen was performed after 4.4 ± 3.7 days in 23 of these. Intravesical pressure was used to assess IAP before and after fascial closure. The resulting IAP was compared to the values of 90 patients undergoing elective abdominal surgery. Parameters of cardiocirculatory, renal, pulmonary, and liver function were also recorded.
Results. After closure of the laparostomy IAP increased significantly from 6.5 ± 3.3 to 12.0 ± 4.1 mmHg. Urine output decreased by 27% on the first postoperative day but regained normal levels thereafter. The central venous pressure increased by 31%. Other parameters of cardiocirculatory, renal, pulmonary, and liver function were unchanged. No case of ACS occurred. In the patients undergoing elective abdominal surgery IAP ranged from 6.5 ± 2.1 to 10.0 ± 4.0 mmHg.
Conclusions. Fascial closure increased the IAP, which was accompanied by short-termed decrease in urine output. At these levels of IAP fascial closure appears to be harmless, but further prospective studies are needed to determine the critical level of IAP for allowing a safe repair of large fascial defects.

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Introduction

The concept of the left-open abdomen or laparostomy is frequently applied in the treatment of peritonitis, mesenteric ischemia or trauma in order to facilitate abdominal re-exploration or to prevent the abdominal compartment syndrome (ACS) [13, 18, 29, 32]. ACS is a frequent and life-threatening condition characterized by an intra-abdominal pressure (IAP) exceeding 20 mmHg, decreased cardiac output, oliguria, and highly increased peak airway pressures in ventilated patients [7, 13, 29]. The increase in IAP is thought to result from an extensive intestinal edema which is enhanced by the volume resuscitation in these patients [30]. increased IAP such as in ACS has also been observed to impair intestinal and hepatic perfusion and may lead to multiorgan dysfunction independently of the underlying illness [7, 21]. The critical threshold of IAP leading to organ impairment is not known exactly, but adverse effects on the outcome of surgical patients have been observed when IAP increases to more than 10–18 mmHg [22, 25, 28].

In the presence of ACS, decompressive laparotomy and the use of laparostomy is the treatment of choice as this has been observed to lead to circulatory, respiratory, and renal recovery [6]. Various materials have been proposed for temporary abdominal closure, for example, plastic bags, palisades, towel clips, zipper systems, and absorbable meshes [30]. Control of intra-abdominal infection and recompensation of the circulation eventually allows the definitive closure of the abdominal wall. In the case of persisting intestinal edema, however, the need for the laparostomy might exceed 14 days, a period beyond which the formation of granulation tissue and adhesions is considered to make the definitive closure increasingly dangerous or even impossible [18, 29]. This situation occurs in up to 90% of surviving patients, which eventually leads to a large abdominal wall hernia requiring mesh-augmented repair [8].

In addition to stabilizing the patient's general condition, the indication for definitive closure of the abdominal wall largely depends on the subjective assessment of the surgeon considering, for example, the intestinal edema. IAP as an objective parameter has not yet been evaluated in the concept of open abdomen. Consequently the threshold below which abdominal closure does not lead to adverse effect is unknown. Knowledge of this critical pressure would facilitate an early, elective, definitive abdominal closure preventing the additional risk and costs of secondary hernia repair. The present study investigated IAP before and after the closure of laparostomy with regard to a possible effect on organ function.

Material and methods

Over a period of 12 months laparostomy was performed in 40 patients because of intra-abdominal bleeding (8%), mechanical obstruction (20%), intestinal ischemia (25%), peritonitis (45%), and abdominal trauma (2%). Patients with peritonitis had a mean Mannheim Peritonitis Index (MPI [3]) of 31.2 ± 3.7 (Tables 1, 2) [19]. Laparostomy was performed in a standardized fashion using a 30×30 cm polyglactin mesh (Vicryl, Ethicon, Hamburg) sutured to the fascial edges with a running suture (Fig. 1).

Table 1. The Mannheim Peritonitis Index (MPI): risk factors and weighting, if present

	Weight
Age > 50 years	5
Female sex	5
Organ failure[a]	7
Malignancy	4
Preoperative duration of peritonitis	4
Origin of sepsis not colonic	4
Diffuse generalized peritonitis	6
Exsudate	
Clear	0
Cloudy, purulent	6
Fecal	12

[a]See Table 2

Table 2. The Mannheim Peritonitis Index (MPI): definitions of organ failure (*PO_2* partial arterial pressure of oxygen, *PCO_2* partial arterial pressure of carbon dioxide)

Kidney	
Creatinine level	> 177 μmol/l
Urea level	> 167 mmol/l
Oliguria	< 20 ml/h
Lung	
PO_2	< 50 mmHg
PCO_2	> 50 mmHg
Shock	Hypo- or hyperdynamic according to Shoemaker
Intestinal obstruction	Paralysis > 24 h or complete mechanical Ileus

Fig. 1. Laparostomy using a 30×30 cm polyglactin mesh sutured to the fascial edges with a running suture

In 17 patients extended visceral edema (Fig. 2) and massive intra-abdominal adhesions made a safe reconstruction of the abdominal wall impossible. In this group the mean stay in the intensive care unit was 16.4 ± 21.3 days. Eight patients died due to the underlying disease leading to laparostomy or because of consecutive complications. Two patients died after transferal to other departments and institutions. In 23 patients the abdomen was definitively closed after 4.4 ± 3.7 days. In this group the mean stay in the intensive care unit after closure was 7 ± 4.7 days. These 23 patients were investigated in the present study. The decision to perform primary closure of the abdominal wall was based on the usual criteria as the attending surgeon was not aware of the current IAP. Closure of the abdominal wall was performed by closing the fascial layer either using a running suture or a single suture technique with resorbable material. This was followed by skin closure in all patients. Mean operation time for closure was 2 ± 0.7 h.

Measurement of the intravesical pressure

IAP was monitored indirectly by the measurement of intravesical pressure (IVP). For this, 100 cc isotonic sodium chloride solution was injected into the bladder via the urinary catheter, and the resulting pressure was measured at end-expiration over a stand pipe

Fig. 2. Example of an extensive intestinal edema preventing fascial closure in a woman with peritonitis

connected to the catheter system (Fig. 3) [17]. The neutral point (zero) of the standpipe was set at the height of the symphysis, and patients were positioned flat and supine. During IVP measurement patients were either treated continuously with a combination of fentanyl and propofol or had analgesia provided by piritramide bolus. To assess normal postoperative values in our patients undergoing elective abdominal surgery we measured IVP in 90 patients on the first postoperative day after conventional cholecystectomy, gastric resection, liver resection, small bowel resection, colorectal resection, or resection of two or more abdominal organs (referred to below as multivisceral resection). In the study group IVP was measured before and after the closure of the laparostomy (twice daily at 8 a.m. and 8 p.m.) over period of up to 7 days: day of closure together with 3 pre- and postoperative days.

Further parameters

Cardiocirculatory function was assessed using heart rate, mean arterial pressure, central venous pressure (CVP). CVP was corrected for the surrounding pressure by subtracting the positive end-expiratory pressure if applied. Respiratory function was evaluated using the mode of respiration (mechanical ventilation or spontaneous breathing), inspiratory oxygen fraction, peak inspiratory pressure, and arterial PO_2 and PCO_2. The need for a reintubation was recorded. Renal function was assessed using the daily urine output, the daily dose of furosemide, and the serum content of creatinine and urea. Hepatic function and integrity were evaluated using the serum content of bilirubine and glutamic-oxaloacetic transaminase. We also recorded the dose of dopamine, noradrenaline, and adrenaline and the Acute Physiology and Chronic Health Evaluation II score [15]. All parameters were recorded twice daily (8 a.m. and 8 p.m.) excluding the daily urine output and the daily dose of furosemide, which were recorded once daily at 8 a.m. All these parameters were measured for 7 days, as described above. The wound infection rate was not assessed.

Statistics

Results are presented as mean ±SD. Further statistical analysis was performed using the paired *t* test and analysis of variance (ANOVA) for repeated measurements after a normal distribution of the data had been confirmed by the Wilk-Shapiro test. If the sample was not normally distributed, a paired test according to Wilcoxon was performed. A randomness level of $P < 0.05$ was considered statistically significant. Whenever necessary, a post hoc test was performed according to Tukey and Bonferroni.

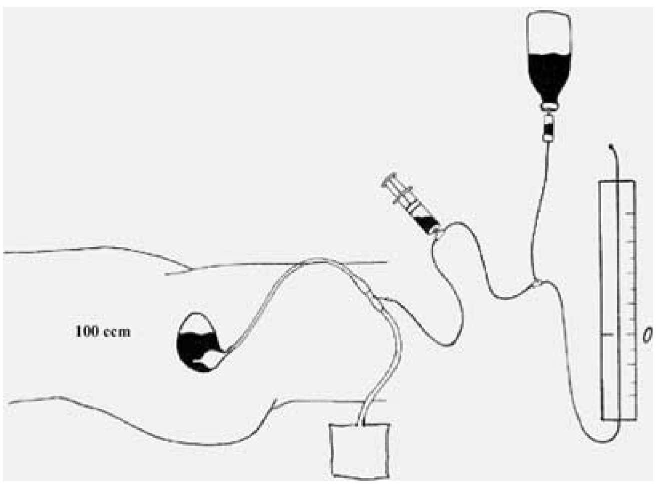

Fig. 3. Measurement of intravesical pressure for the assessment of IAP. Pressure was measured via the connected standpipe system at end-expiration after 100 cc isotonic sterile saline had been injected into the bladder. The neutral point (zero) of the standpipe was set at the height of the symphysis, and patients were positioned flat and supine

Results

IVP in the 90 patients undergoing elective abdominal operations ranged between 6.5 ± 2.1 mmHg (after conventional cholecystectomy) and 10.0 ± 4.0 mmHg (after multivisceral resection) on postoperative day 1 (Table 3). IAP did not differ between the different procedures (n.s., ANOVA). In the 23 patients of the study group IVP decreased ($P < 0.03$, ANOVA) from 11.4 ± 2.9 to 6.5 ± 3.3 mmHg during 3 days before closure of the laparostomy (Fig. 4a). After fascial closure IVP increased significantly from 6.5 ± 3.3 (preoperatively) to 12.0 ± 4.1 mmHg (postoperatively; $P < 0.0001$, paired *t* test; Fig. 4b). During the following 3 days IVP decreased substantially from 10.3 ± 3.0 mmHg on postoperative day 1 to 9.6 ± 7.4 on postoperative day 3 (n.s., ANOVA).

CVP increased significantly after fascial and skin closure from 4.2 ± 4.0 to 5.5 ± 3.0 mmHg ($P < 0.05$, paired *t* test). Heart rate and mean arterial pressure were not affected; heart rate ranged from 86 ± 5 to 98 ± 16 bpm and mean arterial pressure from 86 ± 10 to 100 ± 13 mmHg. The overall number of patients requiring mechanical ventilation decreased continuously during the investigation period. Inspiratory oxygen fraction, peak inspiratory pressure, PO_2, and PCO_2 were unchanged before and after laparostomy closure. No case required reintubation after closure (Table 4).

Daily urine output decreased significantly by 27% on the first postoperative day ($P < 0.01$, paired *t* test) and rose again to the preoperative level over the following 2 days (n.s. ANOVA). Administration of furosemide was not significantly increased after laparostomy closure. Fluid balance, serum creatinine, and serum urea also remained unchanged (Table 5). The glutamic-oxaloacetic transaminase level increased nonsignificantly from 22.4 ± 29.7 to 57.8 ± 98.8 U/l before and after closure of the laparostomy. Bilirubin decreased nonsignificantly from 1.0 ± 1.0 to 0.6 ± 0.3 mg/dl.

Table 3. IVP (mmHg) measured on postoperative day 1 in 90 patients after elective intra-abdominal resections

	n	IVP
Conventional cholecystectomy	5	6.5 ± 2.1
Gastric resection	16	7.9 ± 3.5
Liver resection	10	6.6 ± 3.2
Small bowel resection	12	8.5 ± 4.7
Colorectal resection	26	8.1 ± 3.2
Multivisceral resection	21	10.0 ± 4.0

The Acute Physiology and Chronic Health Evaluation II score remained unchanged before and after reconstruction of the abdominal wall and ranged from 7.5 ± 3.2 to 6.7 ± 3.9 during the investigation period. Dopamine and noradrenaline were significantly reduced from 300.0 ± 268.3 to 176.5 ± 152.2min and from 3.2 ± 0.5 to 0.3 ± 1.2 µg/min($P < 0.05$, Wilcoxon test). Adrenaline remained unchanged (0.3 ± 0.4 to 0.3 ± 1.2 µg/min).

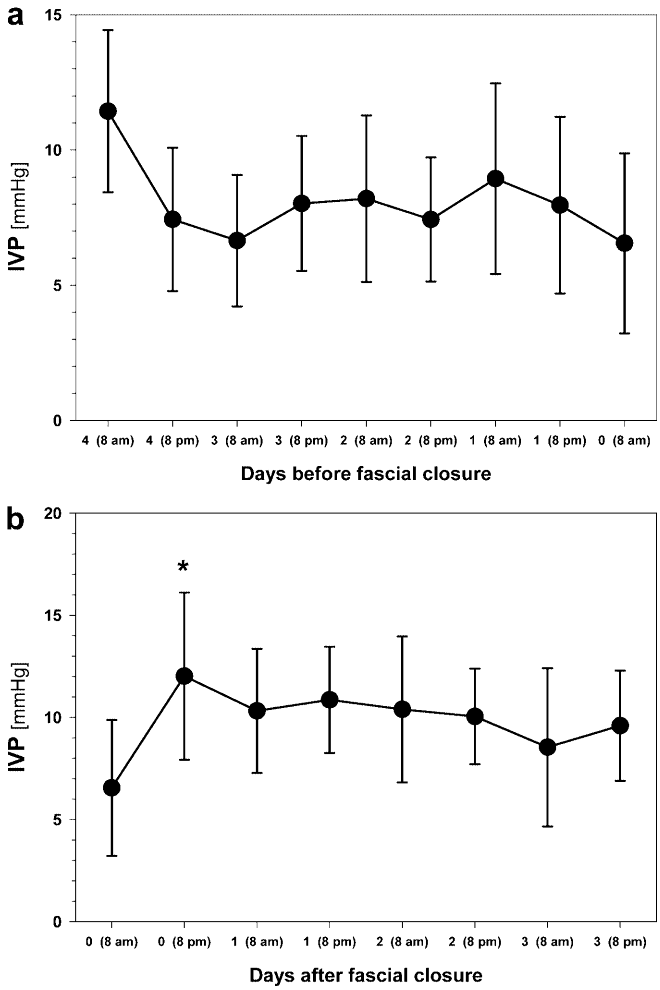

Fig. 4. **a** IVP in 23 patients during 3 days before fascial closure. Note that the IVP decreased significantly ($P < 0.03$, ANOVA) from 11.4 ± 2.9 to 6.5 ± 3.3 mmHg. **b** IVP in 23 patients after fascial closure. Note that the IVP increased significantly from 6.5 ± 3.3 before to 12.0 ± 4.1 mmHg after fascial closure. *$P < 0.0001$, paired *t* test

Discussion

Definitive closure of the abdominal wall after laparostomy must be considered beneficial as it improves wound healing, facilitates mobilization of the patient, and prevents incisional hernia. The time in which a laparostomy can be closed is affected by restoration of a physiological intra-abdominal condition and by the formation of granulation tissue. The indication for abdominal wall reconstruction is based largely on the subjective assessment of the surgeon, and closure rates reported in the literature have been as low as 10% [8].

In the present study evaluating the IAP as an objective parameter in laparostomy therapy the abdomen of 23 patients (77% of surviving patients) was definitively closed after 4.4 days. This was accompanied by an 85% increase in IAP , 31% increase in CVP, and a significant 27% decrease in daily urine output. No case of ACS occurred. In the remaining patients persistent intestinal edema or the extensive formation of granulation tissue prevented fascial closure. These findings are in accordance with reports by other authors of closure rates ranging from 10% to 71% and intervals between first laparotomy and closure ranging from 3.1 to 15 days [1, 8, 14, 30].

Measurement of IVP is considered the gold standard [26, 33] for assessing IAP, although IVP is an direct method and requires a physiological bladder. After elective abdominal operations IAP is reported to range between 5 and 10 mmHg [17, 26]. This is in accordance with the findings in our study, as IAP in 90 control patients varied from 6.5 ± 2.1 after conventional cholecystectomy to 10.0 ± 4.0 mmHg after multivisceral resections.

After complete layered abdominal closure we observed a significant increase in IAP from 6.5 ± 3.3 to 12.0 ± 4.1 mmHg in 23 patients. IAP has not yet been systematically investigated in the context of the left-open abdomen. During the elective repair of large abdominal wall hernias in five patients an increase in mean IAP

Table 4. Cardiocirculatory and pulmonary parameters before and after laparostomy closure (all measurements at 8 a.m.); PCO_2 and PO_2 were measured by arterial blood gas analysis (*PIP* peak inspiratory pressure)

Day	CVP (mmHg)	Ventilated patients (%)	FIO_2 (mmHg)	PIP (cmH_2O)	PCO_2 (mmHg)	PO_2 (mmHg)
Before						
3	4.2 ± 2.6	71	0.41 ± 0.1	24.0 ± 3.6	37.1 ± 4.2	78.5 ± 13.6
2	2.4 ± 4.0	78	0.4 ± 0.1	21.2 ± 3.9	36.9 ± 2.9	84.1 ± 7.3
1	3.1 ± 3.4	71	0.36 ± 0.1	21.6 ± 2.7	36.3 ± 4.5	104.7 ± 12.0
0	4.2 ± 4.0	74	0.36 ± 0.04	21.1 ± 2.7	36.0 ± 4.2	96.7 ± 19.0
After						
0	5.5 ± 3.0*	82	0.34 ± 0.1	21.8 ± 4.1	36.5 ± 4.2	99.7 ± 20.5
1	4.1 ± 3.9	57	0.35 ± 0.1	20.2 ± 4.5	36.5 ± 5.0	87.3 ± 14.6
2	3.7 ± 1.9	47	0.33 ± 0.1	20.5 ± 6.4	37.0 ± 6.8	86.2 ± 12.2
3	2.4 ± 2.6	12	0.42 ± 0.1	21.0 ± 0.8	35.4 ± 6.8	94.6 ± 20.0

*$P < 0.05$, paired *t* test

Table 5. Renal function before and after laparostomy closure (all measurements at 8 a.m.)

	Urine output per day (ml)	Furosemide per day (mg)	Serum creatinine (U/l)	Serum urea (mg/dl)
Before				
3	2826 ± 1284	187.5 ± 324.8	1.7 ± 1.2	72 ± 69.4
2	2829 ± 1566	56.1 ± 156.9	1.4 ± 1.3	70.3 ± 73.8
1	3165 ± 1300	62.7 ± 142.1	1.5 ± 1.1	63.7 ± 62.7
0	3139 ± 1308	41.0 ± 111.4	1.3 ± 1.0	56.6 ± 55.9
After				
1	2300 ± 726*	90.0 ± 324.4	1.2 ± 1.0	48.5 ± 55.2
2	3486 ± 1496	13.1 ± 19.2	1.4 ± 1.2	42.5 ± 30.8
3	3014 ± 1084	22.5 ± 50.4	1.0 ± 0.6	39.7 ± 25.7

*$P < 0.007$, paired t test

from 3 to 10 mmHg was observed, but the size of the fascial defect was not further specified [24]. As the repair of fascial defects is prone to increase IAP [9, 31], further studies focusing on the correlation between size of defect and IAP are needed to evaluate the risk of short-term, i.e., cardiopulmonary, complications. Regarding long-term development of incisional hernia after laparotomy closure, the effect of IAP also remains to be evaluated.

No case of ACS occurred in our patients. Tremblay et al. [30] observed ACS in 11% of patients in the presence of an open abdomen and in 2% of patients shortly after its closure, but this was not correlated to IAP. Their results nevertheless indicate that laparostomy alone cannot prevent the recurrence of intra-abdominal hypertension, and that further monitoring is needed in patients at risk.

The critical level of increased IAP that leads to organ dysfunction is not known precisely as only few clinical studies have been conducted. IAP exceeding 10 mmHg has been considered elevated [20, 25], and it was shown that surgical patients with postoperative IAP above 10 mmHg have significantly more complications than those with IAP less than 10 mmHg [25]. A study by Sugrue et al. [28] found an IAP of 18 mmHg occurring in 41% of surgical patients requiring intensive care treatment to be an independent factor of postoperative renal dysfunction. So far the available data support the view that an IAP of even 10–15 mmHg predisposes to an adverse effect in surgical patients, but further studies are needed to determine the critical level and the patients at risk.

Global circulation is known to be affected by the IAP, although the effect is variable, and the critical level is also unknown. It has been observed that in the presence of an IAP of 15 mmHg the arterial pressure and the CVP can be increased while the venous return is decreased [10, 16]. Accordingly, heart rate might be unaffected [10, 16]. The discrepancy between increased CVP and reduced venous return has been explained by diaphragmatic pressure transduction [2]. This is in accordance with the findings of our study, as the CVP displayed a small but significant increase while mean arterial pressure and heart rate remained unaffected.

An increase in IAP is known to increase the peak inspiratory pressure and to reduce pulmonary compliance via elevated diaphragms [2, 4, 23]. This phenomenon has previously been noted in the presence of an IAP of 12 mmHg [12, 23]. In the present study the portion of mechanically ventilated patients progressively diminished during the investigation period, and the peak inspiratory pressure, PCO_2, and PO_2 remained unchanged. Overall, the increased IAP did not affect the parameters of respiratory function in this study.

We observed a significant reduction in daily urine output of 27% on the first postoperative day. The daily dose of furosemide increased substantially in the meantime, while the serum content of creatinine and urea remained unchanged. On the following day IAP tended to decrease, and daily urine output returned to preoperative levels. IAP is known to have an effect on urine output, and renal impairment has been noted in patients with an IAP of 15–20 mmHg [5, 27, 28]. This is probably the result of a decreased renocortical perfusion, which has been shown to occur independently of a normal cardiac output [11]. Since the patients were on a standardized infusion program, and the fluid balance remained unchanged, the decreased urine output is likely to reflect the increased IAP.

Conclusion

The layered abdominal closure at the end of laparostomy therapy significantly increased IAP. This was accompanied by a short-term but significant decrease of 27% in urine output and an increase in CVP. Other organ systems were not affected, and no case of postoperative ACS occurred. These results suggest that fascial closure can be performed without a negative effect at this level of the IAP. However, further studies are needed to determine the critical level of IAP and the size of fascial defect allowing closure without subsequent complications related to intra-abdominal hypertension.

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