Citation for the published paper:
Mokhtari A, Petzina R, Gustafsson L, Sjogren J, Malmsjo M, Ingemansson R.
"Sternal stability at different negative pressures during vacuum-assisted closure therapy"
Annals of Thoracic Surgery, 2006, Vol: 82 Issue: 3, pp. 1063-7.
http://dx.doi.org/10.1016/j.athoracsur.2006.04.085

Sternal Stability at Different Negative Pressures During Vacuum-Assisted Closure Therapy

Arash Mokhtari, MD[1], Rainer Petzina, MD[2], Lotta Gustafsson, MSc, PhD[2], Johan Sjögren, MD, PhD[1], Malin Malmsjö, MD, PhD[2], and Richard Ingemansson, MD, PhD[1]

Departments of Cardiothoracic Surgery[1] and Internal Medicine[2],
Lund University Hospital, Lund, Sweden

Running Head: Sternal stability and vacuum therapy

Keywords: Mediastinal infection, Sternum, Wound infection, Wound closure

Word count: 2590

Corresponding Author:
Arash Mokhtari, MD
Department of Cardiothoracic Surgery
Heart and Lung Center
Lund University Hospital
SE-221 85 Lund, Sweden
Phone: +46 46 173821
Fax: +46 46 158635
E-mail: arash.mokhtari@med.lu.se

Abstract

Background. Vacuum-assisted closure (VAC) is a widely used therapy in patients with poststernotomy mediastinitis. The aim of this study was to evaluate sternal stability during VAC application at seven negative pressures (-50 to -200 mm Hg) in a porcine wound model.

Methods. Six pigs underwent median sternotomy and 2 steel wires were fixed at each sternal side and connected to a traction device. The device was connected to a force transducer linked to a force recorder. VAC therapy was applied to the wound. At each negative pressure the length and width of the wound were measured before and after traction was started. Traction was increased stepwise up to 400 N.

Results. The diastasis induced by a certain lateral force was similar in wounds treated with -75, -125 and -175 mm Hg. At -75 mm Hg a significant improvement ($p < 0.01$) in sternal stability was seen compared to the open-chest setting. This was not further improved at -125 or -175 mm Hg. High negative pressures (-150 to -200 mm Hg) in combination with a high lateral force (>200 N) increased the risk of separation of the foam from the wound edges with air leakage or organ rupture as a result.

Conclusions. Our results suggest that low negative pressures (-50 to -100 mm Hg) stabilizes the sternum as efficiently as high negative pressures (-150 to -200 mm Hg). Low negative pressures (-50 to -100 mm Hg) were more beneficial, however, because no air leakage or organ rupture was observed at these pressures.

Abstract word count: 252

Introduction

Several studies have reported promising results using vacuum-assisted closure (VAC) therapy in poststernotomy mediastinitis [1-9]. The most commonly used pressure in the clinical situation is -125 mm Hg. This is based on previous basic research demonstrating -125 mm Hg to be the optimal negative pressure for wound healing [10]. Furthermore, granulation tissue formation has been studied at different negative pressures and the maximum increase in growth rate was observed at -125 mm Hg [11].

VAC therapy has been initiated for wound healing in other areas of the body, including diabetic leg wounds, pressure-induced wounds, and burn wounds. There are important aspects that require consideration when VAC is applied to a sternotomy wound. Because to the vital structures in the thoracic cavity the interaction between the polyurethane foam and the surrounding tissue is of importance. It has been proposed, but not scientifically proved, that a less negative pressure (eg, -75 mm Hg) might lead to insufficient sternal stability with an increased risk of organ damage [12]. On the other hand, too high a negative pressure applied to the mediastinum has been suggested to be a risk for right ventricular rupture [13]. An increased wound edge diastasis owing to lateral force might theoretically impair heart and lung function or jeopardize the function of coronary by pass grafts. The aim of the present study was to evaluate the stability of sternotomy wounds during VAC application at seven different negative pressures (from -50 to -200 mm Hg) in a porcine model.

Material and Methods

Animals

Six pigs with a mean body weight of 70 ± 3 kg were used. All the animals received care in compliance with the European Convention on Animal Care. The experimental protocol for this study was approved by the Ethics Committee for Animal Research at Lund University, Sweden.

Anesthesia and Surgical Preparation

Premedication consisted of an intramuscular injection of ketamine (100 mg/mL; Ketaminol vet, Farmaceutici Gellini S.p.A, Aprilia, Italy) at 15 mg/kg body weight, combined with midazolam (1 mg/mL; Dormicum, Roche, Stockholm, Sweden) and xylazine (20 mg/mL; Rompun vet, Bayer AG, Leverkusen, Germany) at 2 mg/kg. Anesthesia was induced by a continuous 20 mg/mL intravenous infusion of propofol. Anesthesia was induced by continuous intravenous infusion of propofol (Diprivan, AstraZeneca, Södertälje, Sweden) at a dosage of 0.1 to 0.2 mL/(kg . min) in combination with intermittent fentanyl (Leptanal; Jenssen-Cilag, Sollentuna, Sweden) and atracurium besylate (Tracrium; Glaxo, Täby, Sweden) at doses of 0.02 µg/kg and 0.2 to 0.5 mg/kg, respectively. Before surgery a tracheotomy (Portex tracheal tube, 7.5 mm internal diameter, SIMS Portex, Keene, NH) was performed.

A ventilator (Servo-Ventilator 900, Elema-Schönander, Sweden) was used for mechanical ventilation. The same settings were used for all animals: volume-controlled, pressure-regulated ventilation, 8.5 L/min, 15 breaths/min, and an inhaled oxygen fraction of 35%.

A lower midline abdominal incision was made over the urinary bladder. The urinary bladder was exposed and a urinary catheter (Silicone Foley Catheter, Tyco Healthcare, Tullamore, Ireland) was inserted, sutured, and connected to a urinary bag (Unomedical a/s, Haarlev, Denmark). The abdominal incision was continuously sutured with Dermalon 2.0 (Davis-Geck, Hampshire, UK). A midline sternotomy was performed and the pleuras were routinely opened. Two 6-0 steel wires for use in sternal closure (Syneture, Tyco Healthcare, CT) were secured between each sternal side and the sternal traction device (Fig. 1). The traction device was connected to a force transducer which was linked to a custom-made force recorder (Fig 2). A layer of polyurethane foam (KCI, Copenhagen, Denmark) was placed between the sternal edges. A second layer of foam was placed over the first layer and sutured to the skin. Two evacuation tubes (KCI) were inserted into the layers of foam. The wound was sealed with a transparent adhesive drape (KCI) and the two tubes were connected to a continuous vacuum source (V.A.C. pump unit, KCI).

Experimental Protocol

After 30 minutes of stabilization, the negative pressure was applied and the length and width of the sternotomy wound were measured (Fig. 1). To eliminate systemic errors, the sequence of applying the seven different negative pressures (-50, -75, -100, -125, -150, -175 and -200 mm Hg) was varied between the animals in a manually randomized design. This was followed by stepwise increases in the traction force 20 N at a time. The maximal traction force was 400 N. Photographs were taken of the VAC foam at different traction forces (Fig. 3).

Data Analysis

The force was expressed in terms of newtons and the change in sternal wound edge diastasis in terms of millimeters. The “force-diastasis” measurements were terminated when the vacuum source failed in more than two wounds (pigs). Calculations and statistical analysis were performed using GraphPad Prism 4.0 software (GraphPad Software, Inc., CA). Statistical significance was defined as $P < 0.05$, using the Kruskal-Wallis test with Dunnett post-test. Values are presented as means ± SEM.

Results

The application of lateral force to an open chest without ongoing VAC therapy caused an increase in wound diameter (Fig. 4A). Increasing levels of lateral force to the sternal wound, during ongoing VAC therapy also caused an increase in the sternal wound diameter (Fig 4B-H). The increase in diameter induced by various lateral forces (100, 200, and 300 N) was similar in wounds treated with -75, -125 and -175 mm Hg (Fig. 5). At -75 mm Hg a significant improvement in sternal stability was seen compared to the open-chest setting. This stability was not further improved at -125 or -175 mm Hg (Fig. 5).

The VAC foam adapted well to the shape of the wound at negative pressures of -50, -75 and -100 mm Hg, and lateral forces up to 400 N did not induce air leakage (Fig. 3). At negative pressures of -150, -175 and -200 mm Hg, the VAC foam was harder and did not adapt to the shape of the wound (Fig. 3). At -150, -175 and -200 mm Hg, in combination with high lateral forces (> 200 N), the foam tended to separate from the wound edges and slide into the thoracic cavity, with air leakage as a result (Fig. 3 and Fig. 4F-H).

Furthermore, in 5 pigs, a sudden air leakage appeared at -175 and -200 mm Hg in combination with high lateral force (> 200 N). This air leakage was terminated by clamping the respirator tube suggesting lung rupture. After the experiment was completed and the VAC dressing was removed, lung ruptures could be seen visually in these 5 pigs.

Comment

The most commonly used negative pressure in VAC therapy for poststernotomy mediastinitis is -125 mm Hg [14-15]. The use of -125 mm Hg is based on small-animal studies on peripheral wounds [10-11]. However, several important aspects must be considered when using VAC therapy in a sternotomy wound. The thoracic cavity contains vital structures (eg, heart, lungs and bypass grafts) at risk for impaired function or organ rupture. In addition, the sternum must be adequately stabilized to ensure proper respiration and mobilization. Finally, the negative pressures that are optimal for granulation tissue formation, increased microvascular blood flow, postoperative pain, and bacterial elimination must be considered. It may well be that the optimal pressures for these variables are not the same.

Our present study demonstrates that low negative pressures (-50 to -100 mm Hg) stabilizes the sternum sufficiently. Of interest was that the wound diameter induced by various lateral forces was similar in wounds treated with low (-50 to -100 mm Hg) and high (-150 to -200 mm Hg) negative pressures (Fig. 5). At low negative pressures, the VAC foam adapts better to the shape of the wound. At high negative pressures, the foam is harder and in combination with high lateral forces tends to separate from the wound edges, with air leakage as a result. Furthermore, lung rupture occurred in 5 of 6 pigs at negative pressures between -175 and -200 mm Hg. Our results suggest that treatment at high negative pressure levels involves a higher risk of organ dysfunction or damage.

Earlier studies support the use of -75 mm Hg instead of -125 mm Hg in sternotomy wounds. We have previously demonstrated that a negative pressure of -75 mm Hg is optimal to increase the blood flow in the peristernal thoracic wall [16]. In a previous study, our research group showed that -75 mm Hg seems more beneficial from a hemodynamic point of view [17]. Granulation tissue formation is reported to be optimal at -125 mm Hg negative pressure [11].

In conclusion, the result of the present study suggest that low negative pressures (-50 to -100 mm Hg), stabilizes the sternum just as efficiently as high negative pressures (-150 to -200 mm Hg).

At low negative pressures, the foam adapts better to the shape of the wound than at high negative pressures. Low negative pressures in combination with high lateral forces (> 200 N) demonstrated no failure of the foam dressings or organ ruptures. We suggest that VAC therapy at -75 mm Hg might be an interesting option in the treatment of poststernotomy mediastinitis.

Acknowledgements

We thank Professor Roland Hetzer at the German Heart Institute in Berlin for valuable support and Nils Göran Ohlsson at Lund University Hospital for his expert contribution in constructing the custom-made traction device. This study was supported by research grants from the Region Skåne Research Funds, the Swedish Heart-Lung Foundation, the Swedish Medical Association, the Swedish Government Grant for Clinical Research, and the Donation Funds of the Lund University Hospital.

References

1. Obdeijn MC, de Lange MY, Lichtendahl DH, de Boer WJ. Vacuum-assisted closure in the treatment of poststernotomy mediastinitis. Ann Thorac Surg 1999; 68: 2358-60.

2. Tang AT, Ohri SK, Haw MP. Novel application of vacuum assisted closure technique to the treatment of sternotomy wound infection. Eur J Cardiothorac Surg 2000; 17: 482-4.

3. Luckraz H, Murphy F, Bryant S, Charman SC, Ritchie AJ. Vacuum-assisted closure as a treatment modality for infections after cardiac surgery. J Thorac Cardiovasc Surg 2003; 125: 301-5.

4. Gustafsson R, Johnsson P, Algotsson L, Blomquist S, Ingemansson R. Vacuum-assisted closure therapy guided by C-reactive protein level in patients with deep sternal wound infection. J Thorac Cardiovasc Surg 2002; 123: 895-00.

5. Sjogren J, Gustafsson R, Dobre M, Koul B, Ingemansson R, Algotsson L. Vacuum-assisted closure therapy in mediastinitis after heart transplantation. J Heart Lung Transplant 2004; 23: 506-7.

6. Domkowski PW, Smith ML, Gonyon DL, Jr., *et al.* Evaluation of vacuum-assisted closure in the treatment of poststernotomy mediastinitis. J Thorac Cardiovasc Surg 2003; 126: 386-90.

7. Fleck TM, Fleck M, Moidl R, *et al.* The vacuum-assisted closure system for the treatment of deep sternal wound infections after cardiac surgery. Ann Thorac Surg 2002; 74: 1596-600.

8. Sjogren J, Gustafsson R, Nilsson J, Malmsjo M, Ingemansson R. Clinical outcome after poststernotomy mediastinitis: vacuum-assisted closure versus conventional treatment. Ann Thorac Surg 2005; 79: 2049-55.

9. Sjogren J, Nilsson J, Gustafsson R, Malmsjo M, Ingemansson R. The impact of vacuum-assisted closure on long-term survival after post-sternotomy mediastinitis. Ann Thorac Surg 2005; 80:1270-5.

10. Morykwas MJ, Argenta LC, Shelton-Brown EI, McGuirt W. Vacuum-assisted closure: a new method for wound control and treatment: animal studies and basic foundation. Ann Plast Surg 1997; 38: 553-62.

11. Morykwas MJ, Faler BJ, Pearce DJ, Argenta LC. Effects of varying levels of subatmospheric pressure on the rate of granulation tissue formation in experimental wounds in swine. Ann Plast Surg 2001; 47: 547-51.

12. Abu-Omar Y, Naik MJ, Catarino PA, Ratnatunga C. Right ventricular rupture during use of high-pressure suction drainage in the management of poststernotomy mediastinitis. Ann Thorac Surg 2003; 76: 974-5.

13. Fleck TM, Grabenwoger M. Letter to the Editor (Reply). Right ventricular rupture during use of high-pressure suction drainage in the managment of poststernotomy mediastinitis. Ann Thorac Surg 2003; 76: 975.

14. Gustafsson RI, Sjogren J, Ingemansson R. Deep sternal wound infection: a sternal-sparing technique with vacuum-assisted closure therapy. Ann Thorac Surg 2003; 76: 2048-53.

15. Hersh RE, Jack JM, Dahman MI, Morgan RF, Drake DB. The vacuum-assisted closure device as a bridge to sternal wound closure. Ann Plast Surg 2001; 46: 250-4.

16. Wackenfors A, Gustafsson R, Sjogren J, Algotsson L, Ingemansson R, Malmsjo M. Blood flow responses in the peristernal thoracic wall during Vacuum-Assisted Closure therapy. Ann Thorac Surg 2005; 79: 1724-30.

17. Sjogren J, Gustafsson R, Wackenfors A, Malmsjo M, Algotsson L, Ingemansson R. Effects of vacuum-assisted closure on central hemodynamics in a sternotomy wound model. Interact Cardiovasc Thorac Surg 2004; 3: 666-71.

Figure legends

Figure 1: A 70-kg pig prepared for a sternal stability test. Arrow points to force transducer. White bars designated width and length.

Figure 2: A custom-made device for investigating sternal stability connected to a force transducer (angled arrow) and a force recorder (straight arrow).

Figure 3: Photographs of vacuum-assisted (VAC) closure settings with (VAC on) and without (VAC off) ongoing therapy at different negative pressures (-75, -125 and -175 mm Hg) in combination with different lateral forces 0, 100, 300 and 400 N.

Figure 4: Change in wound width (solid circle) and length (open circle) in millimeters (mm) without negative pressure (A), and at negative pressures of -50 (B), -75 (C), -100 (D), -125 (E), -150 (F), -175 (G) and -200 (H) mm Hg. Values are presented as means ± SEM.

Figure 5: Increase in wound edge diameter in millimeters at -75, -125 and -175 mm Hg and in an open-chest setting with lateral forces of 100, 200 and 300 newtons (N). Values are presented as means ± SEM. * = $p < 0.05$, ** = $p < 0.01$, n.s. = non significant.

Figure 1:

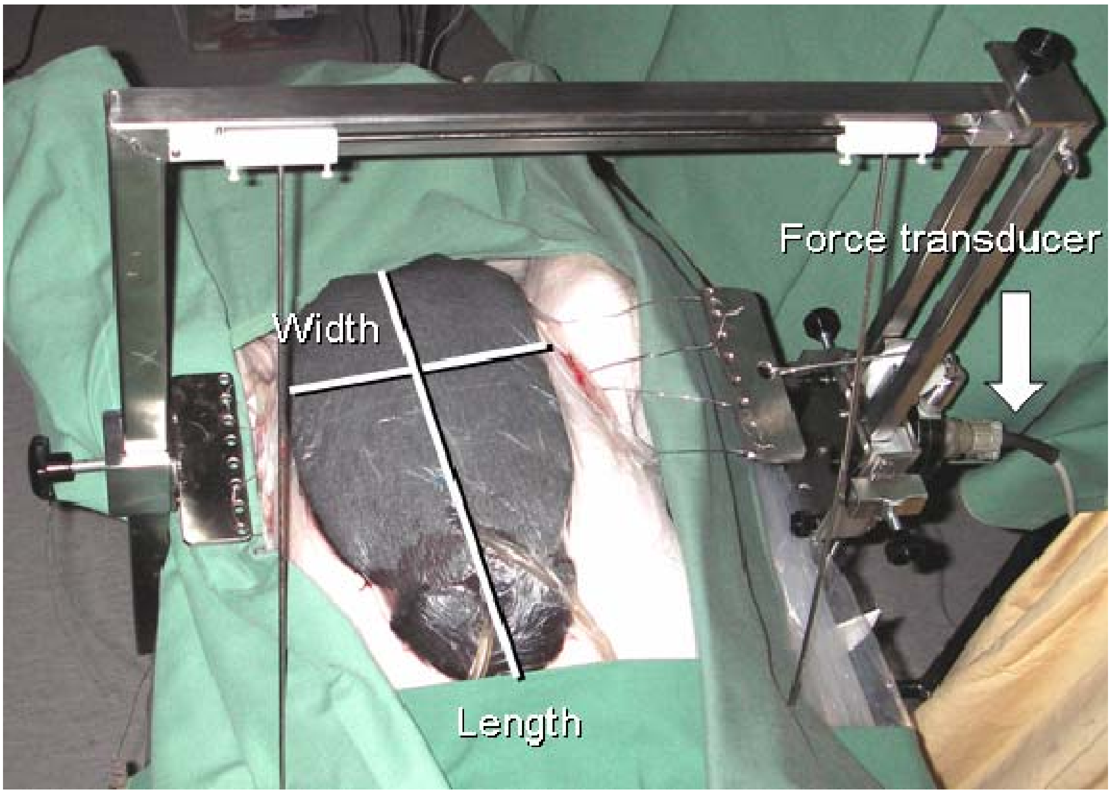


Figure 2:

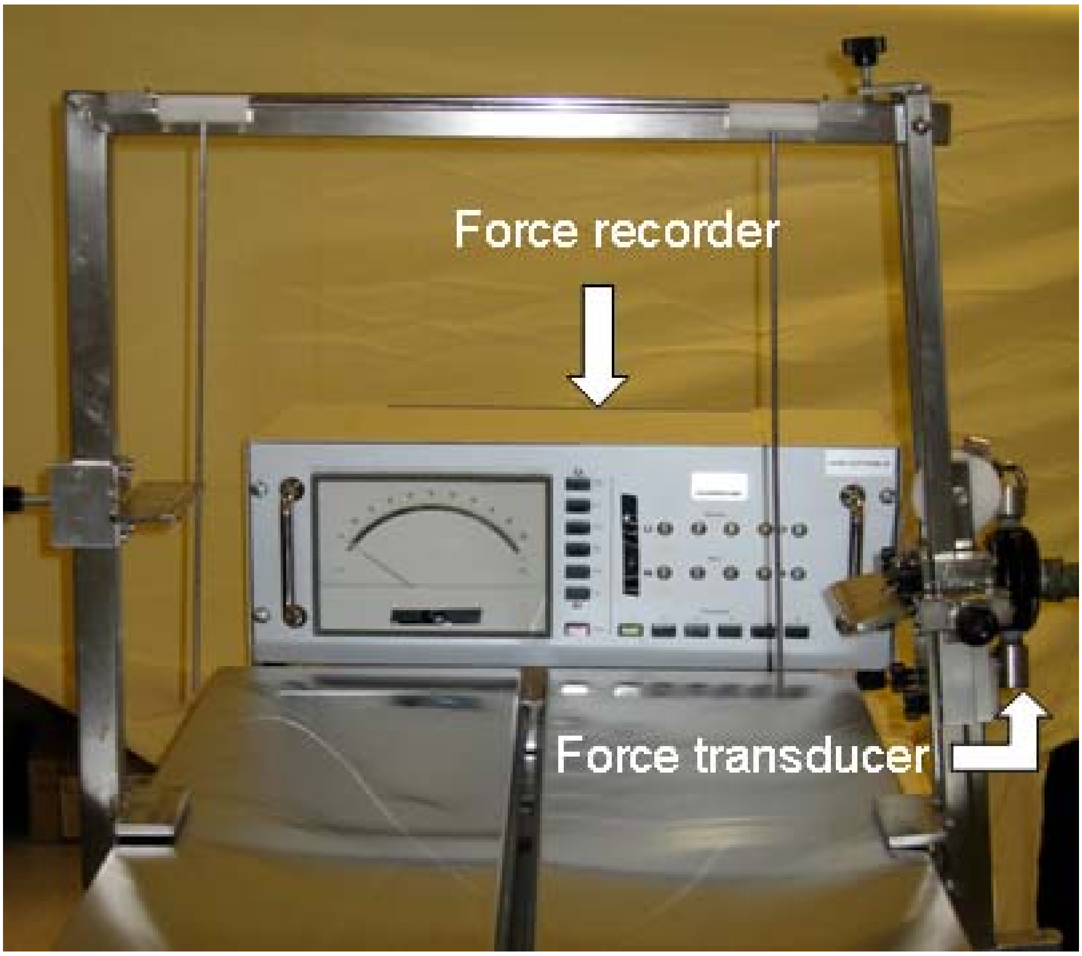


Figure 3:

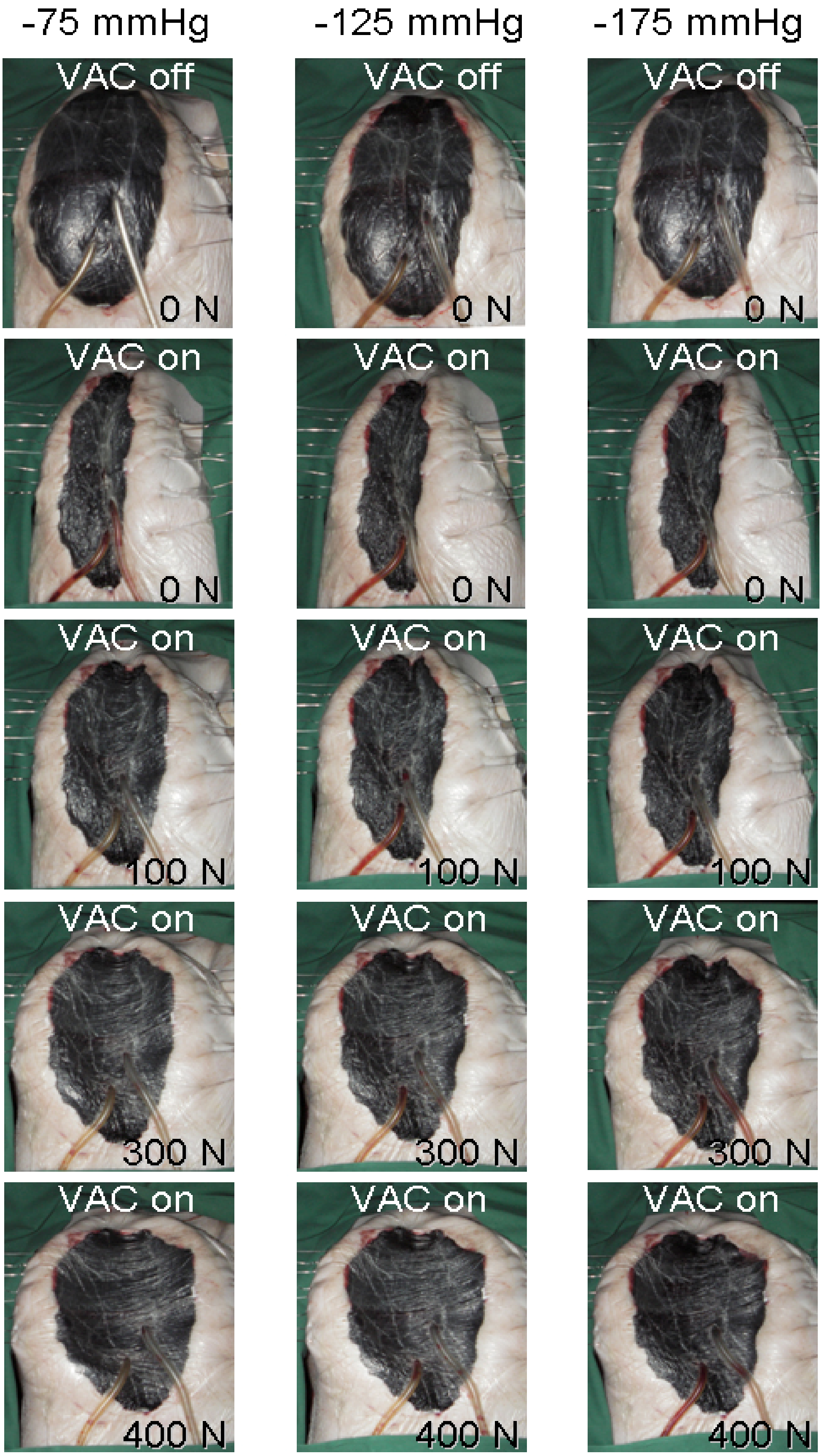

-75 mmHg
-125 mmHg
-175 mmHg
VAC off
0 N
VAC off
0 N
VAC off
0 N
VAC on
0 N
VAC on
0 N
VAC on
0 N
VAC on
100 N
VAC on
100 N
VAC on
100 N
VAC on
300 N
VAC on
300 N
VAC on
300 N
VAC on
400 N
VAC on
400 N
VAC on
400 N

Figure 4:

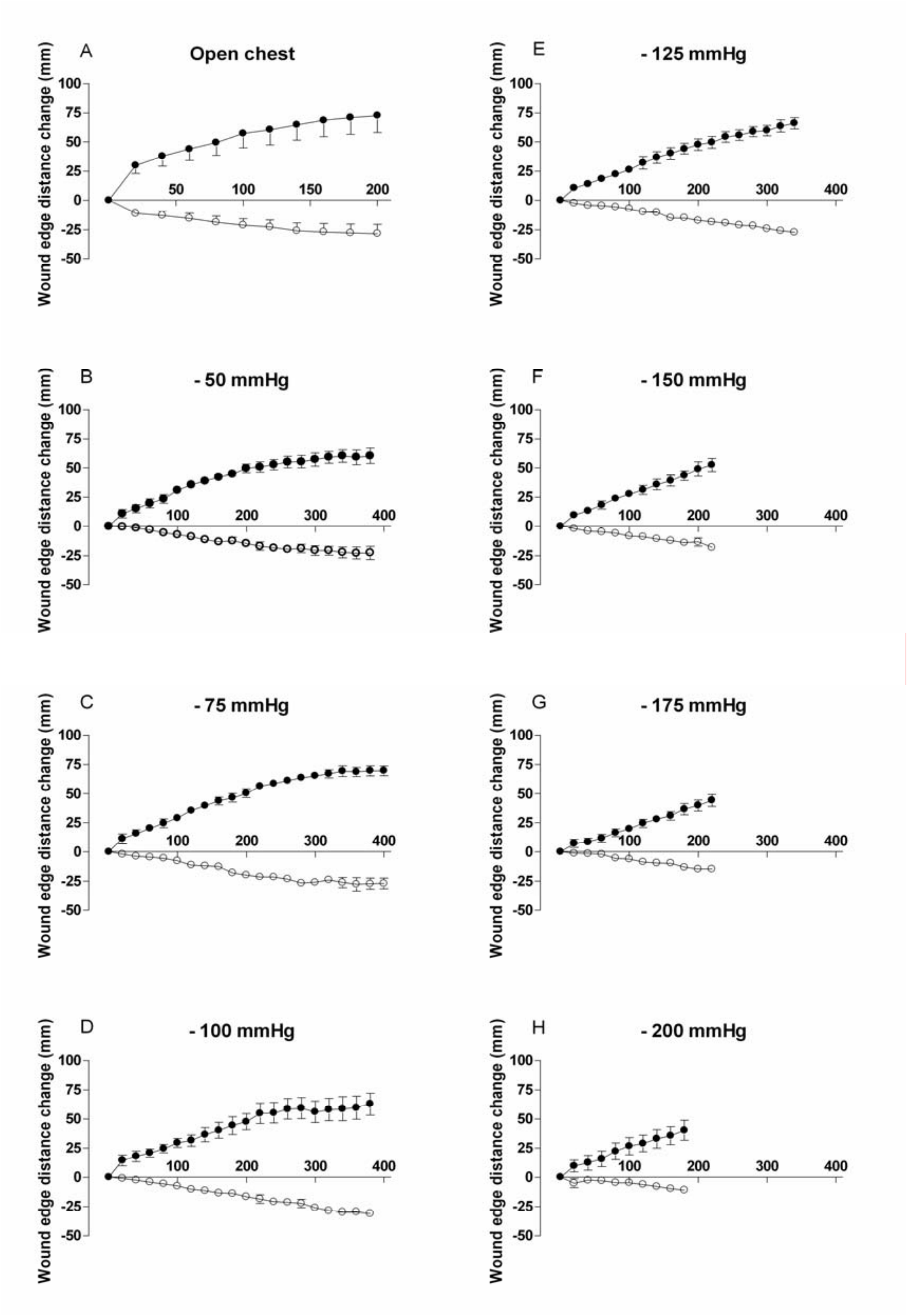
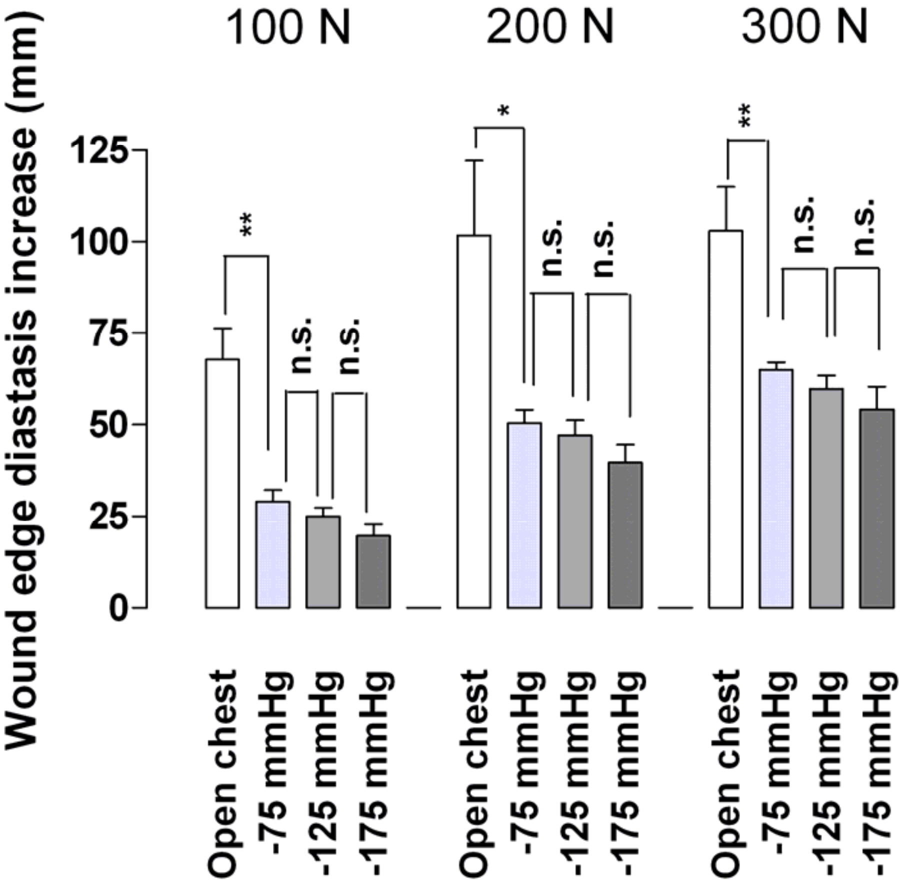

A
Open chest
B
- 50 mmHg
C
- 75 mmHg
D
- 100 mmHg
E
- 125 mmHg
F
- 150 mmHg
G
- 175 mmHg
H
- 200 mmHg
Wound edge distance change (mm)
100
75
50
25
0
-25
-50
50
100
150
200
300
400

Figure 5:


100 N
200 N
300 N
Wound edge diastasis increase (mm)
125
100
75
50
25
0
**
n.s.
n.s.
*
n.s.
n.s.
**
n.s.
n.s.
Open chest
-75 mmHg
-125 mmHg
-175 mmHg
Open chest
-75 mmHg
-125 mmHg
-175 mmHg
Open chest
-75 mmHg
-125 mmHg
-175 mmHg