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## **Sternal stability at different negative pressures during vacuum-assisted closure therapy**

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

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## 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 of 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 bypass 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  $70 \pm 3$  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  $\pm$  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.

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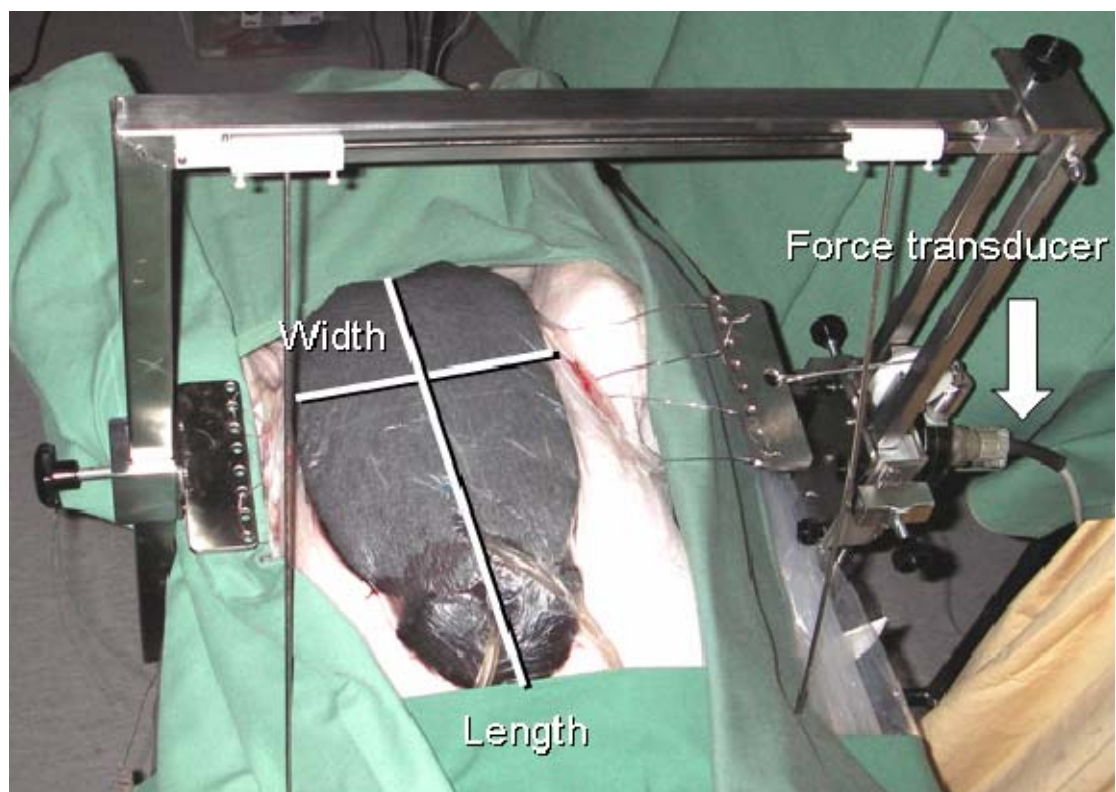
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## Figure legends

- 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  $\pm$  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  $\pm$  SEM. \* =  $p < 0.05$ , \*\* =  $p < 0.01$ , n.s. = non significant.



**Figure 1:**



**Figure 2:**

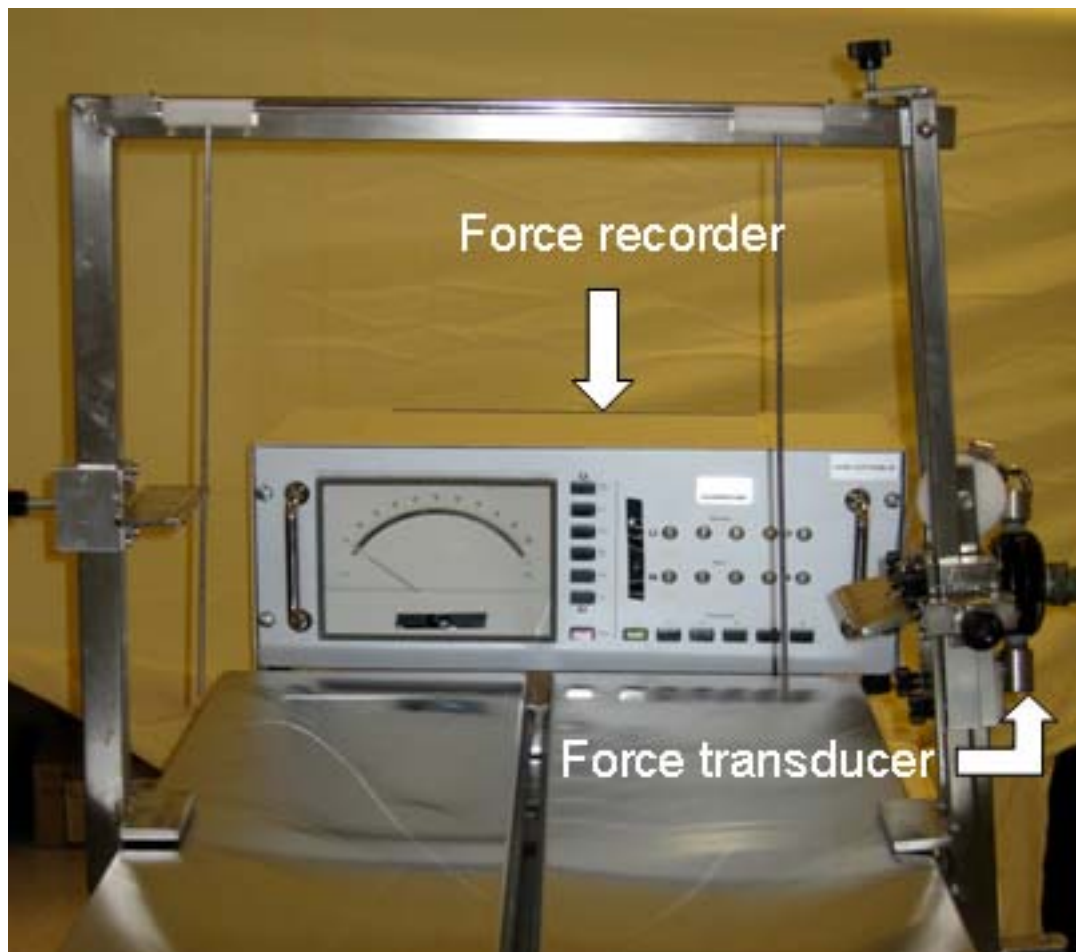


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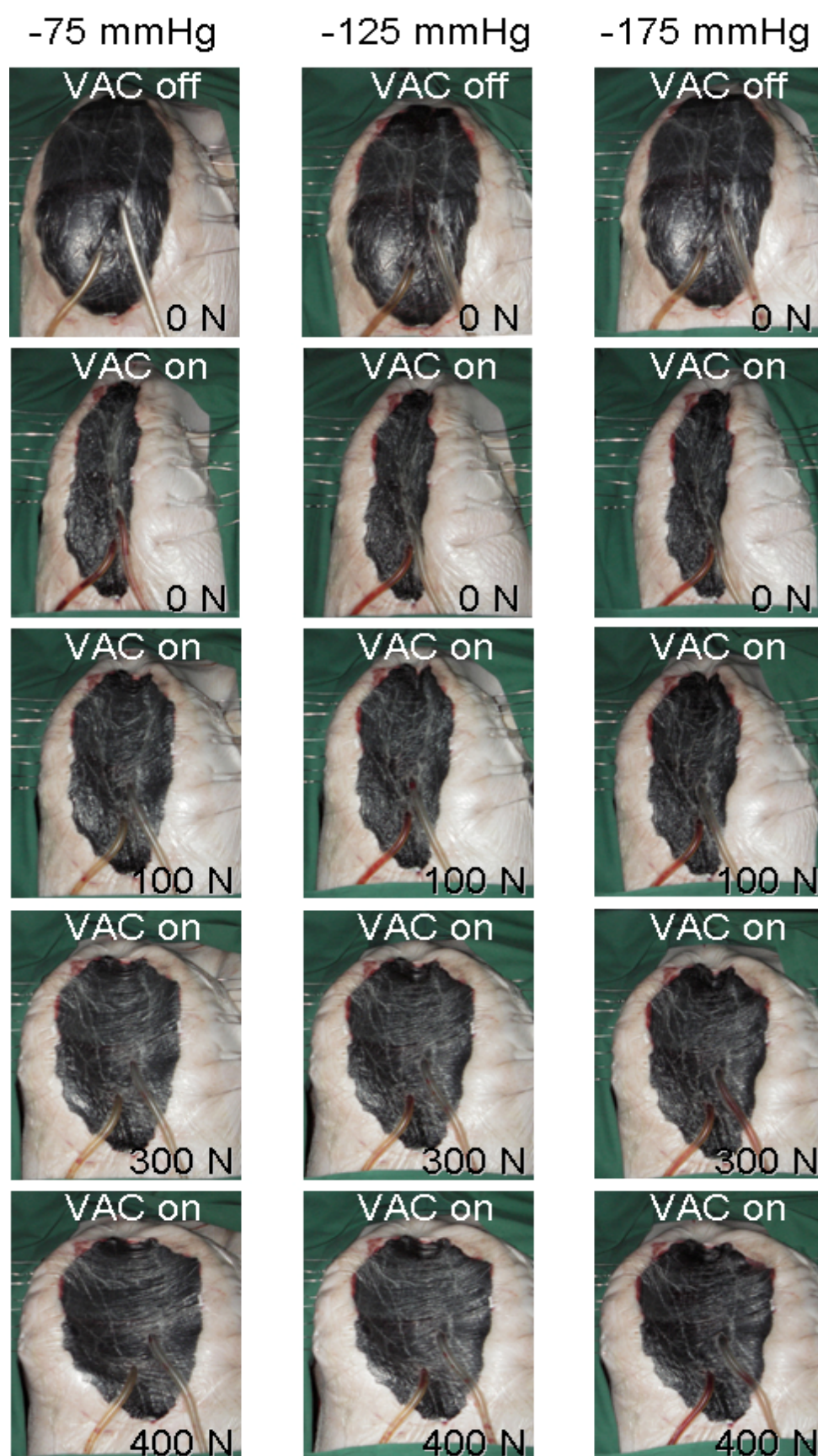


Figure 4:

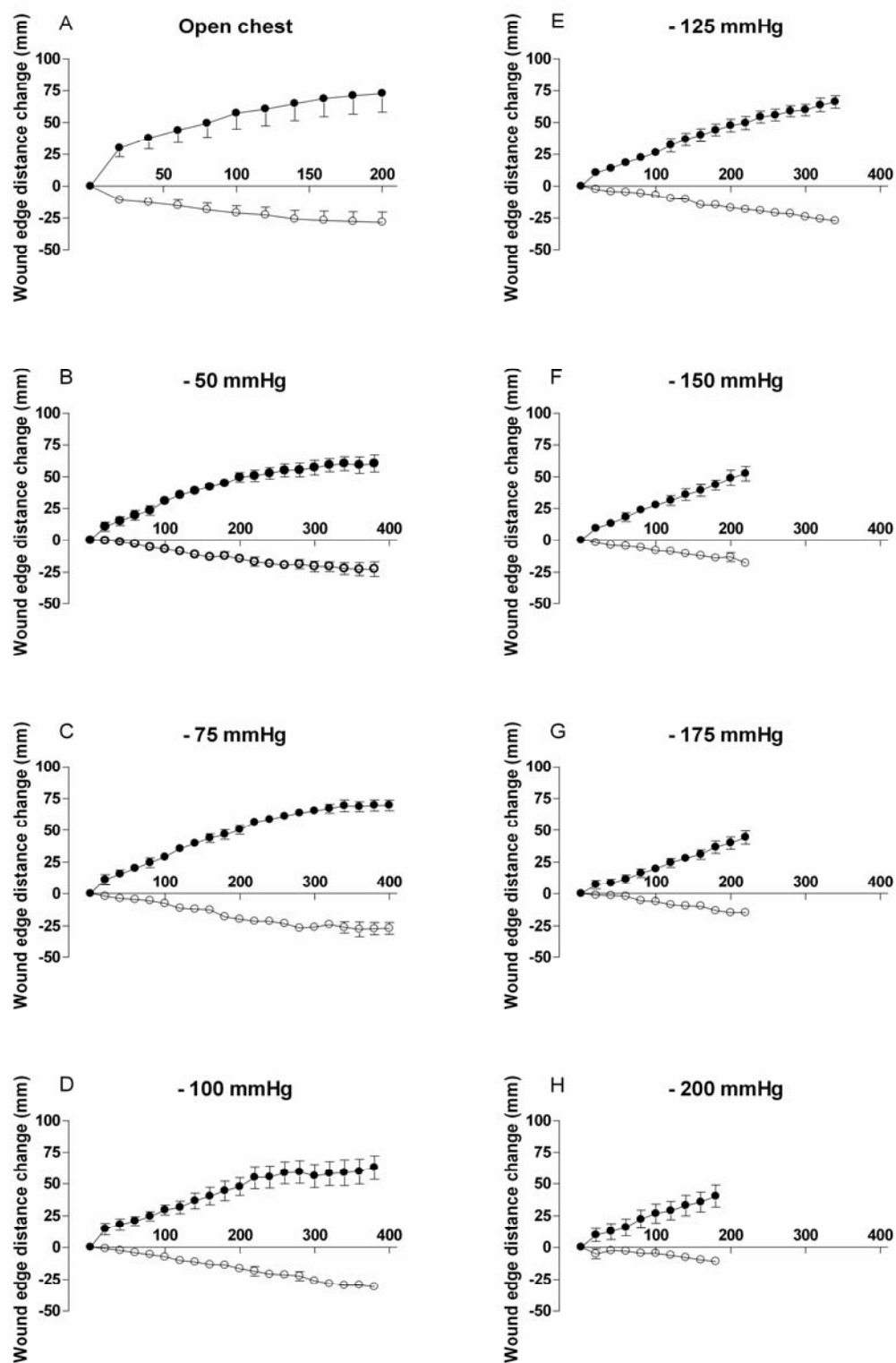


Figure 5:

