Computational modelling of impact of three negative pressure wound therapy systems in supporting the healing of surgical incisions: a finite element simulation study

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INTRODUCTION

Surgical procedures can trigger inflammatory responses with fluid accumulation around the incision site. In combination with tissue tensions along the suture line, caused by suturing opposing wound edges, the resulting elevated mechanical forces on the wound and surrounding tissue (**Figure 1**) can increase the risk of dehiscence, infection, and abnormal scarring, ultimately impairing overall wound healing.[1, 2]

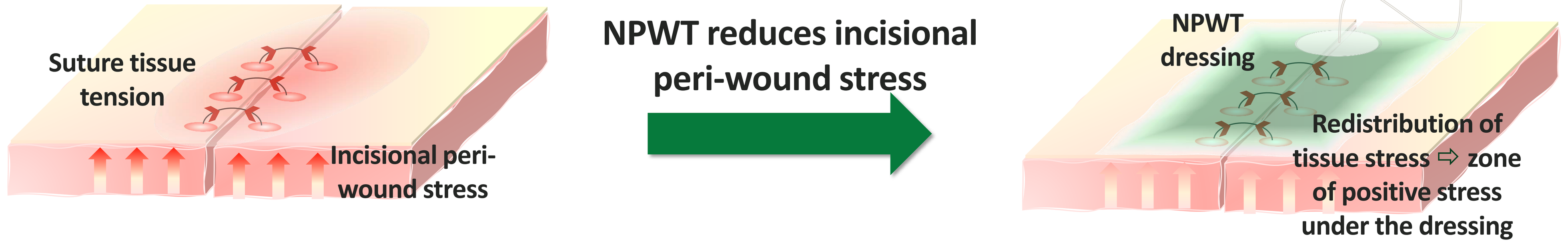


Figure 1: Negative pressure wound therapy (NPWT) is used in the management of closed surgical incision sites, with clinical benefits related to reduction of incisional tissue strain, reduction in edema, and improved perfusion.[3-7]

SCOPE

Finite element (FE) modelling can be used to estimate tissue stresses,[8-12] and was in this study used to evaluate the capacity of marketed single-use NPWT (suNPWT) systems to biomechanically stabilize and support a surgical incision by

- Reduce suture-induced tissue strain
- Establish localized zones of positive pressure to redistribute peri-wound stress (**Fig 1**)

MATERIALS AND METHODS

The suNPWT systems modelled in this study differ with respect to dressing material and magnitude of negative pressure:

System A	System B	System C
MLA dressing	MLA dressing	PP foam dressing
-80 mmHg	-125 mmHg	-125 mmHg

Multilayer absorptive (MLA); Peel-and-place (PP)

Methods

FE models were built using dressing physical properties, validated to show > 95% similarities, and modelled with the magnitude of negative pressure for each system.

The soft tissue incision FE model used validated human tissue properties,[13-17] including skin (epidermis, dermis), fat, muscle and bone layers and closure with seven sutures (**Fig 2**).[16]

FE simulations occurred in three phases
- ⇨suture closure
- ⇨dressing application
- ⇨application of negative pressure

Tissue biomechanical responses were compared before and after simulated application of NPWT (ABAQUS v2022).

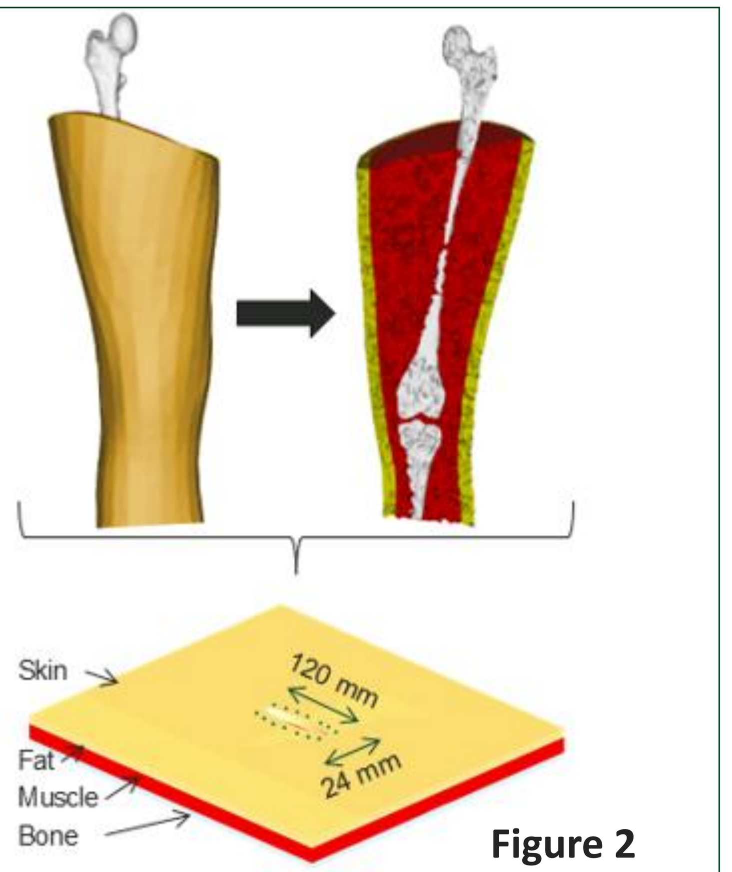


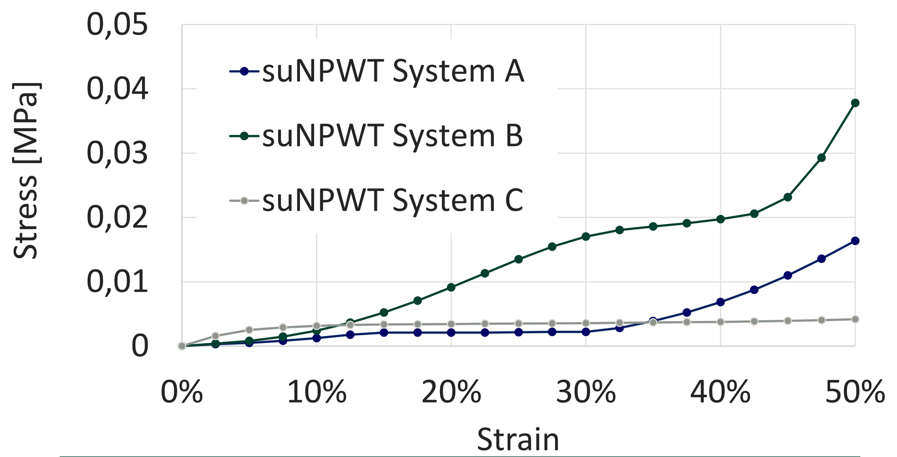
Figure 2

RESULTS

Dressing physical characteristics

Compression behavior

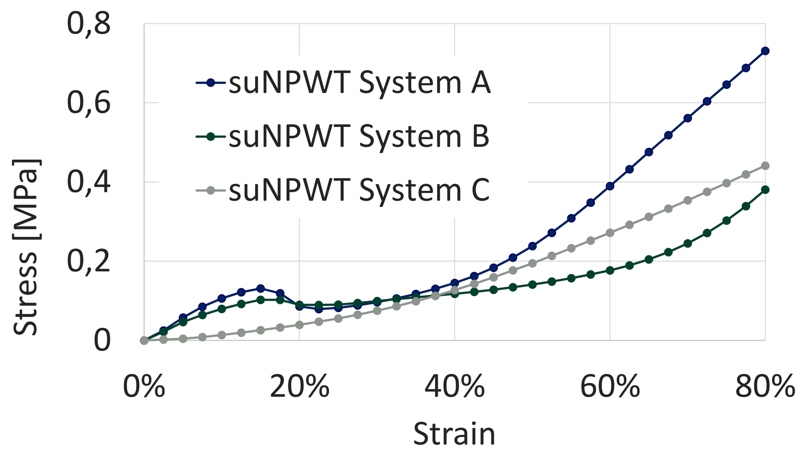
Figure 3. Compression stress-strain curves suggests that the MLA dressings (Systems A and B) were more resilient to deformation vs. the PP foam dressing used in System C. Observations were confirmed by cumulative stress-strain analysis (area under the curve (AUC)). Experimental data collected at strain range 0–50%.



suNPWT System	A	B	C
Cumulative stress [MPa]	0.0020	0.0064	0.0017

Tensile behavior

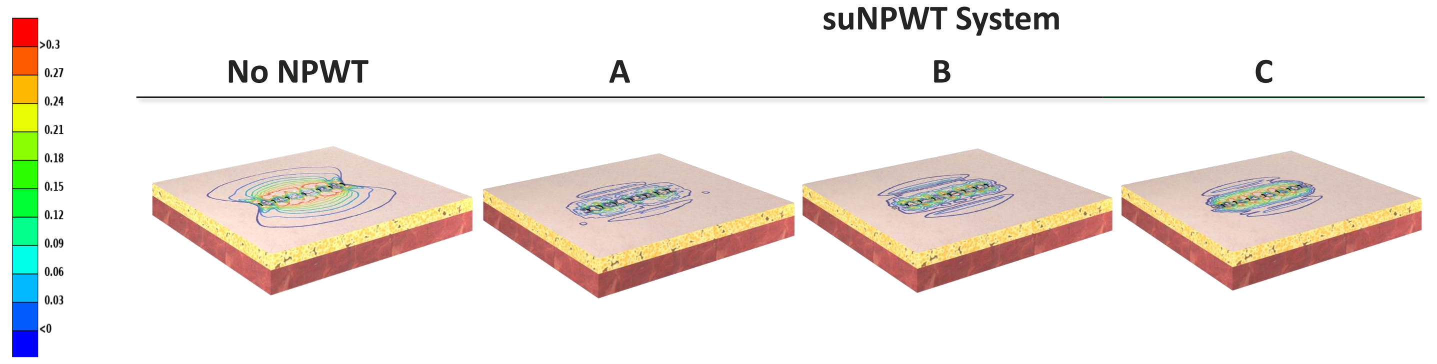
Figure 4. Tensile testing was performed over the 0-80% strain range. Cumulative stress-strain analysis, area under the curve (AUC) over the full strain range, revealed that the MLA dressing in suNPWT System A produced the highest tensile stress, as compared with the dressings in suNPWT Systems B and C.



suNPWT System	A	B	C
Cumulative stress [MPa]	0.20	0.11	0.13

Finite element simulations

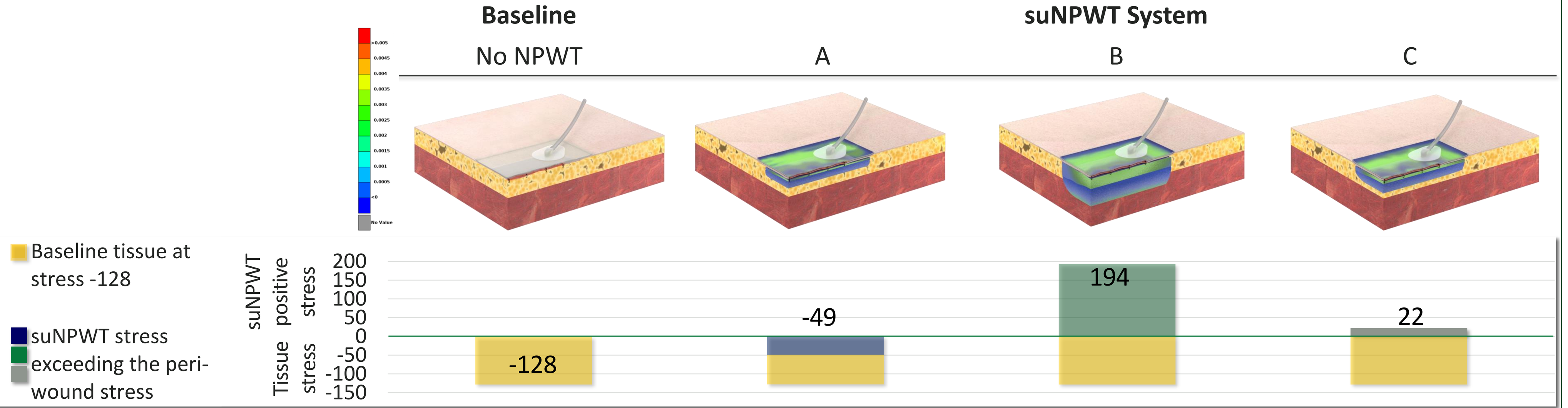
Reduction of incisional tissue tension by application of NPWT



	No NPWT	suNPWT System A	suNPWT System B	suNPWT System C
Max strain in skin around suture (%)	71	27	38	56
Max peri-wound strain area (cm²)	146	41	51	89
Cumulative stress (AUC)	243	44	70	120
Reduction (%)	N/A	82	71	51

Figure 5. Baseline FE analysis showed a maximal suture strain of 71% and a peri-wound strain area of 146 cm². Applying negative pressure markedly reduced both peak suture tension and peri-wound strain. The suNPWT systems with MLA dressings provided the greatest effect, with System A showing the lowest values for peri-wound tension, and lowest peri-wound area affected by tension. Cumulative strain analysis (AUC) confirmed this trend, as MLA-based NPWT systems had the lowest AUC values across strain thresholds >10–30% **.**

Positive pressure to off-load incisional stress in the peri-wound tissue



	Baseline No NPWT	suNPWT System A	suNPWT System B	suNPWT System C
Max stress	-128	79	322	150
Positive stress⇔suNPWT stress exceeding baseline stress	N/A	-49	194	22
Cumulative stress (AUC)	-273	247	518	337
Positive stress⇔suNPWT stress exceeding baseline stress (AUC)	N/A	-26	245	64

Figure 6. From baseline (-128 cm³ at threshold >0,01 MPa), System B redistributed peri-wound stress to generate a localized positive pressure zone of 194 cm³ as compared to a minor zone of 22 cm³ produced by System C. System A did not fully compensate for incisional stress, resulting in a negative stress balance (-49 cm³). Performance was confirmed by cumulative strain analysis (AUC) across strain thresholds 0.01-0.05 MPa, where System B showed the highest capacity to redistribute incisional strain and form a localized zone of positive pressure.

CONCLUSIONS AND KEY FINDINGS

This study used FE modelling to estimate the tissue stress induced by sutures and post-surgical peri-wound fluid accumulation, and to evaluate the biomechanical performance of three marketed suNPWT systems to stabilize and support a surgical incision.

- Suturing of opposing wound edges can generate high, localized tissue strain, both at suture anchor points but also in peri-wound tissue.
- Application of NPWT has the potential to modulate tissue tensile forces by reducing incisional tissue tension caused by sutures and redistributing peri-wound stress through the creation of a localized zone of positive pressure.
- The effectiveness of the NPWT system was not solely dependent on pressure magnitude, but also on the mechanical properties of the dressing material.
- In this study, NPWT systems with MLA dressings provided a better biomechanical support as compared to PP foam dressings and notably with a careful balance between dressing properties and pressure settings

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