

# Biomechanical influence of cavity fillers on periwound soft tissue strains in sacral pressure injuries

**Objective:** Deep cavity pressure injuries (PIs) are commonly managed with wound fillers, the biomechanical role of which remains poorly understood. This study aimed to assess how the mechanical properties of filler influence periwound soft tissue strains.

**Method:** The study combined hydrated mechanical testing of commercial cavity fillers with finite element modelling of sacral stage 3 PIs to assess how filler-related parameters affected periwound soft tissue shear strains.

**Results:** Sensitivity analysis showed that filling ratio was the dominant factor governing the volume of mechanically preserved tissue, outweighing filler stiffness, friction and compressibility. High filling ratios markedly reduced strain concentrations, while more

compliant, adipose-like fillers further improved tissue protection.

**Conclusion:** The findings of this study highlight the importance of dead-space elimination and tissue-matched filler design to mechanically protect the surrounding tissues and thereby improve healing.

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deep cavity wounds • finite element modelling • pressure injury • pressure ulcer • shear strain • soft tissue • wound • wound care • wound dressing • wound fillers • wound healing

In the management of deep cavity wounds, such as stage 3 and 4 pressure injuries (PIs), wound fillers are commonly used to pack the wound volume. Their functions include eliminating dead space, maintaining contact with the wound bed, and managing exudate while preserving a moist healing environment.<sup>1</sup> A broad array of fillers exists (hydrogels, hydrocolloids, foams, alginates and hydrofibres),<sup>2</sup> which makes their selection challenging in clinical practice.<sup>3,4</sup>

To guide clinical decision-making, numerous in vitro studies have characterised the absorption capacity, retention properties and swelling kinetics of these materials.<sup>5–8</sup> In contrast, their mechanical behaviour has received comparatively little attention, despite strong evidence linking PI development to shear strains within soft tissues.<sup>9–11</sup> Moreover, mechanical properties are predominantly assessed using dry dressings,<sup>7,12</sup> although the few studies performed under hydrated conditions show marked changes in material stiffness.<sup>6,13</sup> To the authors' knowledge, only one modelling study has considered the effect of a wound filler in a cavity wound—Fougeron et al.<sup>14</sup>—who showed that the presence of a filler significantly affects

tissue strain fields. However, the filler effect was approximated as a uniform cavity pressure and not represented explicitly. In parallel, several studies have examined the mechanical influence of dressings applied at the skin surface, highlighting the critical role of friction conditions<sup>15–17</sup> and material stiffness in modulating internal tissue stresses.<sup>18</sup> Nevertheless, these approaches do not explicitly represent a material filling the wound cavity.

In this context, the present study aimed to quantify how cavity filler-related parameters influence periwound soft tissue shear strains in a finite element model of a sacral cavity wound in which the cavity filler was explicitly represented as a hyperelastic material. More specifically, the analysis focused on the effects of filling ratio, filler mechanical response, compressibility and friction at the filler–tissue interface. To support a plausible range of filler mechanical behaviours, hydrated tensile and compression tests were performed on several commercial cavity fillers.

## Methods

### Model description

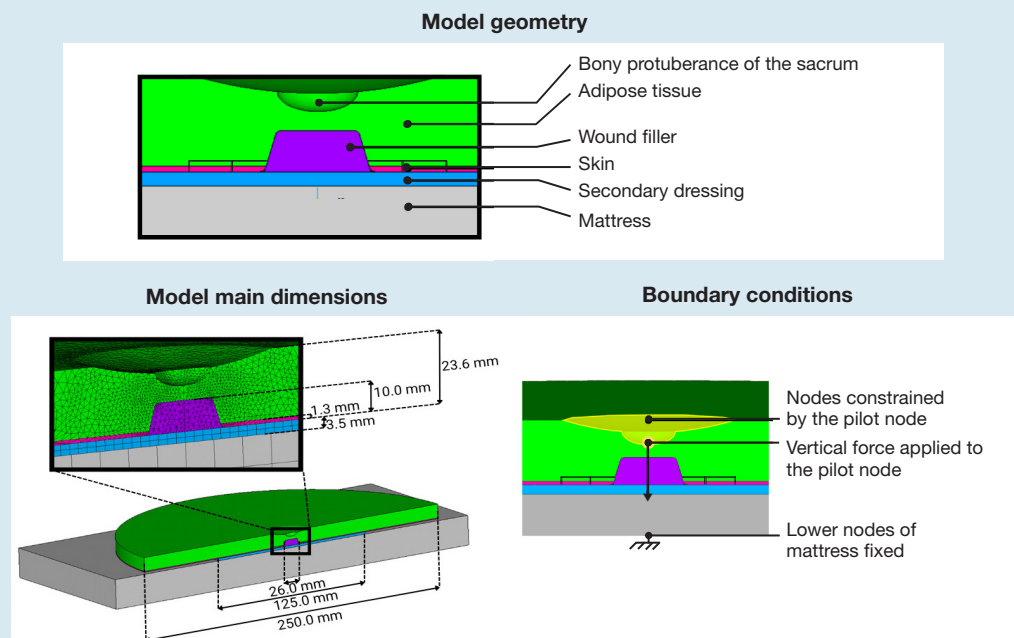
The model used in this study was adapted from that of Fougeron et al.<sup>14</sup> It represents an open cavity wound beneath the sacrum, including the bony prominence, and comprises the skin, adipose tissue, wound filler, secondary dressing and mattress supporting a supine patient (Fig 1). The 10mm wound depth is assumed to represent a stage 3 PI, commonly treated with cavity filler.

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**Fig 1.** Finite element model (adapted from that of Fougeron et al.<sup>14</sup>)

According to Fletcher et al.,<sup>19</sup> clinical wound packing varies, with material densely packed or layered. To reflect this practice, while limiting simulated contact interfaces, the filler was modelled as a solid occupying 70–100% of the cavity volume and in contact with both the wound bed and secondary dressing.

### Mechanical characterisation of materials

#### Tensile and compression tests

To define the mechanical properties of the cavity filler in the numerical model, uniaxial tensile and unconfined compression tests were performed on several commercial wound dressings. The selected products represent the main fibre technologies used for cavity fillers, namely polyacrylate, alginate, polyvinyl alcohol and carboxymethylcellulose. The tested dressings were:

- UrgoClean Rope (Urgo Medical, France)
- Algostéril Compresse (Brothier Laboratoire, France)
- Exufiber (Mölnlycke Health Care, Sweden)
- Aquacel Extra (Convatec, UK).

These tests were intended to inform the finite element model and identify representative hydrated filler behaviours, rather than to provide an exhaustive comparison of commercial products.

All tests were conducted using a Materials Test System (MTS) testing machine (model C42 503,  $\pm 25\text{N}$  load cell, 0.01% accuracy, MTS Systems, US). To represent the worst-case absorption scenario, all samples were tested in a fully saturated state. According to the testing standard NF EN 13726 (Part 3.2 – September 2002) standard for wound dressing test methods,<sup>20</sup> samples were immersed for 30 minutes in a sodium chloride (NaCl)–calcium chloride ( $\text{CaCl}_2$ )

solution with an ionic composition representative of wound exudate. The tests were then conducted with the samples immersed in the same solution bath maintained at  $37 \pm 0.5^\circ\text{C}$ , corresponding to the upper temperature range reported in a wound bed.<sup>6,7,21</sup>

Uniaxial tensile tests were performed on samples measuring  $60.0 \pm 0.5\text{mm} \times 7.0 \pm 0.5\text{mm}$ . Unconfined compression tests were performed by stacking several saturated samples to obtain a thickness of at least 10mm. The stacked samples had a minimum surface area of  $40\text{mm} \times 40\text{mm}$  and were compressed using a circular platen (diameter 30mm) until the sensor's upper limit was reached.

All tests were performed at a displacement rate corresponding to a nominal strain rate of 1%/second. For each dressing type, a representative curve was selected for constitutive fitting.

#### Volumetric compressibility tests

To capture realistic volumetric behaviour, the pressure–volume response of an UrgoClean Rope gauze assembly saturated with NaCl– $\text{CaCl}_2$  solution was measured using the device of Briot et al.<sup>22</sup> A cylindrical chamber containing stacked saturated gauze layers was piston-compressed. The response yielded the bulk modulus, 'K', used to define the reference compressibility parameter 'd' of the homogenised finite element filler.

#### Numerical implementation

The numerical simulations were performed using a finite element model implemented in ANSYS APDL (ANSYS 2023 R2, ANSYS Inc., US) with an implicit quasi-static solver.

**Table 1. Material parameters used in the simulations**

| Material           | Constitutive law                        | Parameters                                                                                                                                | Source                                                    |
|--------------------|-----------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------|
| Skin (animal)      | Isihara et al. <sup>34</sup>            | $C_{10}=2.7 \times 10^{-1}$ MPa<br>$C_{20}=1.9$ MPa<br>$d=7.5 \times 10^{-4}$ MPa <sup>-1</sup><br>( $\nu=0.4999$ )                       | Ni Annaidhet al. <sup>35</sup>                            |
| Adipose tissue     | Yeoh <sup>36</sup>                      | $C_{10}=1.3 \times 10^{-4}$ MPa<br>$C_{20}=0.0$ MPa<br>$C_{30}=12.2 \times 10^{-3}$ MPa<br>$d=1.54$ MPa <sup>-1</sup><br>( $\nu=0.4999$ ) | Sommer et al. <sup>37</sup>                               |
| Secondary dressing | Linear elastic orthotropic              | $E_x=4.4$ MPa<br>$E_y=1.8$ MPa<br>$E_z=2.6 \times 10^{-2}$ MPa<br>$d_{eq}=1.48$ MPa <sup>-1</sup><br>( $\nu=0.2560$ )                     | Fougeron et al. <sup>23</sup>                             |
| Mattress           | Linear elastic isotropic                | $E=0.23$ MPa<br>$d=10.4$ MPa <sup>-1</sup><br>( $\nu=0.3000$ )                                                                            | Fougeron et al. <sup>14</sup><br>Lee et al. <sup>38</sup> |
| Filling material   | Yeoh <sup>36</sup> /Ogden <sup>39</sup> | Varies according to the sensitivity analysis                                                                                              | Experimental tests (Fig 2)                                |

C—Yeoh material coefficient governing the deviatoric response; d—volumetric compressibility; E—Young's modulus;  $\nu$ —Poisson's ratio

### Discretisation

Linear hexahedral elements were used for the mattress and secondary dressing, whereas the soft tissues and wound filler were modelled with linear tetrahedral elements under a mixed pressure–displacement formulation. Mesh convergence was achieved at 42,062 elements in the perilesional region of interest, with relative differences <1.5% for nodal displacement and <0.3% for the tissue preservation metric compared with the finest mesh (863,300 elements).

### Boundary conditions and contact interactions

A vertical load was applied to a pilot node located in the sacral region (Fig 1), corresponding to 47% of the body weight of a 94kg subject to represent a supine patient, following Fougeron et al.<sup>23</sup> To reduce computational cost, only half of the geometry was modelled using a symmetry plane. The bottom nodes of the mattress were fully constrained.

Contact interactions were modelled with surface-to-surface elements using the augmented Lagrangian formulation. Adipose tissue–skin and skin–secondary dressing interfaces were perfectly bonded. A friction coefficient of 0.62 was used between the secondary dressing and mattress, following Fougeron et al.<sup>14</sup> Filler–soft tissue friction was varied parametrically, while filler–secondary dressing friction was set to 0.9. In the absence of dedicated tribological data for this interface, this value was chosen as a conservative worst-case estimate based on available measurements for dry internal layers of multilayer prophylactic dressings (coefficient of friction (COF): 0.78–0.98<sup>24</sup>) and saturated dressing–skin contacts (COF: 0.15–1.5<sup>17,25</sup>). The COF

influence was also expected to be limited under predominantly vertical loading.

### Constitutive equations

Material models were implemented, following Fougeron et al.<sup>23</sup> Skin and adipose tissues were modelled as hyperelastic, whereas the mattress and dressing layer were assumed to be linear elastic. For the wound filler, several constitutive laws and compressibility levels were tested in the sensitivity analysis (detailed below). The filler constitutive behaviour was defined by separating its deviatoric and volumetric responses. Due to the asymmetric behaviour observed between the tensile and compression curves, the deviatoric response was described using a second-order Ogden model fitted in MATLAB R2024a (lsqcurvefit, MathWorks, US) to the experimental compression curves only over the deformation range considered in this study, with a stretch ratio of  $\lambda \in [0.75, 1.00]$ . The volumetric response was introduced independently through the compressibility parameter  $d=(2/K)[\text{Pa}^{-1}]$ ; where: 'K' is the bulk modulus, so that larger 'd' values correspond to higher compressibility. In the following, 'material properties' refers to the Ogden parameters governing the deviatoric response, whereas 'compressibility' refers only to the volumetric parameter.

The material parameters used in the simulations are summarised in Table 1.

### Sensitivity analysis

A sensitivity analysis based on the method of Macron et al.<sup>26</sup> was performed to identify the wound filler parameters that most influenced the volume of mechanically preserved soft tissue. Maximal Green–Lagrange shear strain ( $\epsilon_{\text{shear}}$ ; Equation (1)) is a recognised mechanical biomarker of soft tissue viability and PI risk.<sup>9</sup> Sensitivity was therefore quantified from the soft tissue volume within a perilesional region of interest (ROI), defined as a radius of 1.2 times the wound radius, subjected to maximal shear strain <0.3. This threshold was previously used in PI biomechanics sensitivity analyses<sup>14</sup> and is supported by rat experiments suggesting that strains >0.3 are associated with tissue damage.<sup>9</sup> The ROI was restricted to the periwound region, where filler effects were expected to be the highest.

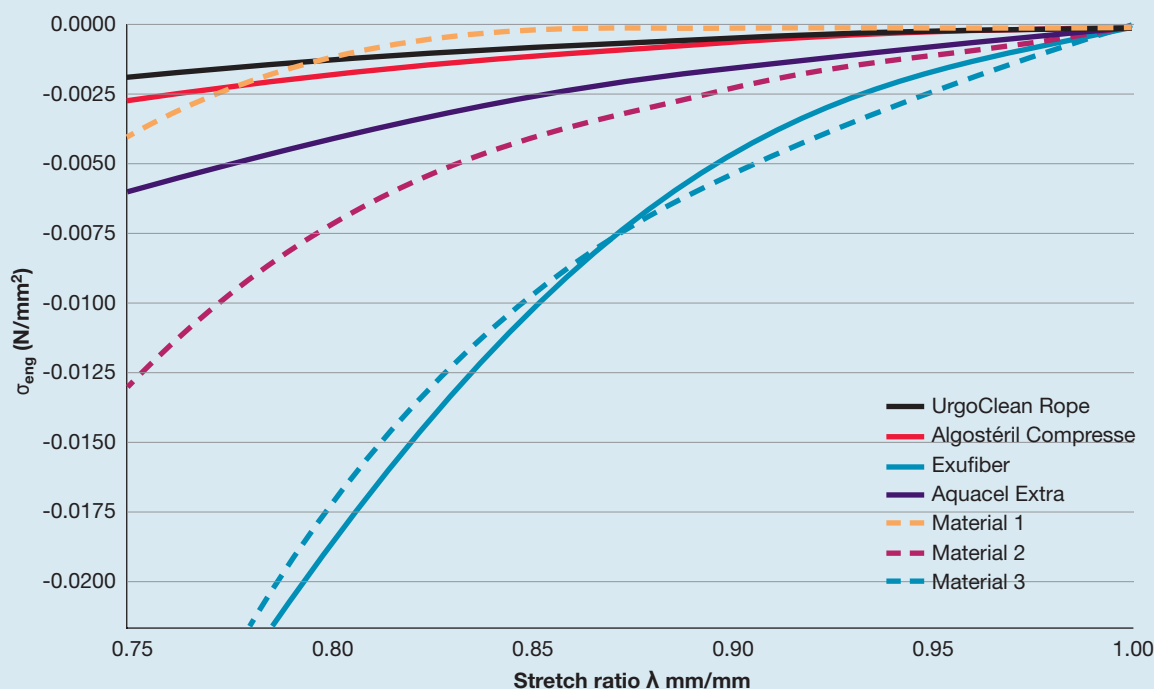
$$\epsilon_{\text{shear}} = \frac{1}{2} \max(|\epsilon_1 - \epsilon_2|, |\epsilon_1 - \epsilon_3|, |\epsilon_2 - \epsilon_3|) \text{ with } \epsilon_i = \frac{1}{2}(\lambda_i^2 - 1), i \in \{1, 2, 3\} \quad (1)$$

with  $\epsilon_i$  the Green–Lagrange principal strains.

To address clinically relevant questions, the following parameters were investigated in the sensitivity analysis:

- **Wound filling ratio:** discussions with clinicians indicated an ideal wound filling ratio of approximately 80%, ensuring contact between the filler, wound bed, and secondary dressing to promote exudate drainage and adipose tissue regeneration. The ratio was varied from 70–100% to reflect clinical variability

**Fig 2.** Engineering stress,  $\sigma_{\text{eng}}$ , versus stretch ratio,  $\lambda$ , for compression tests using a two-term Ogden model<sup>39</sup> for Materials 2 and 3: Material 1 (adipose tissue, refer to Table 1); Material 2 ( $\mu_1=0.01$  MPa,  $\alpha_1=0.01$ ,  $\mu_2=0.001$  MPa,  $\alpha_2=16$ ); Material 3 ( $\mu_1=0.1135$  MPa,  $\alpha_1=0.0989$ ,  $\mu_2=0.0013$  MPa,  $\alpha_2=18.6946$ ). Solid lines: experiments; dashed lines: model fits. Material 1—hypothetical very compliant filler with adipose tissue stiffness properties; Material 2—intermediate filler; Material 3—most rigid filler among the fillers tested. UrgoClean Rope (Urgo Medical, France); Algostéril Comresse (Brothier Laboratoire, France); Exufiber (Mölnlycke Health Care, Sweden); Aquacel Extra (Convatec, UK)



- **Wound filler material properties:** Material 1 was defined as a hypothetical, very compliant filler with properties identical to those of adipose tissue and used as a reference to assess the benefits of a more tissue-like response. Based on the experimental tests described above, the most rigid dressing (Exufiber) was selected as Material 3 and an intermediate material was selected as Material 2. Fig 2 summarises the experimental results and the material choices (Materials 1–3)
- **Compressibility coefficient:** as the compressibility parameter  $d$  of saturated UrgoClean gauze is estimated at  $0.0007 \text{ MPa}^{-1}$ , it was varied from  $0.0007$ – $0.07 \text{ MPa}^{-1}$  to account for effective compressibility from material properties and exudate saturation
- **Friction coefficient between the cavity filler and soft tissues:** friction at this interface is expected to depend on body fluids,<sup>17</sup> wound moisture,<sup>17,25</sup> and filler material properties.<sup>25</sup> To the authors' knowledge, no direct tribological data are available for the cavity filler–soft tissue interface. The investigated range (0.1–1.1) was therefore defined as an exploratory interval based on dressing–skin reported values (0.15–1.5<sup>17,25</sup>), excluding the highest values due to the different hydrated internal interface considered in this study.

Parameter ranges are summarised in Table 2, leading to a total of 81 simulations covering all combinations. The volume of mechanically preserved soft tissue in the

periwound region was then modelled using a full quadratic response surface based on normalised parameters, with coefficients fitted on the converged simulations.

## Results

The model demonstrated an excellent fit and predictive capability ( $R^2=0.9985$ , leave-one-out  $Q^2=0.9976$ ). The

**Table 2. Minimum, intermediate and maximum parameter values in sensitivity analysis**

| Parameters                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Minimal level             | Intermediate level       | Maximal level           |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|--------------------------|-------------------------|
| Wound filling ratio                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 70%                       | 85%                      | 100%                    |
| Material properties                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Material 1                | Material 2               | Material 3              |
| Wound filler compressibility                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | $0.0007 \text{ MPa}^{-1}$ | $0.007 \text{ MPa}^{-1}$ | $0.07 \text{ MPa}^{-1}$ |
| Friction coefficient: soft tissues–wound filler                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 0.1                       | 0.6                      | 1.1                     |
| Material 1—hypothetical very compliant filler with adipose tissue stiffness properties; Material 2—intermediate filler; Material 3—most rigid filler (Exufiber, Mölnlycke Health Care, Sweden). Material 1 (Adipose tissue: Yeoh <sup>36</sup> , $C_{10}=1.3\text{e}^{-4}$ MPa, $C_{20}=0.0$ MPa, $C_{30}=12.2\text{e}^{-3}$ MPa, $d=1.54 \text{ MPa}^{-1}$ ; Material 2 (Ogden <sup>39</sup> , $\mu_1=0.01$ MPa, $\alpha_1=0.01$ , $\mu_2=0.001$ MPa, $\alpha_2=16$ ); Material 3 (Ogden <sup>39</sup> , $\mu_1=0.1135$ MPa, $\alpha_1=0.0989$ , $\mu_2=0.0013$ MPa, $\alpha_2=18.69$ ) |                           |                          |                         |

regression matrix condition number of 6.35 indicated good numerical stability. Only statistically significant parameters ( $p < 0.05$ ) are reported.

The wound filling ratio was by far the main contributor to the variance of mechanically preserved soft tissue volume (98.2%), followed by material properties (1.71%) and friction coefficient (0.133%), while compressibility had no significant influence within the near-incompressible range investigated. The signs of the regression coefficients suggest that an optimal filling configuration requires a high filling ratio, a compliant wound filler and a high friction coefficient. Furthermore, the results of the sensitivity analysis suggest that the influence of the friction coefficient on soft tissue viability was amplified at lower filling ratios and with softer cavity filler material. This influence remained weak, with sensitivities of 0.0647% and 0.00910% for the corresponding interaction terms.

When restricting the sensitivity analysis to simulations corresponding to the optimal filling ratio (100%), the metamodel continued to accurately approximate the quadratic response surface, as indicated by  $R^2 = 0.9939$  and  $Q^2 = 0.9848$ . The relative contributions were then dominated by material properties (92.4%), followed by the soft tissue–gauze friction coefficient (7.78%), while the contribution of compressibility remained negligible.

A key observation was that lower friction coefficients were beneficial for the fully filled configuration but detrimental in the other filling ratio scenarios.

Fig 3 illustrates the importance of the wound filling ratio and the stiffness of the cavity filler on the volume of mechanically preserved soft tissue. Visually, it is clear that reducing the stiffness of the material at a constant filling ratio was important, despite the relatively minor impact of material properties compared to the filling ratio. The ratio of mechanically preserved soft tissue volume to total soft tissue volume in the ROI was  $0.71 \pm 0.063$  for a 70% filling ratio,  $0.89 \pm 0.03$  for an 85% filling ratio, and  $0.93 \pm 0.018$  for a 100% filling ratio. For comparison, the simulation without any filling (black line on Fig 3) yielded a mechanically preserved soft tissue ratio of 0.33. These findings indicate that increasing the filling ratio markedly improved the proportion of mechanically favourable tissue, with gains exceeding 50% relative to no filling.

Fig 4 illustrates the effect of wound filling ratio on the distribution of maximal shear strains. Wound filling prevents the surrounding soft tissues from collapsing onto themselves under the load of a supine patient positioned over a sacral wound. Consequently, increasing the filling ratio reduces tissue deformation

**Fig 3.** Effect of wound filling ratio (a: 100%; b: 85%; c: 70%) and material properties on mechanically preserved soft tissue volume in the region of interest for volumetric compressibility parameter  $d = 0.007$  MPa and friction coefficient 0.6. Green, yellow and red backgrounds indicate safe, potentially injurious and injurious strain regions, respectively.<sup>9</sup> Material 1—hypothetical very compliant filler with adipose tissue stiffness properties; Material 2—intermediate filler; Material 3—most rigid filler among the fillers tested

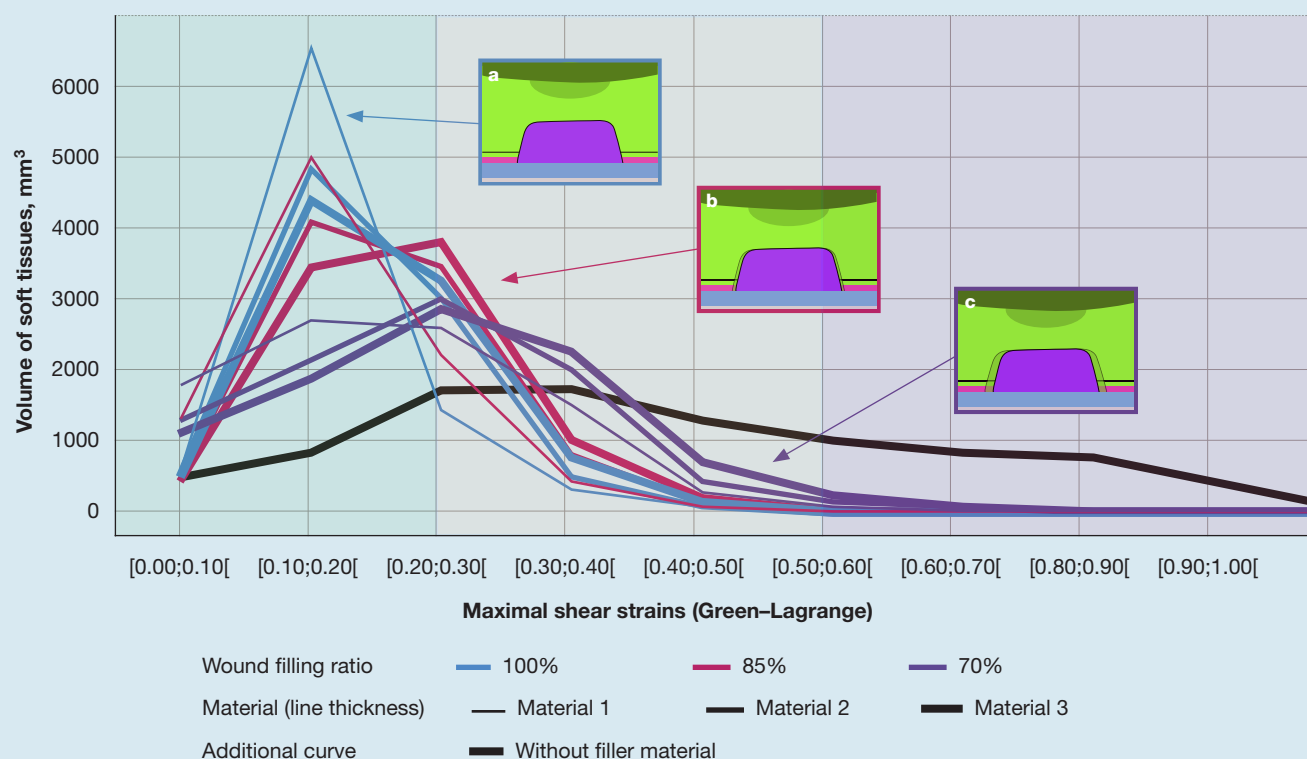


**Fig 4.** Impact of wound filling ratio on maximal shear strain and contact pressure distribution in the region of interest. The potentially damaging Green–Lagrange shear strains are represented in orange–red. The other parameters (coefficient of friction, material properties and wound filler compressibility) are set to their intermediate value

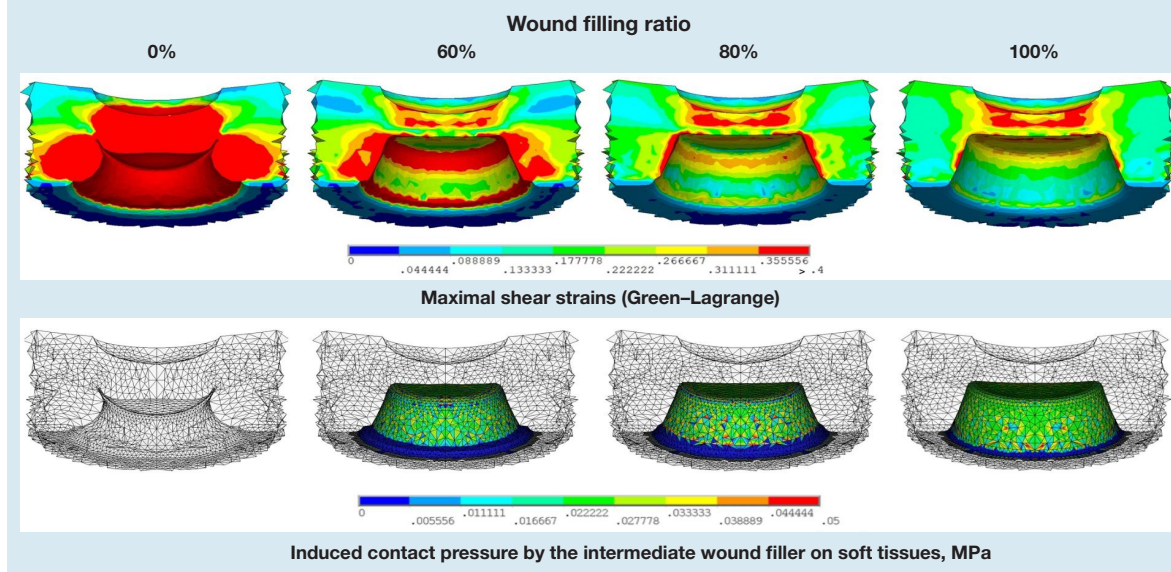
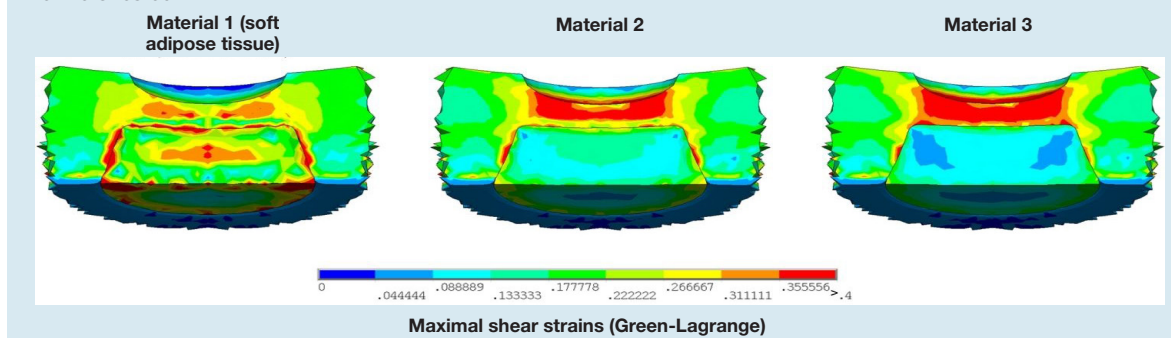


**Fig 5.** Impact of material properties on maximal shear strain distribution in the region of interest. The potentially damaging Green–Lagrange shear strains are represented in orange–red. The other parameters (wound filling ratio, coefficient of friction, wound filler compressibility) are set to their intermediate value. Material 1—hypothetical very compliant filler with adipose tissue stiffness properties; Material 2—intermediate filler; Material 3—most rigid filler among the fillers tested



and leads to lower shear strain levels. Contact pressure distributions at the soft tissue surface further showed that adequate filling improved load redistribution across the wound and reduced local pressure peaks. However, the presence of potentially critical shear strain ( $\epsilon_{\text{shear}} > 0.3$ ) in the completely filled configuration indicated that the filling ratio alone was insufficient to ensure tissue viability under the conditions investigated.

As already demonstrated in Fig 3, the mechanical properties of the wound filler also had a significant influence on the proportion of mechanically preserved soft tissue. Fig 5 shows that more compliant materials accommodated greater deformation, reducing the mechanical load on surrounding soft tissues under vertical loading. Consequently, even at an 85% filling ratio, a filler with adipose-like properties preserved 95% of soft tissue mechanically.

## Discussion

Among the investigated parameters, wound filling ratio had the strongest influence on the periwound mechanical environment. Increasing filling ratio consistently improved tissue mechanical conditions, although filling alone was insufficient to preserve surrounding soft tissues mechanically. Filler stiffness also affected load transfer, with more favourable conditions obtained when the filler response was closer to that of adipose tissue. These results indicate that both adequate cavity filling and mechanical compatibility contribute to protection. The beneficial effect of a high filling ratio may be explained by improved geometric continuity, which promotes greater homogeneous load transfer and reduces local stress and strain concentrations at the wound edge. Conversely, incomplete filling creates structural discontinuities that increase

deformation gradients in periwound tissues. This interpretation agrees with recommendations of the European Pressure Ulcer Advisory Panel, the National Pressure Injury Advisory Panel, and the Pan Pacific Pressure Injury Alliance<sup>1</sup> and the World Union of Wound Healing Societies advocating the elimination of dead space,<sup>1,27</sup> and with the study by Orlov and Gefen<sup>28</sup> showing that reducing stiffness mismatch between dressings and soft tissues improves load redistribution.

The predicted mechanical levels were consistent with the literature. Interfacial pressures ranged from 0–0.04 MPa, which is consistent with a previous report.<sup>14</sup> Green–Lagrange shear strains reported in sacral finite element models range from about 0.2 in low-loading regions to 0.8–1.0 near bony prominences,<sup>29</sup> with similar magnitudes described in studies reporting principal strains.<sup>30–32</sup> The values obtained in this present study (0.15–0.55) were broadly consistent with these previously reported values, although the upper end of the range observed here remains below the highest strains reported near bony prominences.

The influence of friction was more limited and depended on filling configuration. Compressibility showed no measurable effect on the output, despite a 100-fold variation across the studied interval, which is intended to capture hydrated dressing states.<sup>33</sup> However, the present results do not exclude a stronger effect for more compressible fillers.

### Limitations

Several limitations of the present model should be acknowledged. First, the filler was modelled as a homogeneous and isotropic material. This simplification enabled a systematic parametric analysis while avoiding complex contact interactions and numerical artefacts. It was considered appropriate because the study focused on the mechanical response of the surrounding tissues rather than on deformation within the filler microstructure. It may also be viewed as a conservative

approximation with respect to stress transmission to adjacent soft tissues. Second, only the supine position was considered, as this posture corresponds to the condition most frequently maintained by patients at risk of developing such wounds. However, this assumption may lead to an underestimation of frictional effects. Given the potential influence of friction highlighted in this study, future work should investigate additional body positions to more effectively capture the role of interface mechanics under more realistic loading scenarios. Finally, the model was limited to a single wound geometry and did not account for biological processes, such as tissue remodelling or exudate production. In addition, no direct experimental validation of the cavity wound model was performed. The present framework should therefore be interpreted primarily as a comparative and mechanistic tool to assess the relative influence of filler-related parameters, rather than as a patient-specific predictive model.

### Conclusion

The results identified wound filling ratio as the main driver of periwound mechanical conditions in the modelled configuration. However, favourable outcomes also require mechanical compatibility between the filler and surrounding tissue. These findings support the biomechanical importance of dead-space elimination and highlight the potential of highly deformable, tissue-matched wound fillers for deep wound management. Future work should incorporate time-dependent effects, evolving material properties and fluid transport to more accurately represent wound healing conditions as well as experimental validation. **JWC**

### Use of generative artificial intelligence

The first author used ChatGPT (OpenAI) to reduce the word count and improve certain phrasing whilst preserving the original meaning of the text. This tool was used solely for the purposes of linguistic revision and improving readability.

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### Reflective questions

- How should clinicians balance dead-space elimination with the risk of overpacking deep cavity wounds?
- As demonstrated in this study, given the effects of wound filling ratio and the use of materials stiffer than adipose tissue on the viability of surrounding tissues, should absorptive capacity be reconsidered as a secondary property relative to mechanical behaviour? Why?
- How might future wound filler development reconcile the competing demands of mechanical tissue protection and dynamic wound environment variability?

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