Shape memory alloy as an internal splint in a rat model of excisional wound healing

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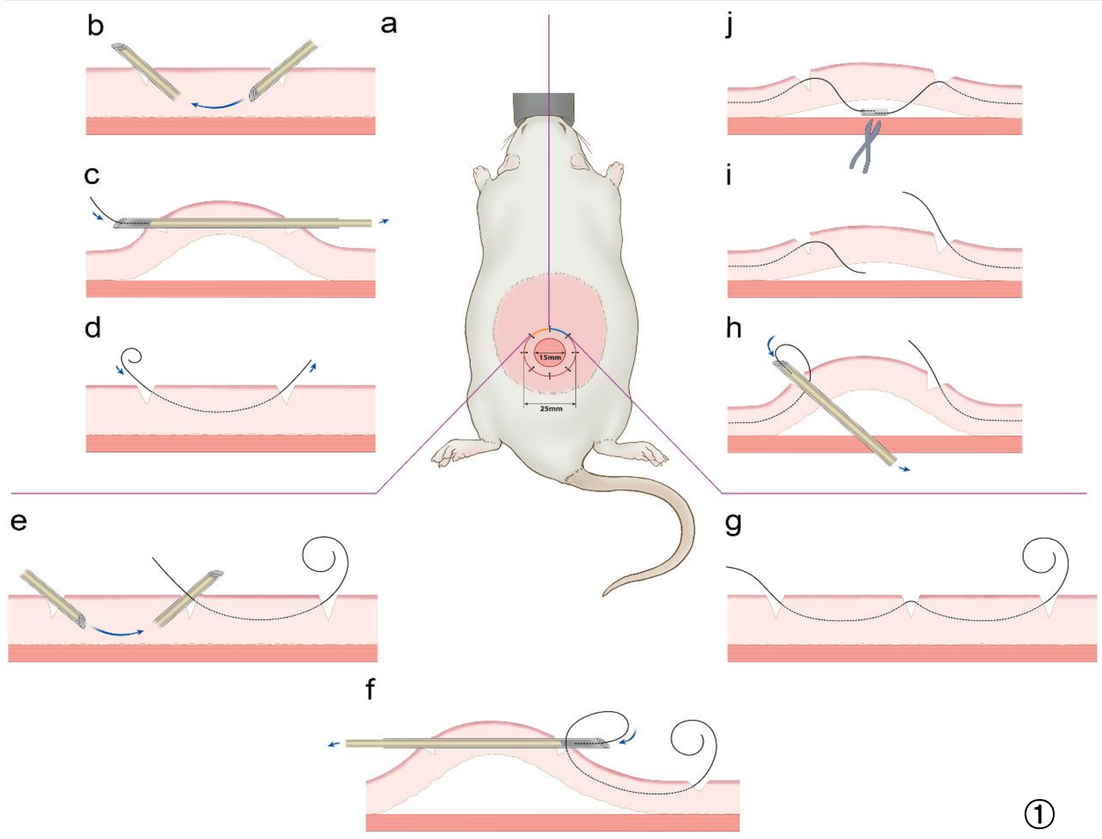
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The purpose of an animal wound model is to replicate the wound healing process of humans as accurately as possible. Although rodents are attractive candidates for animal wound models, the drawback is that their major wound healing occurs by contraction, which is fundamentally different from that seen in humans, where healing is achieved mainly by re-epithelialization and granulation tissue growth.

There has been an attempt to overcome such drawbacks by applying an external splint on wounded mice. This model, however, has a few problems concerning the assimilating ability of external splints with the dynamic soft tissue movements and robustness issues. The authors hereby describe a new animal wound model using an internal splint made of nitinol, one of the shape memory alloys (SMAs).

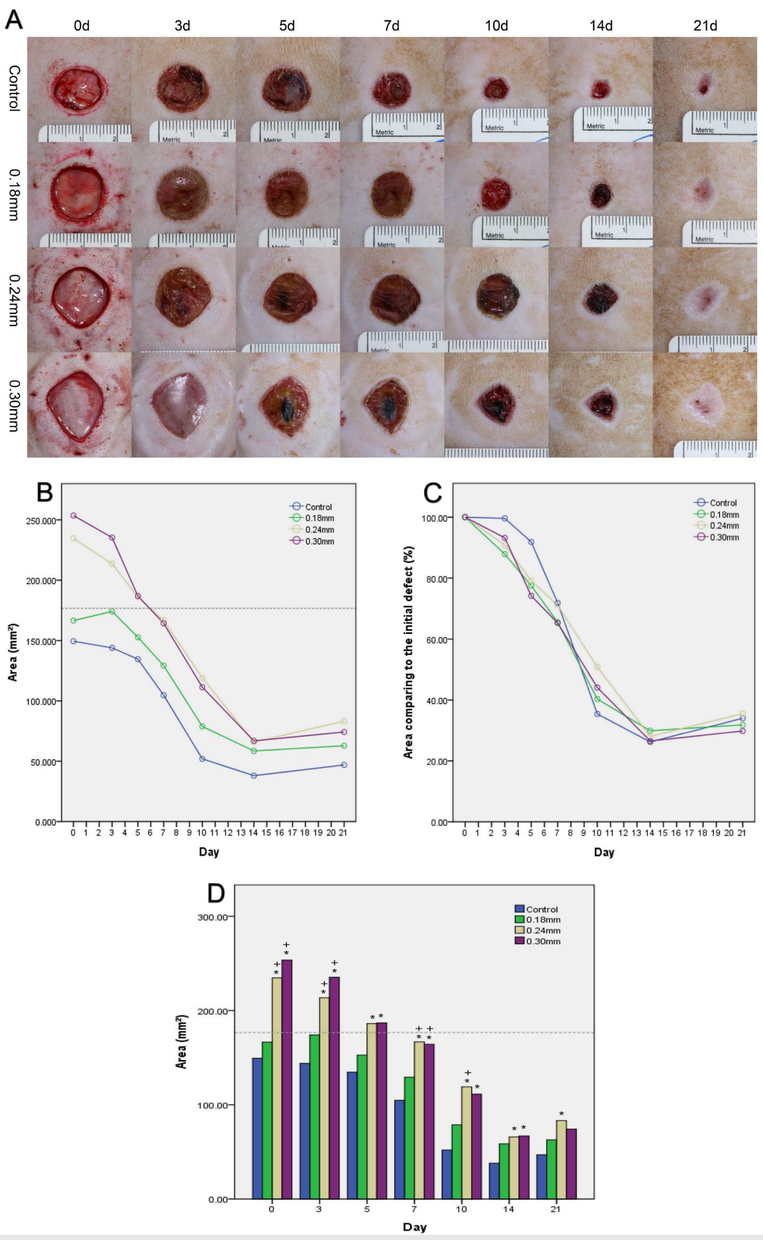
SMA wire was inserted intradermally around the full-thickness excisional wound to act as the internal splint, and its ability to impede wound contraction was analyzed (Fig. 1). In experiment 1, three different sizes of SMAs (0.18 mm, 0.24 mm, and 0.30 mm diameters of thickness) were inserted as the internal splint and their ability to impede the wound contraction was compared. The most effective size of SMA as the internal splint was selected among them (Fig. 2). In experiment 2, contraction of the wound with the selected size of SMA inserted as the internal splint was compared with that of the unsplinted wound.

SMA as an internal splint effectively impeded wound contraction without affecting the re-epithelialization rate, thereby successfully mimicking the human wound healing mechanism (Fig. 3, 4). In this study, the authors introduce a novel animal wound model that replicates the human wound healing mechanism. This model is robust, reliable, and easily reproducible.



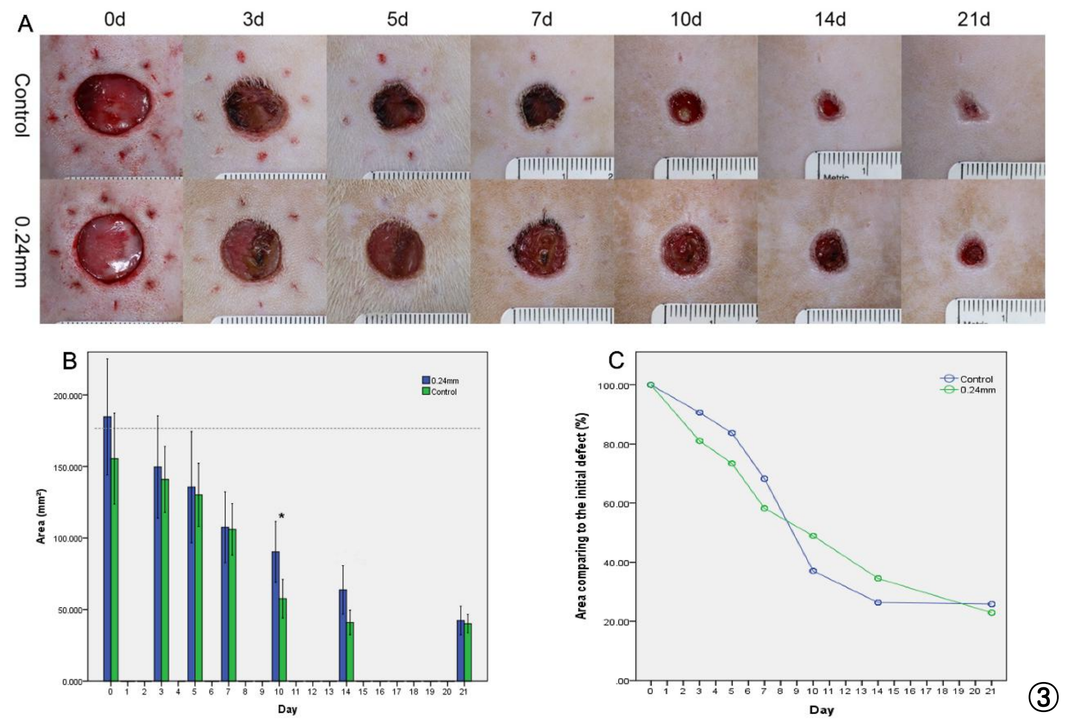
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Fig. 1 Procedures of inserting SMA as an internal splint.



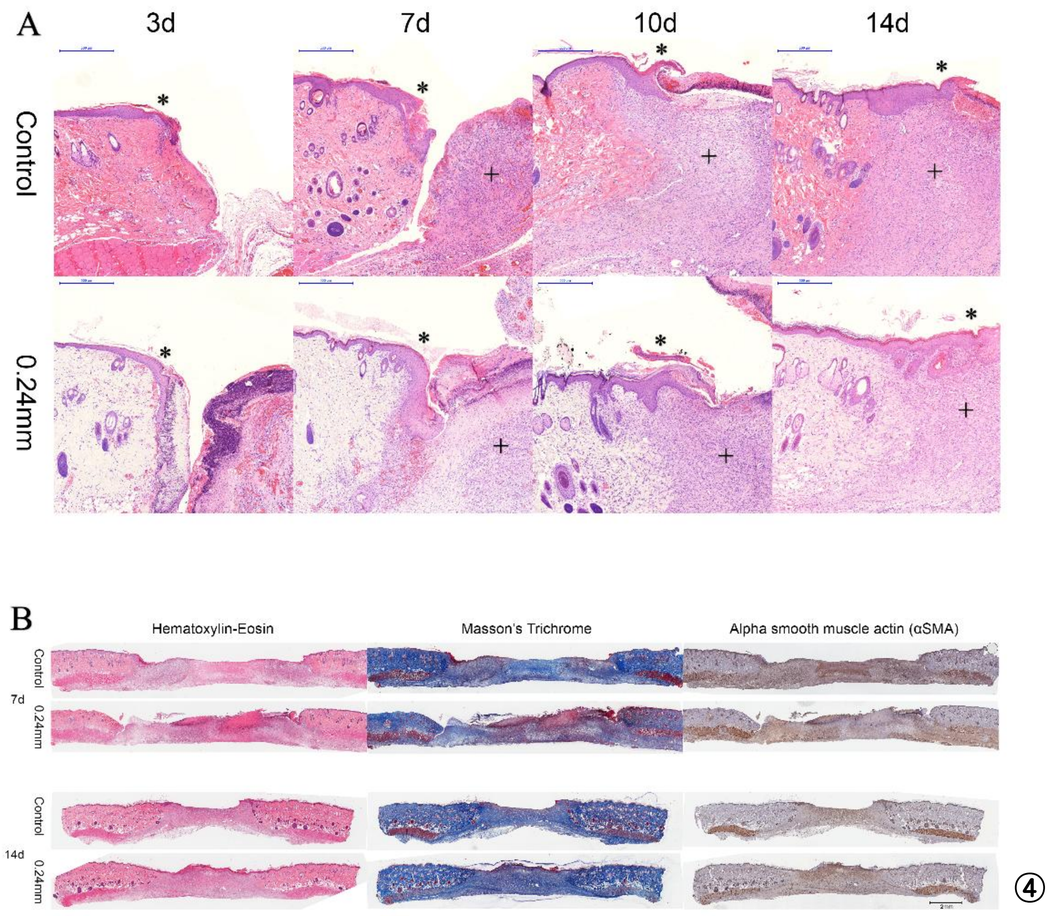
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Fig. 2
(A) Serial view of the wounds with different sized (diameter of thickness) SMA wires splinted intradermally.
(B) The 0.24 and 0.30 mm SMA splints demonstrated superior initial stretching effects compared to the 0.18 mm group. A C-shaped wire with open free ends has limited ability to impede secondary contraction between days 7 and 10.
(C) Wound area at each postoperative day is standardized to the initial wound area.
(D) Statistical analysis confirmed that the 0.24 and 0.30 mm SMA groups significantly maintained larger wound areas compared to both the control and 0.18 mm groups throughout most of the healing process, ultimately selecting the 0.24 mm thickness for its optimal balance of effectiveness and handling efficiency.



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Fig. 3
(A) SMA internal splint model prolonged wound closure time but better preserved the initial round shape compared to the control group.
(B) Serial changes in wound area with the selected SMA (0.24 mm) internal splint model and control group. The dotted line indicates the calculated area of the 15 mm-diameter circle. Slopes of each graph indicate the wound healing rate. The splinted group demonstrates an overall consistent slope, indicating a statistically significant impediment of the secondary contraction between days 7 and 10.
(C) The wound area at each postoperative day is standardized to the initial wound area.



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Fig. 4 Biopsy of the excisional wound margin
(A) On postoperative days 3, 7, 10, and 14 (H&E staining). Comparable re-epithelialization rate and granulation tissue formation are observed between control and splinted groups (scale bar: 500 μm).
(B) On postoperative days 7 and 14.
(1) H&E staining: shows comparable re-epithelialization and granulation tissue formation between control and splinted groups.
(2) Masson's trichrome staining: density of the blue-colored collagen fibers was quantified and compared between control and splinted groups. No significant difference in collagen deposition was observed between the two groups at postoperative days 7 and 14 indicating no difference in the cellular component.
(3) αSMA staining: myofibroblasts and vessel lumens are well observed in both groups (scale bar: 2 mm).
These results demonstrate that the SMA internal splint effectively mimics human wound healing by selectively impeding contraction without negatively affecting the cellular or biological healing process.