Short-term bioabsorbable materials are more effective tissue reinforcements

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Abstract

Purpose: Bioabsorbable tissue reinforcement materials are used to reinforce anastomoses; however, the optimal period for their in vivo absorption remains unclear. This study compared the effectiveness of short- and medium-term absorbable materials as anastomotic reinforcements.
Methods: After incising two-thirds of the small intestine of crossbred pigs (15-25 kg, n=10), four-stitch sutures were made in three places, spaced approximately 50 cm apart. The anastomoses were divided into three groups: the untreated (no treatment at the anastomotic site), medium-term (anastomosis covered with polyglycolic acid [PGA] nonwoven fabric, Neoveil®, with a bioabsorption period of approximately 15 weeks), and short-term (anastomosis covered with 50:50 copolymer of lactic acid and caprolactone , reinforced with PGA fibers, with a bioabsorption period of 6-8 weeks) groups. The anastomoses were removed after 1 and 3 weeks (n=5 in each week) and their tensile strengths were measured using a manometer. The connective tissue thickness at the anastomosis was measured by Elastica van Gieson staining of the resected tissue specimens.
Results: All pigs survived until planned sacrifice, and no anastomotic leakage was observed in the small intestine anastomosis. One week after suturing the anastomosis, the tensile strength and thickness of the connective tissue were the highest in the short-term group, followed by the medium-term group, and the lowest in the untreated group. The short-term group had the strongest tensile strength and thickest connective tissue at the anastomosis. Three weeks after suturing the anastomosis, the tensile strength was equivalent in the short- and medium-term groups, whereas the untreated group had a weaker strength. The thickness of the connective tissue was the highest in the short-term group, followed by the medium-term group, and the lowest in the untreated group.
Conclusion: These results suggest that materials with shorter bioabsorption periods can provide a higher degree of early tissue reinforcement for gastrointestinal anastomoses.

Background
(Short-term reinforcement)

Anastomotic leakage remains a major source of postoperative morbidity and mortality in gastrointestinal surgery . Despite advances in operative technique, stapling technology, suture materials, and perioperative management, the incidence of anastomotic failure has not been eliminated. The introduction of surgical staplers revolutionized anastomotic construction, improving technical consistency and reducing variability in outcomes . Subsequent development of staplers equipped with absorbable reinforcement materials further decreased leakage rates in selected procedures [5, 6]. Nevertheless, anastomotic failure has not been eradicated, and clinically significant leakage continues to occur across gastrointestinal operations.
Early mechanical failure during the first postoperative week remains a critical concern , as tissue integrity is not yet fully restored and the anastomosis depends largely on immediate mechanical support . The biological process of anastomotic healing involves a sequential inflammatory phase, collagen deposition, angiogenesis, and remodeling . During the early inflammatory phase, collagen degradation may temporarily exceed synthesis, resulting in reduced mechanical strength . This transient vulnerability has motivated the development of reinforcement strategies aimed at augmenting early stability, particularly in stapled anastomoses where load distribution is concentrated along the staple line.

Background
(Short-term reinforcement)

- Bioabsorbable buttressing materials compatible with surgical staplers are now widely used to enhance mechanical support. However, most commercially available reinforcements degrade relatively slowly, often persisting for 3–6 months. Whether such prolonged material presence appropriately matches the physiological timeline of tissue healing remains uncertain. Materials that persist longer than necessary may interfere with tissue remodeling, increase stiffness during stapling, or provoke sustained foreign-body reactions, including chronic inflammation or delayed integration. These considerations suggest that further optimization of reinforcement design may contribute to improved surgical outcomes.

Objective
(Short-term reinforcement)

The present study was designed to compare short-term and medium-term bioabsorbable reinforcement materials in a controlled porcine small bowel model, with specific focus on early mechanical strength and tissue response. By directly evaluating degradation-matched reinforcement strategies, we sought to determine whether temporally optimized materials could provide superior early stabilization and thereby offer a pathway toward improved anastomotic outcomes.

Materials and Methods
(Short-term reinforcement)

Study Design and Ethical Approval
This controlled experimental study was conducted in accordance with the National Institutes of Health (NIH) guidelines and the ARRIVE guidelines for the care and use of laboratory animals. All procedures were reviewed and approved by the Animal Care and Use Committee of Saitama Medical University (approval number to be inserted). The study design was structured to comply with the 3Rs principles (Replacement, Reduction, and Refinement). To minimize animal use, multiple anastomoses were created within each animal, allowing each pig to serve as its own internal control. Ten healthy mongrel pigs weighing 15–30 kg were included. Animals were fasted for 12 hours prior to surgery with free access to water. They were randomly allocated to two predetermined sacrifice time points at 1 week (n = 5) and 3 weeks (n = 5) after surgery.
Reinforcement Materials
The short-term reinforcement material consisted of a 50:50 copolymer of lactic acid and caprolactone reinforced with polyglycolic acid (PGA) fibers . The material was engineered to achieve complete in vivo degradation within approximately 6–8 weeks. It formed an approximately 1-mm-thick flexible sheet with greater than 95% porosity, allowing tissue ingrowth while maintaining mechanical flexibility. The embedded PGA fibers provided additional tensile strength during suturing and early postoperative healing (Fig. 1a-c). The medium-term comparator was Neoveil® (Gunze Ltd., Kyoto, Japan), a commercially available nonwoven PGA fabric approximately 0.5 mm in thickness with an in vivo degradation period of approximately 15 weeks (Fig. 1d). This material has been widely used as a bioabsorbable reinforcement scaffold in surgical applications.

Materials and Methods
(Short-term reinforcement)

Animal Model and Surgical Procedure
All procedures were performed under general anesthesia. Anesthesia was induced with intramuscular ketamine (20 mg/kg) followed by intravenous propofol (1 mg/kg). After endotracheal intubation, animals were mechanically ventilated. Anesthesia was maintained with continuous intravenous propofol at 4 mg/kg/h. Standard intraoperative monitoring included heart rate, oxygen saturation, and respiratory parameters. A midline laparotomy was performed under sterile conditions to expose the small intestine. Three separate jejunal segments were identified at standardized intervals to ensure sufficient spatial separation between anastomoses and to minimize mechanical interaction during healing. Each selected segment was transected and reconstructed with a hand-sewn, end-to-end anastomosis using interrupted 4-0 polydioxanone (PDS) sutures. Within each animal, three experimental conditions were created. One anastomosis was constructed without reinforcement and served as the control. A second anastomosis was reinforced circumferentially with the short-term bioabsorbable sheet. The third was reinforced with the medium-term PGA sheet. Reinforcement materials were wrapped around the anastomotic circumference and secured with additional interrupted 4-0 PDS sutures as required to ensure stable fixation without luminal narrowing (Fig. 2). The order and anatomical location of the three conditions were standardized to minimize bias. After thorough irrigation and confirmation of hemostasis, the abdominal wall was closed in layers. Postoperative analgesia and supportive care were provided according to institutional protocols. Animals were euthanized at either 1 week or 3 weeks postoperatively under deep anesthesia. The abdominal cavity was reopened, and bowel segments containing each anastomosis were carefully harvested for mechanical and histological analysis.

Bursting Pressure Measurement
Resected bowel segments were gently cleared of surrounding adhesions while preserving the anastomotic region. One end of each specimen was securely ligated, and the opposite end was connected to a digital manometer system (AS ONE M-382) [18]. Air was insufflated at a constant rate until rupture occurred. The maximum intraluminal pressure at the moment of rupture was recorded as the bursting pressure (mmHg) (Fig. 3). The rupture site was documented as occurring either at the anastomotic line or away from the anastomosis. When measured pressures exceeded the upper limit of the manometer, the value was recorded as 200 mmHg for statistical purposes.
Histological Evaluation
Following mechanical testing, representative tissue samples were fixed in 10% buffered formalin, embedded in paraffin, and sectioned at 4 µm thickness. Sections were stained with Elastica van Gieson (EVG) to evaluate general tissue architecture and collagen deposition. Subanastomotic connective tissue thickness was measured at predefined standardized points using digital microscopy (Fig. 4). Measurements were performed by investigators blinded to group allocation to minimize observational bias. For each specimen, multiple measurements were obtained and averaged to provide a representative value.

Materials and Methods
(Short-term reinforcement)

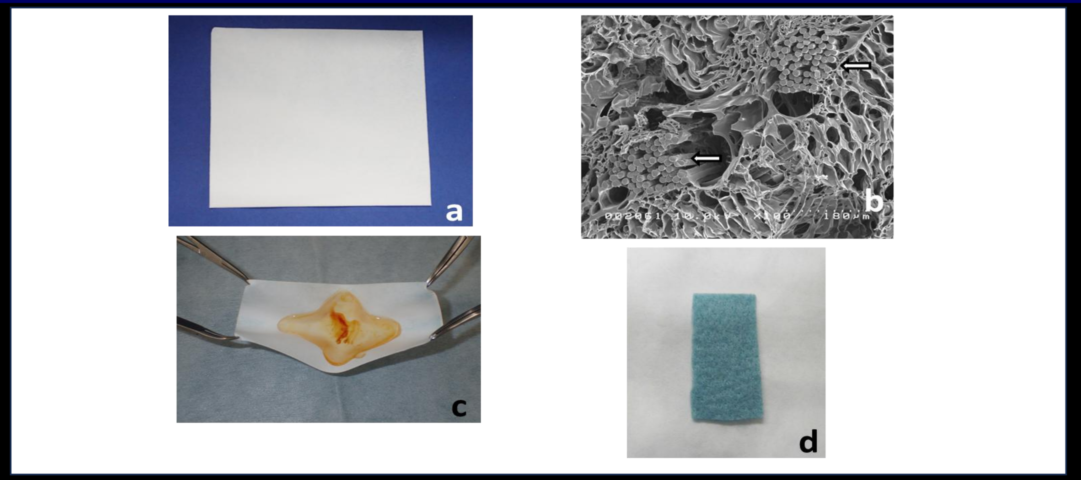


Fig. 1 Characteristics of Short-Term and Medium-Term Bioabsorbable Reinforcement Materials
Short-term reinforcement material:
(a) Bioabsorbable sheet composed of a 50:50 copolymer of lactic acid and caprolactone reinforced with polyglycolic acid (PGA) fibers, designed for complete in vivo absorption within approximately 6–8 weeks.
(b) Scanning electron microscopy demonstrating a lattice arrangement of PGA fibers (arrows), contributing to enhanced tear resistance.
(c) The material exhibits low fluid permeability.
Medium-term reinforcement material:

Materials and Methods
(Short-term reinforcement)

Fig. 2 Surgical Creation of Intestinal Anastomoses
(a) Approximately two-thirds of the small intestine was transected and reconstructed at three sites (~50 cm apart) in each animal using four interrupted 4-0 polydioxanone sutures.
(b) In the short-term and medium-term groups, reinforcement sheets were circumferentially secured over the anastomotic site using 4-0 polydioxanone sutures. No reinforcement was applied in the control group (arrow).

Materials and Methods
(Short-term reinforcement)

Fig. 3 Measurement of Anastomotic Bursting Pressure
At 1 and 3 weeks postoperatively, excised intestinal segments were ligated at both ends. A catheter was inserted into the distal lumen and connected to a digital manometer. Air was insufflated at a constant rate until rupture occurred. The maximum recorded pressure was defined as the intraluminal bursting pressure. Values exceeding the measurement limit were recorded as 200 mmHg for statistical analysis.

Materials and Methods
(Short-term reinforcement)

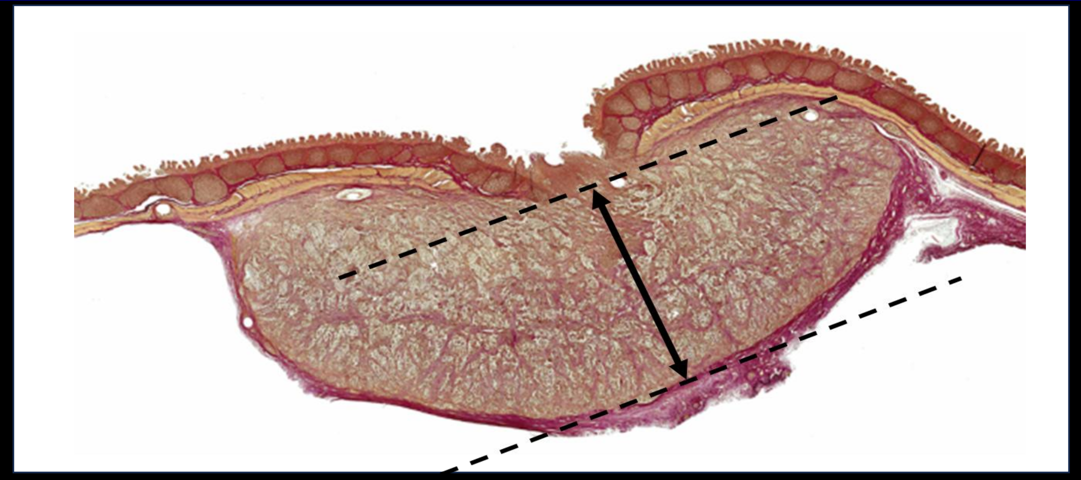


Fig. 4 Histologic Measurement of Subanastomotic Connective Tissue Thickness
Elastica van Gieson staining was performed on sections oriented perpendicular to the anastomotic line. The maximum thickness of subanastomotic connective tissue was measured microscopically (double-headed arrows).

Results
(Short-term reinforcement)

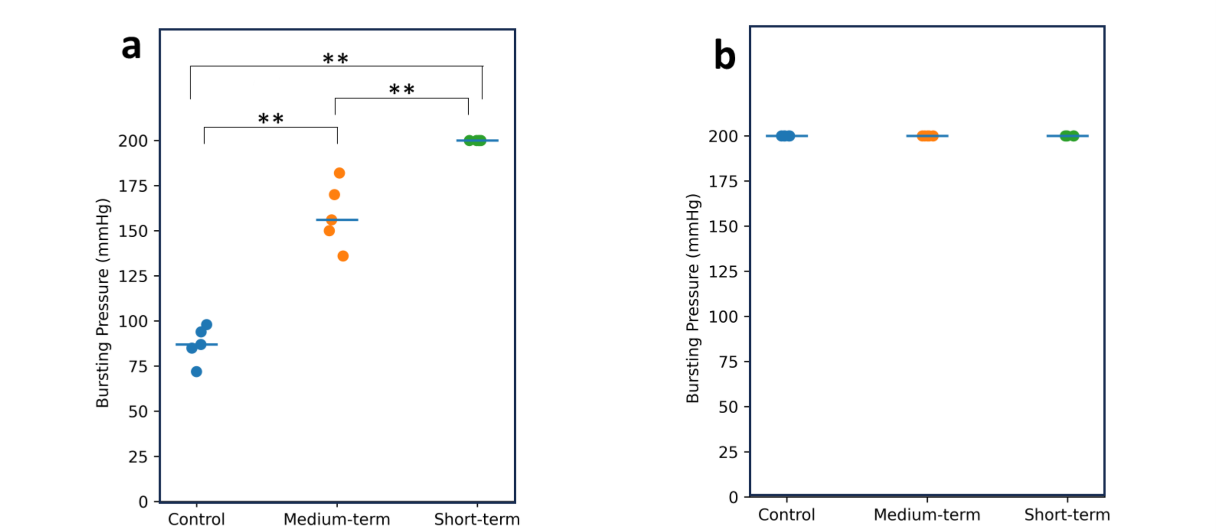
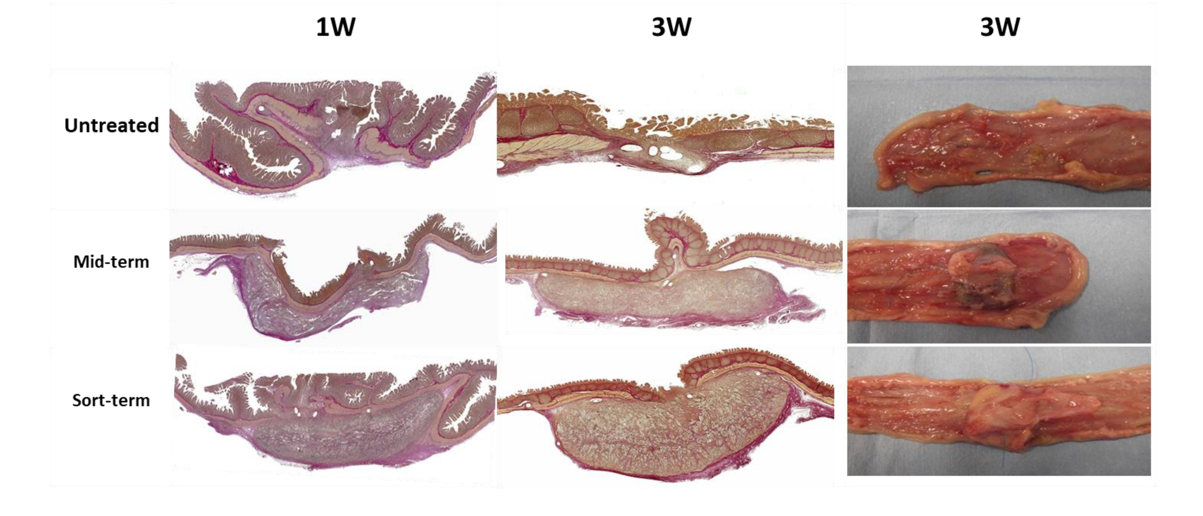


Fig. 5 Individual Bursting Pressure Values at 1 and 3 Weeks
(a) One week postoperatively (n = 5 per group). Scatter plot of individual bursting pressure measurements. Horizontal bars indicate median values. A significant overall difference among groups was observed (Kruskal–Wallis test, $p < 0.001$). Post hoc analysis demonstrated that both reinforcement groups had significantly higher bursting pressures than controls, and the short-term group showed significantly higher values than the medium-term group ($p < 0.01$).
(b) Three weeks postoperatively (n = 5 per group). All specimens exceeded the upper measurement limit of the manometer (>200 mmHg), resulting in a ceiling effect that precluded statistical comparison of absolute pressure values. Despite similar recorded pressures, rupture location differed significantly among groups (Fisher's exact test, $p < 0.01$).
**$p < 0.01$.

Results
(Short-term reinforcement)



Untreated:Group without reinforcement applied to anastomosis
Short-Term : Group with short-term bioabsorbable reinforcement material wrapped around the anastomosis
Mid-term: Group with mid-term bioabsorbable reinforcement material wrapped around the anastomosis
1W:One week after suturing the anastomosis
3W:Three weeks after suturing the anastomosis

Fig. 6 Representative Macroscopic and Histologic Findings
Left column (1 week): Representative histologic sections demonstrating differences in subanastomotic connective tissue thickness among groups.
Middle column (3 weeks): Progressive connective tissue maturation observed in all groups.
Right column (3 weeks): Macroscopic findings demonstrating moderate, easily separable adhesions across conditions.

Results
(Short-term reinforcement)

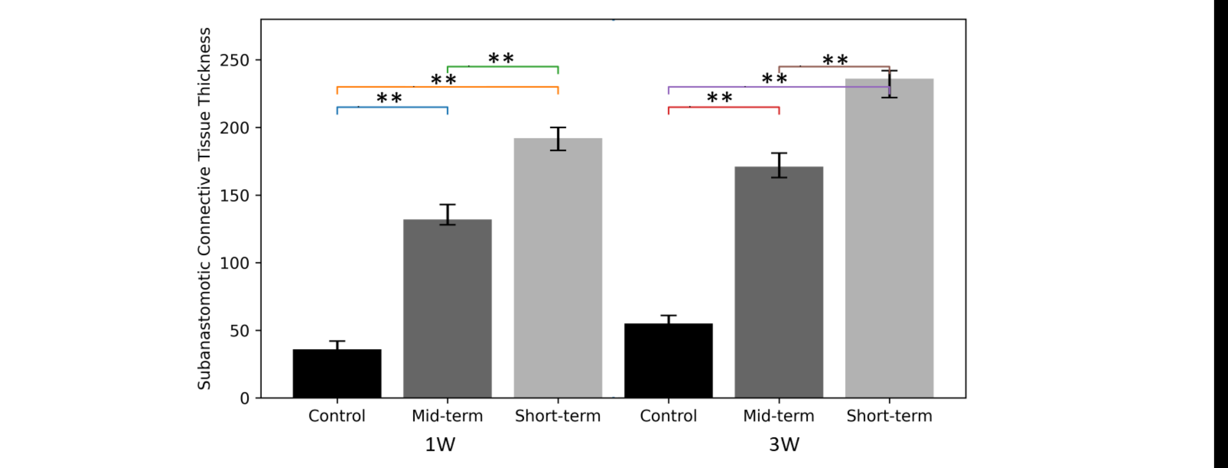


Fig. 7 Quantitative Comparison of Subanastomotic Connective Tissue Thickness
Bar graph illustrating subanastomotic connective tissue thickness in the control, medium-term, and short-term groups at 1 and 3 weeks postoperatively. Data are presented as median and interquartile range. At 1 week, reinforced groups demonstrated significantly greater connective tissue thickness compared with controls. By 3 weeks, connective tissue thickness increased across all groups, consistent with progressive remodeling; however, reinforced segments maintained greater structural organization. Statistical comparisons were performed using the Kruskal–Wallis test followed by Dunn's post hoc analysis. **$p < 0.01$.

Conclusion and Discussion
(Treatments for Benign Bile Duct Injuries)

- Short-term bioabsorbable reinforcement produced a marked enhancement of early mechanical strength during the critical first postoperative week and promoted restoration of structural competence at the anastomotic interface. By concentrating mechanical support within the period of greatest intrinsic vulnerability, short-term materials may more effectively reduce the risk of postoperative anastomotic leakage compared with longer-persisting scaffolds. These findings suggest that optimization of degradation kinetics represents a rational strategy to improve anastomotic reliability and potentially enhance overall surgical outcomes.

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Disclosure
First Author: Mitsuo Miyazawa MD, PhD, FACS

There are no conflicts of interest to disclose.