Management of Surgical Incisions Using Incisional Negative-Pressure Therapy

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Summary: Use of negative-pressure therapy (NPT) is a well-established therapy for chronic, open, contaminated wounds, promoting formation of granulation tissue and healing. The application of NPT after primary closure (ie, incisional NPT) has also been shown to reduce surgical site infection and surgical site occurrence in high-risk procedures across multiple disciplines. Incisional NPT is believed to decrease edema and shear stress, promote angiogenesis and lymphatic drainage, and increase vascular flow and scar formation. Incisional NPT may be considered when there is a high risk of surgical site occurrence or surgical site infection, particularly in procedures with nonautologous implants, such as hernia mesh or other permanent prosthetics. Here we discuss the proposed physiologic mechanism as demonstrated in animal models and review clinical outcomes across multiple specialties. (*Plast. Reconstr. Surg.* 143: 15S, 2019.)

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The economic and human impact of surgical site infection (SSI) and surgical site occurrence (SSO) is well established. SSIs account for the highest proportion of hospital-acquired infections, doubling length of stay and increasing readmission rates.[1–5] An SSI costs approximately $20,000 per patient, with a loss in profit of $2.2 million annually per hospital, and costs US healthcare $1.6–3.6 billion annually.[1,2,4] Complexity, contamination, or patient comorbidities increase risk of SSI or SSO.[5] SSIs occur in up to 16% of sternotomies, 19% of revisional joint operations, 29% of open colorectal procedures, and 30% of vascular groin procedures.[6–9] SSOs develop in 29%–66% of abdominal wall reconstruction cases.[10–12] National guidelines and implementation of the Surgical Care Improvement Protocol sought to decrease the incidence of SSI.[13,14] However, these protocols do not address incisional care, leaving a compelling target for high-risk patients and procedures.

Surgical incisions are traditionally dressed in dry sterile gauze to wick exudate and provide a mechanical barrier to contaminants. Saturation of such dressings promotes tissue breakdown, biofilm formation, and subsequent bacterial colonization and infection.[15,16] Ideal surgical dressings would control moisture and mechanically shield from environmental contamination.[16]

Negative-pressure therapy (NPT) was first developed to promote healthy granulation tissue in chronic and contaminated open wounds.[17] Incisional NPT (iNPT) has since been adopted as a dressing after primary wound closure. This article will discuss the proposed physiologic mechanism, review published clinical outcomes, and suggest clinical applications of iNPT. All cited values have $P < 0.0.5$ unless otherwise stated. For methods regarding literature review, please **see Document, Supplemental Digital Content 1**, which shows the methods and literature review, ***http://links.lww.com/PRS/D186***; **Table, Supplemental Digital Content 2**, which shows the clinical trials, ***http://links.lww.com/PRS/D187***; **Table, Supplemental Digital Content 3**, which shows the preclinical studies, ***http://links.lww.com/PRS/D188***; and **Table,**

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Supplemental Digital Content 4, which shows the meta-analyses, literature reviews, and cost analyses, ***http://links.lww.com/PRS/D189***.

BASICS OF INPT

History

The application of NPT to open surgical wounds was first described in 1997 in a porcine model with full thickness wounds,[17] and a large series of 300 open wounds described decreased edema and induration, improved granulation tissue, and successful flap or skin graft closure.[18] Multiple subsequent clinical trials established the utility of NPT for open and/or contaminated wounds.

With NPT well established, Stannard et al[19] published 2 prospective randomized trials in 2006 on prophylactic iNPT after primary closure of high-risk orthopedic procedures. First, iNPT shortened drainage time with no difference in wound dehiscence or infection. Then, iNPT decreased SSI from 28% to 5% when applied to high-energy open fractures.[20] As described below, multiple studies have since examined the laboratory parameters, clinical outcomes, and cost-efficacy of iNPT.

NPT Systems

Most NPT systems have 4 components:

1. Foam sponge cut to the size of the open wound
2. Nonpermeable adhesive drape covering the sponge and surrounding skin
3. Noncollapsible tube attached through the adhesive drape to the sponge
4. Vacuum pump generating pressure between −50 and −200 mm Hg

Modification of this system for iNPT adds a permeable barrier between the foam sponge and a closed incision, protecting the skin from irritation by direct contact with the sponge. A narrow strip of sponge is placed on the permeable barrier, along the surgical incision. The rest of the system is applied as above (Figs. 1–3).

Mechanism of Action and Laboratory Studies

Laboratory and clinical studies have investigated NPT mechanisms of action in porcine models in open wounds. Explicit mechanisms have not been studied in humans. NPT is hypothesized to improve angiogenesis, local vascular flow and lymphatic drainage, to contract wound edges, and to reduce lateral stress. This is associated with decreased bacterial contamination and SSI,[6,15,17] promotion of stronger scar formation,[21,22] and shortened healing time.[19,23]

On an open wound, NPT decreases microvascular flow 0.5 cm from the wound edge and increases flow at 2.5 cm.[24–27] Wound edges show hypoxia when under wet-to-dry or NPT dressings, but angiogenesis at a NPT-treated wound edge shows more organized and functional

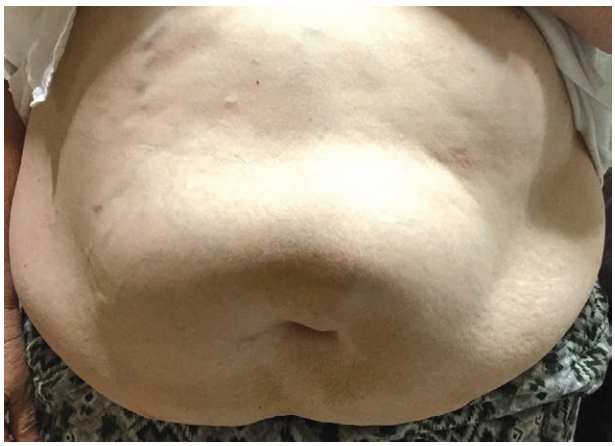

Fig. 1. Patient with large, symptomatic ventral incisional hernia and loss of domain, presenting for repair after 30 lbs weight loss.

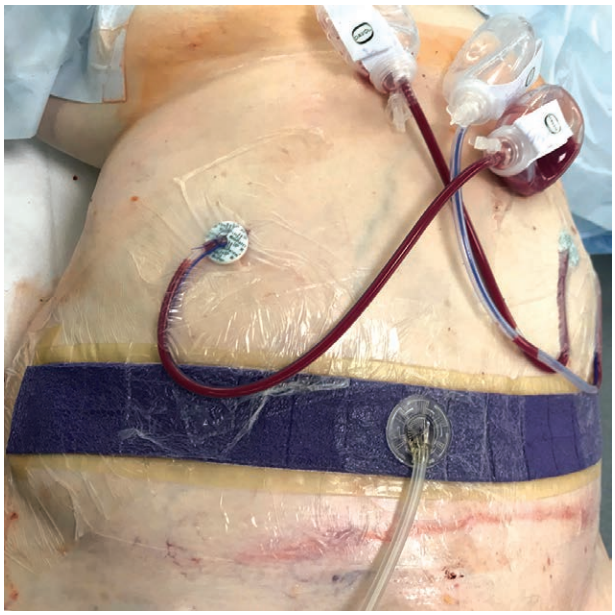

Fig. 2. Immediately after abdominal wall reconstruction with panniculectomy, component separation, preperitoneal mesh placement. Postoperative application of incisional negative-pressure wound therapy. Patient also has two 19-French closed suction drains: 1 between fascia and mesh and 1 in the subcutaneous space.

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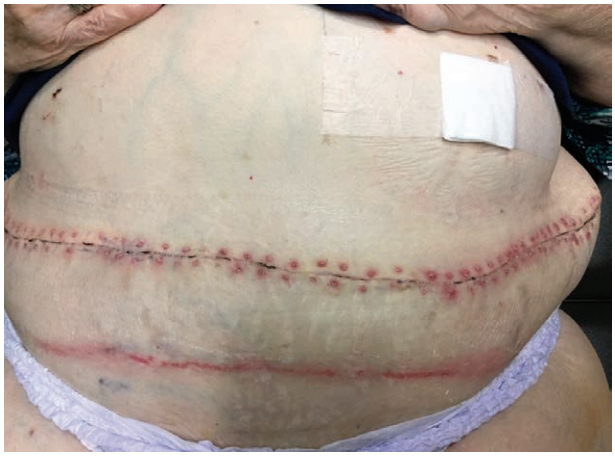

Fig. 3. Fourteen days postoperatively, after staple removal.

angiogenesis.[26,28] The impact of NPT on blood flow and angiogenesis when applied to closed wounds has not been as thoroughly investigated. However, increased perfusion with iNPT has been demonstrated in using indocyanine green fluorescence angiography when applied after complex abdominal wall reconstruction.[29]

iNPT is believed to improve lymphatic drainage, as demonstrated by improved clearance of nanosphere markers to lymph nodes in pigs after creation of subcutaneous flaps with primary closure.[30] Lymphatic drainage causes decreased edema and seroma formation, improved clearance of infectious agents, and better healing. Indeed, ultrasound revealed decreased hematoma and seroma formation associated with iNPT in this model.[30] Compared to dry sterile dressing, use of iNPT was also associated with decreased inflammatory markers.[22]

Finally, the application of iNPT is believed to alleviate lateral wound tension. Wilkes et al[31] described decrease of lateral forces and alignment of wound edges using 2-dimensional and 3-dimensional modeling, and iNPT resulted in a 43%–51% increase in distraction forces required to stretch the tissue 10 mm across an incision in a silicone model.[31,32] Healed incisions treated with iNPT in a porcine model are stronger under mechanical strain and show narrower scars on histologic examination.[21,22] This has not been studied in humans.

CLINICAL TRIALS OF INPT

Efficacy of iNPT has been demonstrated in multiple high-risk procedures including vascular, cardiothoracic, obstetric, general, colorectal, plastic, and orthopedic surgery. Patients undergoing abdominal wall reconstruction with components separation and panniculectomy had lower SSO with iNPT (22% versus 63%) and reduced skin dehiscence (9% versus 39%).[33] One study suggests lower recurrence rate at 14 months follow-up (3% versus 25%),[34] whereas others show decreases in wound complication and dehiscence.[35,36] Results vary, as Pauli et al[37] did not find a significant difference in infection when iNPT was applied in patients undergoing contaminated open ventral hernia repair.

Application of iNPT decreases SSO and SSI in high-risk abdominal procedures. Blackham et al[38] described decreased incidence of SSI (26.4% versus 16.3%) and skin dehiscence (27.6% versus 16.3%) after laparotomy when compared with lower risk patients without iNPT. Other studies have shown iNPT associated with significantly lower SSO (12.5% versus 29.3%), after open colorectal procedures, lower-than-expected incidence of SSI in comorbid patients after laparotomy for gynecologic malignancy, and decreased postoperative length of stay after laparotomy (6.1 versus 14.7 days).[8,39–41] After abdominoperineal resection, perineal placement of iNPT decreased SSI [odds ratio (OR), 0.11] but increased length of stay (11 versus 8 days).[42] In pancreaticoduodenectomy, use of iNPT halved postoperative SSIs (OR, 0.45).[43]

Mastectomy and breast reconstruction may benefit from iNPT, with decreases in SSO and flap necrosis demonstrated.[41,44] Galiano et al[45] applied iNPT and gauze dressing to contralateral breasts after reduction mammoplasty and demonstrated decreased rates of "healing complications" (56.8 versus 61.8%) and dehiscence (16.2 versus 24.6%) with iNPT-treated breasts.

Multiple poststernotomy studies have demonstrated decreased SSI and improved skin perfusion in this high-risk population.[46–50] In prospectively randomized high-risk sternotomy patients, the iNPT group showed a lower SSI rate (4% versus 16%) and fewer bacteria on wound swab (1 versus 10 Gram-positive cultures).[6] In vascular groin incisions, iNPT is associated with significantly lower SSI (6% versus 30%), despite more surgically complex patients, and similar findings have been noted in other high-risk vascular patients.[9,51]

Ultrasound examination has shown decreased size and incidence of postoperative seroma with iNPT after orthopedic surgery (18% versus 80% after hemiarthroplasty and 40% versus 90% after total hip arthroplasty).[52,53] Similar findings have been demonstrated after neurosurgical intervention.[54,55] iNPT decreased duration of drainage and

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need for surgical intervention after hip arthroplasty, implying an association of seromas with decreased wound healing.[19,56] After inguinal lymphadenectomy, Tauber et al[57] demonstrated an association of iNPT with multiple endpoints, including lymphoceles (20% versus 62%), lymphorrhoea (7% versus 45%), lymphedema (0 versus 46%), and reintervention (7 versus 23%).

META-ANALYSIS OF INPT

Multiple meta-analyses have examined the impact of iNPT after various surgical interventions. A meta-analysis of 5 ventral hernia repair studies showed that iNPT significantly decreased SSI (11.8% versus 27.0%), wound dehiscence (4.3% versus 19.7%), and hernia recurrence (2.4% versus 10.1%).[58] In a meta-analysis of 14 publications on abdominal, groin, extremity, and chest/back procedures, the incidence of SSI was lower in all subgroups when iNPT was used (6.6% versus 9.4%; OR, 0.44; 95% CI, 0.32–0.59).[59] Another review of 21 studies showed benefit of iNPT, but not in all procedures.[60] Finally, a product-specific meta-analysis of 16 publications did show an absolute reduction of SSI from 9.7% to 4.8% across multiple procedure types.[61]

These analyses demonstrate iNPT decreasing complications after multiple high-risk procedures. Analysis is limited by variable complication rates of specific procedures, and variable indication, duration, and pressure settings of the applied therapy.

CLINICAL APPLICATION OF INPT

iNPT costs more than standard gauze dressings, with estimates ranging from $200 to $500 per patient. Cost-utility analyses have found iNPT to be cost-effective after procedures with high infection rate. Chopra et al[62] described savings of $1,546 per patient after abdominal procedures with a SSI risk greater than 16%. Similar cost-effectiveness has been demonstrated in obese patients undergoing cesarean section, particularly if iNPT would decrease SSI by at least 30%.[63,64]

Current literature does not specify the ideal pressure setting and duration of iNPT as specific to procedure and wound type. The definition of "high risk" varies by specialty, procedure, and publication. Dressing components and pressure settings vary, with therapy lasting from 2 to 7 days and pressure ranging from −75 to −125 mm Hg.[24,25,27] Cost analyses of iNPT have not accounted for associated home health cost, time, and mobility burden imposed on the patient. Finally, the devastating long-term implications of an infected nonautologous implant such as an orthopedic joint, hernia mesh, or vascular graft are not quantified.

The application of iNPT is most appropriate for patients in whom postoperative complications have significant consequences. The 2017 International Multidisciplinary Consensus Recommendations recommend consideration of iNPT in patients at high risk for SSI and SSO as defined by patient (diabetes, age, and obesity), incision (tension, undermining, and contamination), and surgical factors (vascular and cardiovascular).[65] Careful risk stratification and randomized studies will help further elucidate value and set guidelines for incisional management.

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