ACUTE WOUND FAILURE

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A general surgeon closes thousands of abdominal incisions during a typical career, and most surgeons do this quite well. It would be presumptuous to say that this article delineates the technique of wound creation and closure that all surgeons should adopt to minimize acute wound failure. The search for the optimal laparotomy technique has gone on for more than 100 years and will continue. Contained here is a review of what has been studied and what is believed to be true regarding acute wound failure; an opinion is given on which methods currently seem best to avoid and manage this problem.

DEFINITION

Acute wound failure (also known as wound dehiscence, wound disruption, burst abdomen, evisceration, and eventration) is defined as postoperative separation of the abdominal musculoaponeurotic layers, which is recognized within several days and requires some form of intervention, usually during the same hospitalization.

INCIDENCE

The sad commentary on its [wound dehiscence] present status is the fact that the literature continues to report its incidence relatively unchanged.

—J. D. NORRIS, 1939

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The incidence of wound disruption in 12 studies before 1940 (including more than 71,000 incisions) is 0.4% (range 0.24% to 3.0%). An incidence of 0.59% (range 0.24% to 5.8%) was calculated from 34 studies of dehiscence published between 1950 and 1984, including 320,000 incisions. The author noted that the incidence of dehiscence reported in prospective studies (1% to 3%) tended to be higher than that reported in retrospective reviews. Wound disruption data published after 1985 are given in Table 1. The incidence of dehiscence in 18,133 incisions is 1.2%, which does not demonstrate a downward trend from the earlier reviews.

**DIAGNOSIS**

Wound disruption may occur without warning; the diagnosis may be obvious if evisceration is present. Patients often note a "ripping sensation" or a feeling that "something has given way." Drainage of serosanguinous fluid from the incision precedes dehiscence in 23% to 84% of cases. The average postoperative day of dehiscence in large reviews is about 7, but the exact day may range from 1 to more than 21.

### Table 1. INCIDENCE OF DEHISCENCE AND MORTALITY AFTER DEHISCENCE IN STUDIES PUBLISHED AFTER 1984

<table>
<thead>
<tr>
<th>Reference</th>
<th>Number of Patients</th>
<th>Number of Dehiscences</th>
<th>Dehiscence Incidence (%)</th>
<th>Deaths after Dehiscence</th>
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<td><strong>TOTAL</strong></td>
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<td><strong>221</strong></td>
<td><strong>1.2</strong></td>
<td><strong>62</strong></td>
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NA = Data not available. The denominator used to calculate the dehiscence-associated mortality derives from studies in which mortality data were available.
PREDICTION

Attempts at predicting acute wound failure have been done by assessing patient characteristics. Riou et al.\textsuperscript{163} and Makela et al.\textsuperscript{126} reported in case control studies that patients with three to five factors (such as age greater than 65, wound infection, pulmonary disease, hemodynamic instability, ostomy within the incision, hypoproteinemia, sepsis, obesity, uremia, hyperalimentation, malignancy, ascites, steroid use, and hypertension) were at a higher risk for dehiscence than the control patients. All patients with eight or more conditions disrupted their wounds.\textsuperscript{163} Individual risk factors are examined later. Pareira and Serkes\textsuperscript{130} prospectively palpated 1266 laparotomy incisions for a “healing ridge”; none of the 17 burst abdomens developed a ridge prior to dehiscence, whereas all but nine of the remaining 1249 incisions did have a ridge. The absence of a healing ridge in a laparotomy incision by postoperative day 5 could be construed as a sign of impending disruption.

STUDIES OF FASCIAL HEALING

Development of Wound Strength

An older report on fascial healing that has an inadequate description of methods claimed that a fascial incision in dogs attained 100% of "normal strength" in 20 days.\textsuperscript{88} Later investigators\textsuperscript{3, 56, 121, 143} created a paramedian incision in rabbits and found that immediate wound strength (with sutures in place) was 40% to 70% of that of unwounded tissue. There was little strength with the sutures removed until a rapid gain occurred between days 7 and 14. Wound strength (both with and without sutures) plateaued at 40% to 80% of that of unwounded tissue at about 3 to 6 weeks and increased only slightly over the next 1 to 3 months. Douglas\textsuperscript{47} found that an incision of the rabbit lumbar aponeurosis recovered 20% of control tensile strength (with sutures removed) at 2 weeks; this increased to 50% at 1 month and plateaued at 60% to 80% at 6 months (Fig. 1).

The course of fascial healing is somewhat variable in these animal models, but some generalizations can be made: Unsupported wounds have little to no inherent strength in the first week of healing; a rapid gain of strength occurs after the first week until about 4 to 6 weeks, when wound strength is perhaps 50% of that of unwounded tissue; strength gain after this initial rapid phase is gradual and strength may never reach 100% of that of unwounded tissue.

Healing Zone of a Wound

Adamsons et al.\textsuperscript{2} made a midline incision in guineau pigs and found that the biochemically active region of the wound (that is, the zone of
collagenolysis and matrix degradation) extended out in a gradient 0.75 cm from each wound edge. It was implied that sutures placed within this region would have less holding power than sutures lateral to it. Hogstrom et al\(^6\) tested the bursting strength of midline incisions in rats with sutures 1.5 and 3 mm from the wound edge. The incisions with 3-mm bites were three times stronger than the 1.5-mm bite incisions. The 1.5-mm bite incisions lost 50% of their strength by 48 hours, but the 3-mm bite incisions retained their strength. The explanation for the loss of incisinal strength in the 1.5-mm bite group was that these sutures were in the biochemically active region of the wound. An argument was made for avoiding fascial suture placement in this region.

The Importance of Inflammation

Experimentally, a disrupted and resutured wound gains strength faster than a primary wound. Savlov and Dunphy\(^{173}\) performed a paramedian incision in rats, disrupted and resutured it on day 3, and then disrupted it again 3 days later. The bursting strength of the disrupted and resutured wound was four times greater than that of the 3-day primary wound (but not as strong as that of a 6-day primary wound). The disrupted wound was thought to heal more rapidly because the healing process had already been initiated. Other investigators have observed the same phenomenon.\(^{85, 169, 179}\) Miro et al\(^{140}\) found that the strength of an incised and sutured musculoaponeurotic wound in the mouse was 50% higher at 3 weeks than the strength of two nonincised
musculoaponeurotic folds sutured together, and they concluded that optimal healing requires a minimal injury to the wound edge (such as that from a knife) to initiate inflammation. Some investigators have found in animals that a controlled wound infection hastens the onset of wound tensile strength (see later). All of these studies reveal the importance of inflammation in aponeurotic healing.

**Tension**

Clinically, tension is considered bad for fascial healing. Experimental examples, however, have been seen in which carefully applied tension improves wound strength. Thorngate and Ferguson\(^{191}\) performed bilateral vertical paraspinal aponeurotic incisions in rabbits; one side was allowed to heal in the presence of an adjacent relaxing incision (no tension), and the other was not (wound tension of 12 to 20 gm/cm). Wound strength after 10 to 83 days of healing was approximately 50% greater in the wounds healing under tension than in tension-free incisions. Pickett et al\(^{153}\) produced an average tension of 23 gm/cm by closing an excisional skin wound on the dorsum of rats and found that early wound strength was greater with tension than without it. Stephens et al\(^{183}\) observed that wounded rats allowed freedom of movement develop greater wound strength at 7 days than do confined rats, which suggests a prohealing effect of dynamic stress. Not all models of wound stress have a positive effect, however: Borgstrom and Sandblom\(^{24}\) applied tension to dorsal skin incisions in rabbits with a metal brace and demonstrated a small (approximately 20%) but significant loss in strength at 5 days compared with wounds healed without tension.

The explanation for the prohealing effect of tension is speculative; it may produce an improvement in collagen organization. The pertinence of animal models of wound tension to anterior abdominal incisions in humans is unclear. Perhaps a small amount of tension would be beneficial, but this would be difficult to regulate. The current clinical consensus is that tension should be minimized when closing an abdominal incision.

**Cadaver Wound Bursting Strength**

Wound bursting strength in cadavers is twice as great in transverse as in midline incisions when sutures are placed 10 mm from the wound edge. Tera and Aberg\(^{188}\) also found that transverse cadaver incisions were 33% stronger than midline incisions when they used a 0.5-cm tissue bite. However, when a midline incision was closed with sutures through-and-through the rectus sheath (that is, a wide bite), the bursting strength was 200% and 150% greater than those of the previous midline and transverse incision, respectively. Paramedian incisions were the weakest.

Haxton\(^{79}\) insufflated the peritoneal cavity of cadavers and found
that a midline wound has a higher bursting pressure than a paramedian incision (230 versus 175 mm Hg) and that a midline wound is 50% stronger with a continuous horizontal mattress suture than with a continuous over-and-over suture. Retention sutures did not add significantly to the bursting pressure. Boerema placed single nylon sutures 4 mm from the wound edge in upper midline incisions in patients during laparotomy and applied tension until either the suture broke or the tissue tore. The stitch tore out of the tissue in almost all patients at 7 to 10 kg of tension (range 1.5 to 10 kg). The force required to tear out full-thickness sutures placed 1 cm from the wound edge was equal in cadaver midline and transverse incisions.\textsuperscript{118}

Cadaver experiments suggest that a transverse incision is stronger than a vertical incision when a small tissue bite is used. The strongest cadaver incision studied, however, appears to be a midline incision with wide through-and-through tissue bites of the rectus sheath. The predominant failure mechanism of burst-tested cadaver incisions is suture cutting through the tissue.

CAUSES OF ACUTE WOUND FAILURE

A well-known, very able gynecologist had performed a hysterectomy for fibroid of the uterus. It was his custom to use imported silk and interrupted sutures for closing the fascia throughout the entire length of the wound. The wound disrupted on the twelfth day and the entire row of intact sutures with no sign of infection, was visible. The wound looked as if made the day before, all clean tissue—no suppuration. There was no reaction of the tissues toward healing. The use of silk and the kind of sutures did not save that patient from evisceration.

—C. J. HEYD, 1934\textsuperscript{45}

This is perhaps a universal experience of one who performs laparotomy and seems to illustrate the most common cause of wound disruption. The causes of acute wound failure may be reduced to four: a suture break, a slipped knot, a loose or an excessive stitch interval which allows protrusion of viscera, or suture tearing through the fascia. The last is the most common cause of wound dehiscence.\textsuperscript{5, 61, 71, 122, 144, 171} Poole et al\textsuperscript{155} ruptured 1-week-old midline incisions in 116 rats by insufflating the abdomen and found that the suture tore through the fascia in 106 wounds and the abdominal wall burst at a remote site in the other 10. No wound burst secondary to a slipped knot or broken stitch. Knot slippage or suture breakage in a similar rat study was 4.3% and 9.0%, respectively.\textsuperscript{175} The cause of dehiscence in patients rarely has been suture failure, except when catgut is used.\textsuperscript{67, 71, 182}

One might ascribe the cause of suture tearing through tissue to inadequate tissue strength, which implies that patient-related factors are responsible. This may be the explanation in some burst abdomens, as a
number of patient risk factors have been elaborated that may compromise the closure (see below). It has been observed in animals and cadavers, however, that greater tissue strength is obtained by taking a wider bite of fascia. Madsen et al.\textsuperscript{124} could not identify any risk factor in half of their 198 wound disruptions; they attributed the cause in these cases to technical error. All of these data, in light of the most common cause of dehiscence (tissue tearing), suggest that the predominant cause of acute wound failure is an inadequate tissue bite with the suture needle.

We, as surgeons, must be more heroic as the tragedy is much our fault.

—J. W. KENNEDY, 1934\textsuperscript{108}

**RISK FACTORS**

**A Note on Statistical Methods**

A common problem among randomized trials in medicine is that the number of patients enrolled is not large enough to detect a difference of the size the investigators believe to be present between or among the treatment groups. This puts the investigator at risk for committing a type II error—that of concluding no difference exists when in reality it does. Another common problem related to inadequate patient numbers is the determination of risk factors for a certain disease. A risk factor may be elucidated using the chi-square test, but this method does not determine if a putative risk factor is independent. A regression analysis can determine if a factor by itself elevates risk for disease or if the factor becomes significant only when combined with another factor(s). Unfortunately, regression analysis often requires more patients than the usual single institution experience can produce in a reasonable amount of time.

Many reports on wound dehiscence may be criticized regarding the possibility of a type II error or the determination of risk factor independence. The relevance of the conclusions of a study that does not contain enough patients and/or does not use the better statistical test may be questioned. However, when multiple reports reach the same conclusion, that conclusion probably is valid. This article stresses these concurrences.

**Opening the Abdomen**

*Incision Type*

It has been suspected from retrospective data that the rate of dehiscence in midline incisions is higher than in transverse incisions.\textsuperscript{42, 76, 77, 106, 109, 178} The explanation for this belief is that the midline incision is
"nonanatomic"; that is, it cuts across the aponeurotic fibers, as opposed to the transverse incision, which cuts parallel to the fibers.\textsuperscript{135, 161} Contraction of the abdominal wall muscles tends to pull the midline incision apart but brings the edges of the transverse incision together. Furthermore, it is thought that sutures in a midline incision tear out more easily than in a transverse wound because ripping in the former occurs parallel to the fibers. Data describing the force required to approximate midline versus transverse wounds under nonparalyzing anesthesia are conflicting.\textsuperscript{171, 180}

The belief that transverse incisions suffer less dehiscence has not been substantiated by recent reviews\textsuperscript{126, 156, 163} and the available prospective controlled trials. A randomized study with 50 patients per group comparing transverse with paramedian and midline with paramedian incisions (all with mass closure) reported only one dehiscence, which occurred in a paramedian wound.\textsuperscript{51} Greenall et al\textsuperscript{70} randomized 579 patients between midline and transverse incisions and found 2 burst abdomens (0.4%), both in the midline group (not a significant difference).

Two groups in England have reported a remarkably low incisional hernia rate (less than 0.1%) for the lateral paramedian incision (a vertical incision through the rectus fascia "at a point two thirds the width of the rectus abdominis from the midline," and closed in layers).\textsuperscript{39, 45} One of these groups reported a nil dehiscence rate (after 850 consecutive lateral paramedian incisions\textsuperscript{45}); the other group's dehiscence rate was comparable to that for other incision types.\textsuperscript{39} The former group's zero burst abdomen rate was accomplished despite small tissue bites (0.5 cm) of the anterior sheath.\textsuperscript{45} The purported advantage of the lateral paramedian incision is a buttress effect of the rectus muscle, which is claimed to make the incision inherently strong.\textsuperscript{45} No one as of yet has reported duplication of the above results with the lateral paramedian incision. It is not clear whether general surgeons should convert to this incision; confirmatory trials (by other investigators) would be desirable.

\textit{Incision Location}

An incision located in the upper abdomen has been thought to have a higher risk of disruption than an equivalent incision in the lower abdomen.\textsuperscript{62, 66, 77, 92} This belief has not been verified by the available prospective data.\textsuperscript{162}

\textit{Incision Opening}

Vertical incisions in rats made with the coagulation current of an electrocautery device had 10- and 21-day wound strength reduced by one third compared with incisions that were opened with a scalpel.\textsuperscript{160} A coagulation current is short bursts of electrical energy that allow the contacted and surrounding tissues to heat, dehydrate, and denature. Published clinical correlation to suggest that coagulation current predis-
poses to dehiscence is lacking, but it seems wise to avoid this current type when cutting the fascia.

**Closure**

The message I have in this discussion as to the cause of disruption of the abdominal wound so closely concerns the method of closure of the incision that I almost entirely exclude all prolonged discussion as to the many constitutional predisposing causes of divulsion of the abdominal incision.

—J. W. KENNEDY, 1934^{108}

Kennedy made an impressive claim in 1934: Between him and his mentor, Joseph Price, not one wound disruption with evisceration occurred in 56 years of abdominal surgery.\textsuperscript{108} Kennedy attributed this result to their constant technique of closure: through-and-through (from peritoneum to skin) sutures of silkworm placed “three to the inch” along the length of the incision and tied loosely. Baldwin\textsuperscript{12} also reported a similar result with a similar technique. This salutary method of some 60 years ago illustrates some vital points in wound closure: wide tissue bites, short stitch interval, and nonstrangulating tension on the suture.

**Size of Tissue Bite and Suture Length-to-Wound Length Ratio**

Jenkins\textsuperscript{301} noted a wound dehiscence rate of 1.6% (8 of 507) in his vertical wounds when a suture length-to-wound length ratio (SL:WL, see Fig. 2) of approximately 2:1 was used, which represents a stitch

![Figure 2. An incision (vertical line) sutured in an over-and-over fashion (solid and dashed line). Suture length to wound length ratio (SL:WL) may be calculated with the Pythagorean theorem applied to the shaded triangle: \( (SL)^2 = (a/2)^2 + (2b)^2 \), where \( a = \) stitch interval and \( b = \) width of tissue bite; \( WL = a/2 \).](image-url)
interval of 1 cm and a tissue bite of 0.5 cm. Jenkins noted that postoperatively an abdominal incision may lengthen by 30% if the patient becomes distended. The stitch interval elongates in step with the incision, and when combined with a small (0.5 cm or less) tissue bite, there is an increased tendency for the suture to cut through the tissue. Suture from three of Jenkins' dehisced wounds had a mean SL:WL of 1.3:1. Jenkins believed that his relatively small tissue bite was responsible for his wound failures. He subsequently recorded 1 dehiscence in 1505 vertical incisions (0.07%) using running closure with a SL:WL of 4:1 or greater, and he recommended maintaining SL:WL at this level.

If both the stitch interval and the tissue bite (dimension a and b, respectively, in Fig. 2) are 1 cm, then the SL:WL is 4.1:1. Increasing the bite to 2 cm produces a ratio of 8.1:1. Jenkins repaired 50 incisional hernias with a 0.5-cm stitch interval and a 2.5-cm tissue bite (SL:WL of 20:1). There were four small recurrences. This failure rate of 8% is especially low considering that all of these repairs were done without prosthetics. Israelsen and Jonsson reported 3 burst abdomens in 454 laparotomies (0.7%), 2 of which had a SL:WL of 1.25. The SL:WL also was found to be a risk factor in the development of incisional hernia. Krukowski et al. closed 757 midline incisions with a SL:WL of at least 4:1 and had a dehiscence rate of 0.3%. Gallup et al. closed 285 midline wounds using continuous polyglyconate with 2-cm bites at 1.5-cm intervals and recorded 1 dehiscence (secondary to knot failure). Martyak and Curtis advocated an even larger tissue bite—2.5 to 4 cm from the wound edge—and recorded no dehiscence or hernia in 280 midline incisions closed this way with running nylon. Interestingly, Kendall et al. recorded no dehiscence in 137 lateral paramedian incisions with a mean SL:WL of 2.6 but had 3 disruptions in 108 midline wounds with a mean SL:WL of 3.7. The difference was attributed to the inherent strength of the former incision (see earlier). The preponderance of the data, however, supports the use of a SL:WL of greater than 4:1 for running mass closure.

Tension on the Suture

The tissue strength gained with wide bites may be negated if the suture is pulled too tight. Suture tension that raises the interstitial pressure in the center of the incision above capillary pressure (30 to 40 mm Hg, but variable) may cause necrosis; this has been demonstrated angiographically in rats. Tight sutures also cut through fresh cadaver fascia at a lower distraction force than do loose sutures. Sanders et al. demonstrated that rat midline incisions closed using wide bites (5 mm from the wound) tied loosely (just enough tension to approximate the edges) had 25% more strength than incisions closed using narrow bites (1 to 2 mm) tied as tightly as possible. Ideal suture tension should approximate the fascia yet allow perfusion of healing tissue. A short stitch interval (1 cm or less) with a loose closure should prevent omentum or intestine from protruding between suture loops.
Little is written about dehiscence that occurs because the closure was too loose. Mayer et al,\textsuperscript{131} however, reported a randomized trial involving 302 mass closures with continuous nylon, comparing suturing with "normal" tension to suturing with "compression," in which each loop of suture was tightened with a 5-kg spring balance. Only one dehiscence occurred (in the normal-tension group, secondary to abdominal wall "disintegration" because of infection), but the hernia rate at 6 months was twice as high in the normal-tension group (10.0% versus 5.5%). The authors attributed the difference to the fact that compression suturing took up the stretch inherent in nylon, which otherwise might allow a closure to become too loose and provide a herniation site. No confirming study has been published.

**Suture**

The use of catgut for fascial closure has been condemned because of associated dehiscence rates of 10% to 12%.\textsuperscript{5, 63} Some surgeons earlier this century reported dehiscence rates of less than 1% with use of catgut without retention sutures.\textsuperscript{38, 178} It has been shown, however, that chronic catgut has an in vivo tensile strength half-life as short as 1 week, which is not long enough to secure fascial healing.\textsuperscript{157} Catgut usually is found dissolved during repair of fascial dehiscence in which catgut was the original closure material,\textsuperscript{67, 135} a phenomenon not observed with other sutures.

The slowly absorbed monofilaments (polydioxanone and polyglyconate) are the strongest sutures in the fresh state, followed by the nonabsorbable monofilaments (nylon and polypropylene), and then the braided sutures (polyglactin, polyglycolic acid, polyester) and gut.\textsuperscript{74} Silk, the weakest of the commonly used sutures, has about 15% of the strength of polydioxanone and has been associated with a 7.4% dehiscence rate in a randomized trial.\textsuperscript{113} The in vivo tensile strength half-life (from product insert information and independent investigators\textsuperscript{27, 130}) of some common absorbable sutures in weeks are poliglecaprone 25 (Monocryl), 1; polyglactin 910 (Vicryl) and polyglycolic acid (Dexon), 2; polyglyconate (Maxon), 3; and polydioxanone (PDS), 6. "Nonabsorbable" sutures are not always so: Silk has lost most of its tensile strength at 1 year, and nylon (Ethilon, Dermalon) loses 15% to 25% per year. Polypropylene (Prolene, Surgilene), polyethylene (Ethibond, Ticron, Tevdek), and polybutester (Novafil) seem to retain their strength indefinitely,\textsuperscript{130} although one study has noted some strength loss of polypropylene after 6 weeks in rats.\textsuperscript{74} Polybutester suture is more elastic than nylon, which may reduce the risk of tissue tearing.\textsuperscript{164}

A small controversy surrounding suture choice involves absorbable versus nonabsorbable suture. Randomized trials have not found a difference in dehiscence rates between absorbable and nonabsorbable sutures,\textsuperscript{32, 34, 36, 114, 120, 197} so the choice seems to be one of personal preference. It may be wise, however, to use a nonabsorbable monofilament in the patient who has an excessive number of risk factors for delayed healing.
Peritoneal Closure

Wound disruption was thought to originate from a peritoneal defect through which omentum and bowel insinuated itself; therefore, emphasis was placed on peritoneal closure.\textsuperscript{28, 145} It has been demonstrated, however, that peritoneal defects heal by simultaneous regeneration of the layer over the entire defect, not in incremental advancement from the wound edge, as is seen with skin.\textsuperscript{50, 89} Hugh et al\textsuperscript{91} and Ellis and Heddle\textsuperscript{52} compared in randomized trials one-layer closure (peritoneum not sutured) with two-layer closure (peritoneum closed) in paramedian and midline incisions and found no difference in the wound disruption rate. Suturing the peritoneum is not vital to prevent wound dehiscence.

Mass Versus Layered Closure

Closure of the abdominal wall in layers has been the traditional approach.\textsuperscript{109} Some nonrandomized data have been published, however, that suggest that mass closure (all layers taken together) is equivalent to or better than layered closure in preventing dehiscence.\textsuperscript{*} One randomized trial of mass versus layered closure with nylon in 282 incisions found no difference in dehiscence: 0.7\% versus 1.5\%, respectively.\textsuperscript{9} Mass closure appears to be favored currently because of its safety, efficacy, and speed.

Interrupted Versus Running Closure

Two studies in rats found that continuous closure resulted in a marginally higher wound bursting strength in 1-week-old midline incisions than did interrupted closure.\textsuperscript{155, 175} Miro et al\textsuperscript{140} found that 60\% to 80\% of interrupted nonabsorbable sutures had extruded from the musculoaponeurotic incision of mice after 3 weeks and hence were no longer effective in securing the wound. Running closure was not tested for this phenomenon. Currently no data are available on suture extrusion in humans. If it had been a major problem, however, there should have been more wound failures attributed to it. Haxton\textsuperscript{79} noted elevated wound strength in cadavers when he used a continuous horizontal mattress suture; clinical experience with this suturing technique is minimal, however. One might conclude from the experimental data that running closure is better than interrupted.

The Smead Jones closure (interrupted sutures with bites far and near from the wound edge, essentially an internal retention suture)\textsuperscript{104} enjoys popularity among gynecologic surgeons, who report dehiscence rates of less than 0.5\%.\textsuperscript{16, 44} Running closure was found to have a smaller (but not significant) burst abdomen rate than interrupted closure (1.6\% versus 2.0\%) in a multicenter randomized trial of 3135 midline incisions closed with polyglycolic acid.\textsuperscript{53} The authors had calculated that approxi-

\textsuperscript{*}References 18, 33, 35, 84, 111, 133, and 154.
mately 1500 patients in each group would be needed to detect a suspected difference. Smaller randomized trials comparing running with interrupted closure also reveal no difference in the incidence of wound disruption.61, 149, 162, 166, 192, 197 Running suture is a reasonable closure technique because of its safety, efficacy, and speed.

Knot Security

Tied suture loops break at the knot 95% of the time when subjected to stress testing.186, 187, 189 Most knots lose some strength after 7 days in vivo.62, 186 Generally speaking, the more throws, the more secure the knot; double throws are more secure than single throws; and square knots are more secure than non-square knots.43, 186, 187, 189

Retention Sutures

Few prospective controlled data evaluate the efficacy of retention sutures in preventing dehiscence. Baldwin12 and Kennedy198 closed thousands of incisions with running chromic gut routinely reinforced with silkworm retentions and experienced no dehiscence (see earlier). The weight of retrospective data supports the use of prophylactic retention sutures.* Miles et al139 found that the wound strength of paramedian incisions in dogs was 50% greater with retention sutures in place. It should be noted, however, that one quarter of the patients in several large reviews had retention sutures in place at the time of dehiscence.76, 132 Guiney et al75 noted that retention sutures were placed at the original operation in 47% of 232 patients with burst abdomen compared with 51% of case controls. One prospective randomized study has been done in which 203 incisions had retention sutures placed and 209 did not; there were three disruptions in the former group and none in the latter.80 In summary, the controlled and uncontrolled data regarding prophylactic placement of retention sutures conflict. Routine placement of retention sutures currently is not commonly done and is not recommended. It is difficult to know if prophylactic retention placement in the occasional high-risk patient would produce a more secure wound than running a mass closure with wide bites (2 to 3 cm).

Male Sex

Most reviews of wound disruption report male sex as a risk factor on the basis that among patients men outnumber women by at least 2 to 1.75, 77, 92, 106, 113, 132

Age

Advanced age (defined variably as over 50 to 65) has been proposed as a risk factor for dehiscence because the incidence in the “aged” is higher than in the “young.”\textsuperscript{106, 133, 138, 144, 163} In animals an association is seen between advanced age and delayed incisional healing.\textsuperscript{65} The bursting strength at 4 to 7 days of skin and fascial wounds in elderly rats was 33\% to 75\% of the strength in young rats.\textsuperscript{16, 151} The complicating issue in patients is that “advanced age” often is accompanied by medical problems that also may affect healing, so it is difficult to discern the importance of advanced age as a risk factor for dehiscence.

Emergency Operation

Emergency operation is a risk factor for dehiscence in some case control studies.\textsuperscript{61, 126, 144} Mendoza et al\textsuperscript{136} and McGinn\textsuperscript{134} reported wound disruption rates of 6.2\% and 12.6\%, respectively, after emergency operation for hemorrhagic duodenal ulcer. The risk for dehiscence from emergency operation may be related more to hemodynamic instability than to the unscheduled procedure (see section on anemia).\textsuperscript{163}

Surgeon in Training

Wounds closed by registrars were found to have a higher incidence of failure (defined as dehiscence and/or hernia) than wounds closed by consultants (13.2\% versus 4.3\%) in a trial comparing suture materials.\textsuperscript{95} Other data regarding the influence of trainee status on wound dehiscence are inconclusive and not extensive.\textsuperscript{106}

Obesity

Most studies that evaluate obesity as a risk factor for burst abdomen report no association.\textsuperscript{10, 61, 106, 126} One recent case control study, however, did report obesity (defined as greater than 50\% above ideal body weight) as a risk factor.\textsuperscript{163}

Diabetes

Prior to the availability of insulin, incisions in insulin-deficient diabetics failed at a rate of 25\%, usually secondary to wound sepsis.\textsuperscript{152} The introduction of insulin improved operative results.\textsuperscript{72} Clean wound infection rate, however, was still higher in diabetic patients (10.7\%) than in the general patient population (1.8\%) in a 1973 review of 23,649 surgical wounds (all types).\textsuperscript{41} It is unclear whether the increased infection
risk of diabetics places them at a higher risk for burst abdomen (see section on infection).

Animals that have been made insulin deficient and given a skin incision demonstrate 25% to 35% less wound tensile strength during the first several weeks of healing than do controls.\textsuperscript{6, 138, 165, 199} This effect seems to be partially reversible by administering insulin during the acute healing phase. Application of the results in diabetic animals to patients is difficult because most patients undergoing operation have a different cause for their diabetes (insulin resistance), and the animal data describe healing of skin, not fascia. The clinical consensus, however, appears to be that well-controlled diabetes is not a risk factor for fascial dehiscence.\textsuperscript{64, 126, 144, 163}

**Renal Failure**

Anecdotal experience suggests that acute renal failure predisposes to wound dehiscence.\textsuperscript{138, 142, 174} Nayman\textsuperscript{141} performed laparotomy in dogs and then induced renal failure with intravenous uranium nitrate at various times postoperatively. Acute renal failure within the first 5 postoperative days resulted in dehiscence in all animals and after 9 days produced no disruption. Early hemodialysis prevented wound dehiscence. Surgically created renal failure (five-sixths nephrectomy) established 2 weeks prior to skin wounding in rats resulted in a decrease in wound strength by one third at 10 days; the wound strength correlated more closely with body weight than with serum creatinine, however, suggesting that uremia-induced malnutrition was involved.\textsuperscript{115} Other investigators using a similar rat model could not demonstrate a detrimental effect of uremia on aponeurotic healing.\textsuperscript{176} The presence of an elevated risk for burst abdomen attributable to uremia in the well-compensated chronic renal failure patient is speculative. Hyperalimentation properly adjusted for the renal failure patient may counter the putative defect of healing associated with uremia.\textsuperscript{177}

**Jaundice**

Rats that have undergone common bile duct ligation have a 25% to 50% reduction in bursting strength of the abdominal incision at 1 week compared with controls.\textsuperscript{8, 15} Rats whose common duct is ligated 2 weeks prior to the creation of the test incision, however, do not demonstrate a loss in wound strength.\textsuperscript{68} It is unclear whether the defect in wound healing associated with jaundice is secondary to hyperbilirubinemia, malnutrition associated with chronic biliary obstruction, both, or some other factor(s).

Irvin et al\textsuperscript{196} recorded 13 burst abdomens in 22 patients (60%) undergoing laparotomy for malignant jaundice but did not observe dehiscence in 26 patients with benign jaundice. Armstrong et al\textsuperscript{17} compared 373
wounds in jaundiced patients (bilirubin greater than 50 μmol/L) with 760 wounds in anicteric patients (incision types were evenly distributed between groups) and found that the former group's dehiscence rate was six times higher than the latter's rate (3.2% versus 0.5%). Multivariate analysis revealed preoperative hematocrit less than 28, albumin less than 3.6 g/dL, pancreatitis, and malignant biliary obstruction as independent risk factors for dehiscence. Malignant biliary obstruction is the common entity between the above two studies and probably represents a true risk factor for dehiscence.

**Anemia**

Animals that are bled into acute anemia, not resuscitated, and then given an incision have lower wound bursting strength than nonphlebotomized controls.\(^ {134, 167, 169, 200}\) Rats that are maintained in shock for 30 to 60 minutes with phlebotomy and then given back their blood still have decreased wound strength.\(^ {134}\) Animals that are bled but promptly made normovolemic with an expander, however, do not have lower wound bursting strength than controls.\(^ {20, 167, 200}\) It would seem from these results that hypovolemia and shock, but not acute anemia alone, reduce wound strength.

Bains et al.\(^ {11}\) produced iron deficiency anemia in rats by two methods (chronic phlebotomy and iron-free diet) and found that with a red cell mass of 50% to 75% of control, wound bursting strength at 1 week dropped to 50% of control strength. These investigators demonstrated that the blood volume and serum protein level were equivalent in the iron-deficient rats and controls and concluded that the decrease in wound strength was not secondary to hypovolemia or malnutrition. Similar rodent studies do\(^ {100}\) and do not\(^ {58, 123, 196}\) confirm a decrease in laparotomy wound strength in iron-deficient animals. Chronic anemia secondary to iron deficiency may result in decreased wound strength, but the data are conflicting.

Clinical data regarding the effect of anemia on fascial healing are mixed. Low hemoglobin has been found to be a risk factor in some case control studies,\(^ {75, 106, 126}\) but not in others.\(^ {5, 10, 163}\) The animal data suggest that iron deficiency anemia, anemia associated with severe malnutrition, and hemorrhagic anemia with shock may predispose a patient to wound dehiscence.

**Malnutrition**

**Protein Deficiency**

Thompson et al.\(^ {190}\) made dogs acutely hypoproteinemic with plasmapheresis and found that 72% of laparotomy incisions subsequently failed to heal. Irvin\(^ {94}\) fed rats a protein-free diet for up to 8 weeks, performed
a laparotomy with partial colectomy, and measured the bursting strength of the anastomosis, fascia, and skin at 7 days postoperatively. Protein-starved rats lost 44% of body weight and had a 90% diminution of fascial wound strength compared with well-nourished rats. Rats protein starved and then fed an amino acid supplement demonstrated a wound bursting strength only one-third that of the normally fed rats (an improvement). A brief rescue with protein hyperalimentation thus was shown to be efficacious in protein-deficient animals. Other investigators have found in animals a correlation between the degree of protein-calorie malnutrition and deficiency of wound strength.173

Measurement of serum albumin is the most common method used to assess nutrition status in publications of wound disruption. Low serum albumin often is associated with dehiscence,* and, as a marker of malnutrition, hypoalbuminemia probably represents a real risk factor. The recommended dietary allowance for protein in normal adult men and women is about 1 gm/kg/day40; this value should be increased to 1.5 to 2.0 gm/kg/day with severe sepsis and burns.

**Vitamin C Deficiency**

Subclinical vitamin C deficiency has been assumed to impair healing and predispose to wound failure. Occasionally a higher incidence of wound disruption is noted during winter months,77 but whether this is secondary to reduced vitamin C intake is speculative. Wolfer et al198 performed wound-strength experiments with skin and fascia lata in 14 medical students. The group maintained on a vitamin C-deficient diet had breaking strengths 50% less than those of controls at 1 week. Other investigators fed guinea pigs a scorbutic diet for 1 to 2 weeks preoperatively and found that laparotomy wound strength at 7 to 10 days also dropped to 50% or less of that in control animals.1, 14, 78, 116 If a scorbutic animal is given vitamin C immediately after wounding, the incision attains strength almost in step with a control animal’s incision.

Bourne26 regulated the intake of vitamin C in guinea pigs for 1 week preoperatively and then created dorsal skin wounds. Vitamin C showed a dose-response effect on wound bursting strength, with the strongest wounds in pigs receiving the highest dose of vitamin C (30 mg/day) and the weakest wounds (nearly nil strength) in pigs receiving no vitamin C. The vitamin C level in the blood also correlated with the bursting strength. Some investigators have found that vitamin C supplementation in animals can increase wound strength above that of controls,193 but others have not observed this.78 Vitamin C is critical for strength gain in healing wounds. Routine vitamin C supplementation seems reasonable in malnourished (if not all) surgical patients. The recommended dosage is controversial but ranges from 30 to 75 mg/day.99

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*References 5, 38, 62, 67, 71, 126, 144, and 163.
Zinc Deficiency

The role of zinc in wound healing has not been resolved. It is known, however, that zinc is required by more than 300 enzymes, many of which are vital to both wound healing and life itself. A healing human wound sequesters zinc; a known complication of zinc deficiency is impaired wound healing. Rats fed a zinc-deficient diet for 2 weeks prior to wounding have an incision breaking strength 75% of that of control incisions at 2 to 3 weeks. Zinc deficiency is uncommon but may be seen with burn injury, alcoholism, gastrointestinal fistula, and zinc-deficient parenteral nutrition. The recommended allowance of zinc is 12 to 15 mg/day.

Other Preoperative Diagnosis

Operations for malignancy and operations on the stomach have been variably noted as risk factors for dehiscence. These conditions more appropriately would be called associations because no specific aspect of them has been shown to cause fascial disruption.

Postoperative Elevation of Intra-abdominal Pressure

Increased intra-abdominal pressure secondary to coughing, vomiting, or abdominal distention is frequently cited in retrospective reviews as an instigator, if not the source, of dehiscence. Evisceration has occurred during postoperative esophagogastroduodenoscopy. Bitterman et al observed a 13% rate of dehiscence in 46 patients undergoing hiatal herniorrhaphy for intrathoracic abdominal organs. The high rate was attributed to an increase in intra-abdominal pressure (not documented) after the abdominal organs were returned to their anatomic position.

Haxton inserted a balloon into the peritoneal cavity of men undergoing inguinal herniorrhaphy and found that a healthy awake man could generate 60 to 80 mm Hg of intra-abdominal pressure with a Valsalva maneuver. Drye measured postoperative intra-abdominal pressure in laparotomy patients with an intraperitoneal balloon connected to a catheter exiting through a separate stab incision. Intra-abdominal pressure (in cm H2O) was noted as 8 at rest, 35 with defecation, 60 with vomiting, and 80 and above with coughing. Unfortunately, no data could be obtained in a patient experiencing wound disruption; as noted earlier, however, Haxton’s cadaver incisions burst in the range of 200 mm Hg. One might conclude from these data that a properly sutured incision should withstand the intra-abdominal pressures generated postoperatively.

*References 10, 28, 38, 42, 62, 67, 76, 125, 132, and 163.
Wound Infection

Wound infection also is a frequently cited risk for dehiscence.* It is not possible to discern from these reports to what degree wound infection was responsible for the disruption. Infection certainly may be blamed for a dehiscence in which the fascia has disintegrated from a necrotizing infection, but this is an uncommon scenario. Dehiscence often occurs before wound infection becomes established, so the role of infection is not clear.

Infection slows gain of wound strength in some animal studies. Smith and Enquist\(^{181}\) inoculated vertical musculoaponeurotic incisions in rats with *Staphylococcus aureus* and observed a 25% to 40% loss in wound strength throughout the 8-week study period. Bucknall\(^{21}\) found that rat skin wounds inoculated with 10\(^8\) *Pseudomonas aeruginosa* per milliliter had only 33% of control bursting strength at 5 and 14 days postoperatively; *S. aureus* and *Proteus mirabilis* inoculation decreased wound strength to a lesser extent. Another group working with rats found that both local and distant infection with *P. aeruginosa* produced a decrease in laparotomy wound strength.\(^{21}\)

Enquist’s group found later, however, that inoculating abdominal wounds with gram-positive organisms other than *S. aureus*, gram-negative organisms (including *P. aeruginosa*), or mixtures of gram-positive and gram-negative organisms produced increases of 50% in wound strength over controls at 2 weeks.\(^{185}\) Botsford\(^{25}\) observed a similar phenomenon in animal skin wounds infected with *Bacillus subtilis*. These experimental infections were well tolerated by the animals. It is possible that the additional degree of inflammation that a modest wound infection can produce may hasten the healing process. No one, of course, has suggested that a patient’s wound routinely be inoculated with bacteria.

Corticosteroids

Glucocorticoids are known to adversely affect healing, and anecdotal evidence of wound failure associated with their use has been published.\(^{10, 163}\) Green\(^{69}\) noted 7 partial or complete wound disruptions in 38 patients (18%) who were on perioperative steroids. Some reports, however, have not demonstrated an association between steroid use and burst abdomen.\(^{106, 126, 144}\) Steroid use in patients has not been a consistent risk factor for dehiscence.

Some of the concern over steroid use in laparotomy patients has originated with animal studies. Rats administered cortisone have a 30% diminution of dorsal skin wound strength at 7 days compared with control rats.\(^{49}\) The effect of cortisone on wound strength was not seen if the steroid was given 3 days prior to or 2 days after wounding.\(^{168, 173}\) Cortisone administration also prevents disrupted and resutured wounds

*References 5, 42, 61, 71, 84, 106, 144, and 163.*
from rapidly regaining tensile strength.\textsuperscript{85, 173} Hydrocortisone was more potent in decreasing skin wound bursting strength in mice than dexamethasone or methylprednisolone.\textsuperscript{46} The effect of cortisone on skin wound strength is negated if vitamin A is given concurrently.\textsuperscript{49} No data are available regarding administration of vitamin A in patients receiving steroids, but empirically such therapy seems reasonable.\textsuperscript{93} The recommended dose of vitamin A is about 1 mg/day.\textsuperscript{148}

**Antineoplastic Agents**

A variety of cytotoxic drugs administered to wounded animals delays gain in wound tensile strength.\textsuperscript{54, 57} It has been customary to delay administration of an antineoplastic agent in a postoperative cancer patient until the acute healing phase is over (usually 2 to 3 weeks) because of concern that the drug may have an adverse effect on wound healing. Few studies in humans, however, evaluate the effect of perioperative chemotherapy on postoperative healing.\textsuperscript{54, 57} Klausner et al\textsuperscript{112} started a 10-day course of fluorouracil intraoperatively in 40 patients with carcinoma of the gastrointestinal tract and observed one dehiscence and no anastomotic breakdown. They concluded that this regimen had no clinically relevant effect on wound healing. Perioperative adjuvant chemotherapy has a theoretical advantage\textsuperscript{37} but whether a survival difference exists between patients with perioperative and delayed administration of chemotherapy is not known.\textsuperscript{57} The pattern of delayed administration of chemotherapy is a reasonable treatment option until further information becomes available.

**Radiation Therapy**

Skin wounds in animals that receive a radiation dose of 18 Gy within 2 days after wounding have 50% of the strength of control incisions at 7 and 14 days.\textsuperscript{18, 194} The effect of radiation on experimental healing when it is administered 1 week or more after wounding is equivocal and probably negligible. Although the data are incomplete, perioperative regional radiation therapy probably does not affect fascial healing if given 2 weeks or more before or after the operation.

**TREATMENT**

**Nonoperative Treatment**

Nonoperative treatment of dehiscence, or “tamponade,” is performed with bedside gauze packing and binder application to the disrupted abdominal wound.\textsuperscript{42, 137} The wound subsequently may contract to closure; or, if the patient’s condition improves, delayed operative
closure may be performed. Hernia is a common sequela to this treat-
ment. Earlier this century tamponade was performed in patients deemed
too feeble to return to the operating room. This technique also has been
used in the management of difficult fascial closure in trauma patients.17

Operative Treatment

Retention Sutures

The prevalent technique for repairing fascial dehiscence is immedi-
ate resuture with placement of retention sutures (also known as stay or
tension sutures).* Retention sutures may be placed by a number of
 techniques, but the basic principles include heavy nonabsorbable suture
material, usually monofilament; wide interrupted bites (3 cm or more
from the wound edge), either external (peritoneum through skin) or
internal (all layers except skin); a stitch interval of 3 cm or less; a buttress
device to prevent suture erosion into the skin; and suture removal (if
external) after 3 weeks or more. Data are insufficient to indicate which
retention suture technique is best or how running mass closure with a
high SL:WL ratio would compare with retention closure of a burst
wound. Currently the most conservative approach to the operative treat-
ment of wound dehiscence is placement of retention sutures as out-
lined above.

Repair with Prosthetic Materials

Closure of an abdominal wound in which an acute loss of abdomi-
nal wall has occurred can result in dehiscence in greater than 50% of
cases.130 Nonelective mesh closure of an abdominal incision is usually
indicated in cases of abdominal wall destruction and/or massive visceral
edema in which primary closure would result in enough tension to
make tissue tearing inevitable.35, 127, 184 Marlex mesh has been used com-
monly for this purpose. Emergency reconstruction of the abdominal
wall with mesh may salvage an otherwise unmanageable closure, but
subsequent complications of fecal fistula, mesh extrusion, and hernia
have a combined incidence of about 50%.103, 184, 195

The use of polytetrafluoroethylene (PTFE) in an animal model of
abdominal wall reconstruction in the presence of contamination and
peritonitis was associated with less bacterial adherence and fewer adhe-
sions than the use of polypropylene mesh.29 The clinical implication of
this study is unclear, but no one has yet reported a case of fecal fistula
directly attributable to PTFE, as has occurred with Marlex.105, 184

Absorbable mesh may also be used for closure of a difficult abdo-
men; this usually commits the patient to an elective ventral hernia repair
later on.30, 73 Recurrent dehiscence does not seem to be a problem with

the use of absorbable mesh. Enterocutaneous fistula still occurs, perhaps with less frequency than with polypropylene mesh. Fistula associated with absorbable mesh may be easier to manage than fistula associated with nonabsorbable mesh.

SEQUELAE

Mortality

The mortality rate in 20 reviews of wound disruption published before 1940 (representing 622 disruptions) was 36% (range 0% to 75%).\textsuperscript{28} Poole\textsuperscript{156} found a median mortality rate of 18% in a review of 34 studies from 1950 to 1984. The average mortality rate from recent reviews is 25% (see Table 1). The dehiscence-associated mortality rate does not appear to be declining. Madsen et al\textsuperscript{124} reviewed 198 burst abdomens from 1972 to 1987 and found that cardiorespiratory failure was the most common cause of death (24 of 48 deaths = 50%); peritonitis was the second most common cause (15%). Advanced age (not quantified), female sex, and postdisruption mechanical ventilation were risk factors for death after dehiscence occurred.

Recurrent Wound Failure

Madsen et al\textsuperscript{124} observed repeat dehiscence in 11 of 198 (5.5%) burst abdomen patients (7 of the 11 died). Ventral hernia was noted in 28 patients (14%); all 198 patients had undergone immediate resuturing of the incision after diagnosis of disruption. Grace and Cox\textsuperscript{46} reported 2 recurrent dehiscences in 103 cases (1.9%) and a 48% incidence of ventral hernia after burst abdomen; this latter rate may have been higher because one third of the patients were lost to follow-up. All patients with nonoperative management of dehiscence developed a hernia. Mann et al\textsuperscript{125} reported a postdisruption ventral hernia rate of 28%.

Other Postoperative Complications

Other surgical complications after wound disruption repair that have been described in a large series include wound infection (14%), fistula (6%), and intra-abdominal abscess (4%).\textsuperscript{124}

SUMMARY AND RECOMMENDATIONS

The elimination of postoperative wound dehiscence is entirely within the jurisdiction of the operating surgeon.

—J. D. NORRIS, 1939\textsuperscript{155}
Acute wound failure has demonstrated an incidence and associated mortality rate that has not decreased during this century. A patient at risk for wound disruption may be identified by a number of factors that have been associated with dehiscence and by the absence of a healing ridge. The most common cause of acute wound failure is suture tearing out of the tissue. The cause of the tearing may be secondary to both patient- and doctor-related factors. The precise contribution of any one factor toward increasing the dehiscence risk is difficult to know, but certainly a patient with many putative risk factors is at a higher risk than a patient with none. The most important intervention the surgeon can make to prevent tissue tearing and wound dehiscence is to perform running mass closure with wide bites of fascia (2 cm or more) and a short stitch interval (1 cm or less) so that the SL:WL ratio is well above 4:1. Tension on the suture must approximate but not strangulate the tissue. Suture choice does not seem important, but it may be wise to use nonabsorbable material in a patient with multiple risk factors for wound disruption. Immediate reoperation with resuture and retention suture placement is the accepted treatment of choice for fascial dehiscence. Acute wound failure should be viewed more as a consequence of inadequate technique than as a consequence of high risk in a patient.

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