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Original Article

Risk Factors for Dehiscence of Operative Incisions in Newborns after Laparotomy

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Graphical Abstract

Graphical Abstract. *Overview of risk factors for the development of surgical wound dehiscence in newborns.*

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Abstract

Background Surgical wound dehiscence (SWD) in neonates is a life-threatening complication. The aim was to define risk factors of postoperative incision dehiscence in this population.

Methods Data of 144 patients from 2010 to 2020 were analyzed retrospectively. All full-term newborns or preterm newborns up to 42 weeks of amenorrhea (adjusted) who had a laparotomy within 30 days were included. Descriptive patient information and perioperative data were collected. SWD was defined as any separation of cutaneous edges of postoperative wounds.

Results Overall, SWD occurred in 16/144 (11%) patients, with a significantly increased incidence in preterm newborns (13/59, 22%) compared with full-term newborns (3/85, 4%; $p < 0.001$). SWD was significantly associated with exposure to postnatal steroids (60% vs. 4%, $p < 0.001$) and nonsteroidal anti-inflammatory drugs (25% vs. 4%, $p < 0.01$), invasive ventilation duration before surgery (median at 10 vs. 0 days, $p < 0.001$), preoperative low hemoglobin concentration (115 vs. 147 g/L, $p < 0.001$) and platelet counts (127 vs. 295 G/L, $p < 0.001$), nonabsorbable suture material (43% vs. 8%, $p < 0.001$), the presence of ostomies (69% vs. 18%, $p < 0.001$), positive bacteriological wound cultures (50% vs. 6%, $p < 0.001$), and relaparotomy (25% vs. 3%, $p < 0.01$). Thirteen of 16 patients with SWD presented necrotizing enterocolitis/intestinal perforations (81%, $p < 0.001$).

Conclusion This study identified prematurity and a number of other factors linked to the child's general condition as risk factors for SWD. Some of these can help physicians recognize and respond to at-risk patients and provide better counseling for parents.

Keywords

- wound dehiscence
- surgical incision
- neonate
- preterm newborns
- full-term newborns

Introduction

Wound dehiscence is defined as a "partial or total separation of previously approximated wound edges, due to a failure of proper wound healing."[1] Surgical wound dehiscence (SWD) is not a rare condition. It is estimated that approximatively 1 to 3% of adult patients will present this postoperative complication.[2–5] This number is even higher in newborns due to their particular global physiopathological condition and has been reported to reach 6%.[6] SWD is a dreaded postoperative complication leading to several morbidities[7] and a mortality rate reaching as high as 45%.[8–11]

Several factors influence the proper healing of a wound. Wound healing is classically characterized by four phases: hemostasis, inflammation, proliferation, and remodeling; any factor influencing one of these phases can have an impact on this complex process.[12] Local and general factors that have an impact on multiple phases, such as infection, oxygenation, age, drug exposure, and nutrition, have shown to be associated with poor wound healing.[13] For example, impaired neutrophils[14] or macrophages in diabetes[15,16] alter inflammation processes and delay wound healing.

Many studies have been carried out in the adult population to determine risk factors for SWD, yet very few have been conducted in children and only one strictly limited to neonates.[6,17,18] Those studies identified, among others, age, midline incisions, emergency of the surgery, wound contamination, anemia, hypoproteinemia, and weight as potential risk factors.

The present study aimed to determine the incidence of SWD in a large population of surgical neonates and to identify risk factors for SWD in neonates. Based on clinical experience, two hypotheses were defined in relation to the population of newborns having undergone abdominal surgery: (1) preterm newborns might have a higher risk of developing SWD than full-term newborns and (2) the child's general condition might be a predominant factor for SWD.

Material and Methods

Patients

Patients who underwent abdominal surgery from January 2010 to December 2020 in the Division of Child and Adolescent Surgery of the Geneva University Hospitals were retrospectively enrolled. All full-term newborns or preterm newborns up to 42 weeks of amenorrhea (adjusted) who had a laparotomy within 30 days were included. Exclusion criteria were as follows: (1) thoracotomy, (2) herniotomy, (3) Tenckhoff catheter placement for peritoneal dialysis, (4) vesicostomy, (5) abdominal drainage, (6) death at less than 3 days after surgery, and (7) weight more than 5,800 g. The study was conducted on a final cohort of 144 patients (►Fig. 1).

Data Collection

Clinical data were collected from the institutional database and transferred to a separate secure, anonymized database (*REDCap 10.6.28* - © 2022 Vanderbilt University). Data of 10% randomly selected patients were reviewed a second time to ensure accuracy. The following variables were taken into account: (1) *patient information* including age at surgery,

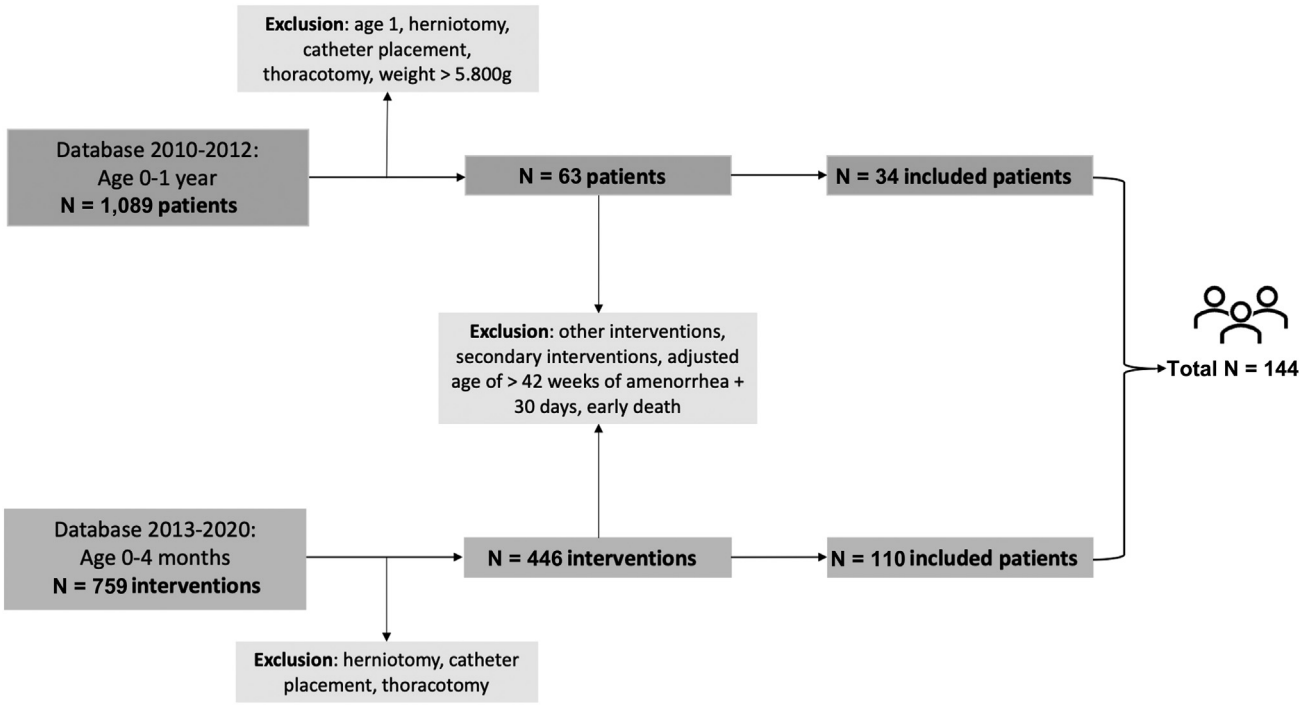

Fig. 1 Flowchart of included and excluded patients.

gestational age at birth, sex, birth weight, Apgar score at 10 minutes, intrauterine growth restriction (< 10th percentile), postnatal steroid and nonsteroidal anti-inflammatory drug (NSAID) exposure; (2) *preoperative* data including intubation time before surgery, hemoglobin, hematocrit, leukocytes, neutrophils (absolute count), lymphocytes, platelets, C-reactive protein (CRP), lactates, type of diagnosis leading to surgery and cases of relaparotomy; (3) *intraoperative* data including minimal oxygen (O_2) saturation, inspiratory oxygen fraction (FiO_2) at the end of surgery, use of antibiotics, use of amines, blood transfusion, operating time, suturing technique and material used to close skin and fascia, presence of ostomy, ostomy placement within or outside the incision, and incision orientation (horizontal, vertical, or umbilical); (4) *postoperative* data including use of amines (within 5 days after surgery), intubation (within 5 days after surgery), presence of wound redness, abscess, positive bacteriological cultures, and SWD within 30 days after surgery.

Variables with more than 30% of missing data were excluded. Inflammatory markers (neutrophils, leukocytes, and CRP) were taken into account despite the amount of data since these values are only measured in certain situations and are therefore not stricto sensu missing data. Prematurity was defined as birth at fewer than 37 weeks of amenorrhea. All serological values were evaluated by standard methods and taken at most 72 hours before surgery. SWD was defined as any type of postoperative separation of wound edges. All types of SWD (irrespective of its size) were considered, that is, total and partial dehiscence of the incision. This information, as well as redness and abscess formation of the postoperative wound, was retrieved from the daily notes in the medical records, documented by floor physicians. Bacteriological cultures were considered positive when a bacteriological wound smear after dressing removal revealed bacteria.

All types of NSAIDs and postnatal steroids were considered. Blood transfusion included both red blood cells and plasma transfusions. Postoperative follow-up was done over a maximum of 30 days, as SWD were reported to occur at a median of 5 to 12 days after surgery.[10,11,19]

Statistical Analysis

A power analysis was not performed since the study was purely observational. Continuous variables were presented as median and interquartile range (IQR, Q1–Q3), and categorical parameters as counts and percentages. Statistical analyses were performed with *RStudio version 2022.02.0 + 443*. Double entry was applied. Shapiro–Wilk test was applied to test for normality of the distribution. To assess the differences between two independent groups, Welch's *t*-test and Mann–Whitney *U* test were used for continuous variables with normal or nonparametric distribution, respectively. For categorical variables, chi-square test was used for *n* greater than 5, and Fisher's exact test for *n* 5 or lower. A *p*-value of less than 0.05 was considered significant.

Ethical Considerations

This study was approved by the regional research ethics committee (CCER) (Project-ID 2021-00560). The committee exempted from requiring written informed consent.

Results

Patient demographics are shown in ►Table 1. Mean follow-up was 24 days (IQR, 11).

Table 1 Patient demographics

Characteristics	Entire cohort ($N = 144$)		Preterm newborns ($N = 59$)		Full-term newborns ($N = 85$)		*p*-Value
Patient information							
Age at surgery (d)	8 (2–31)	144	10 (3–42)	59	4 (1–25)	85	**0.03**
Gestational age at birth (wk)	$37^{3/7}$ ($33^{5/7}$–$39^{2/7}$)	144	$30^{6/7}$ ($26^{3/7}$–$34^{6/7}$)	59	$39^{1/7}$ ($38^{1/7}$–$40^{1/7}$)	85	< **0.001**
Sex		144		59		85	0.57
Female	34%	49	31%	18	36%	31	
Male	66%	95	69%	41	64%	54	
Birth weight (kg)	2.7 (1.8–3.3)	139	1.5 (0.8–2.2)	58	3.2 (2.8–3.6)	81	< **0.001**
Apgar score at 10 min	10 (8–10)	119	9 (8–10)	54	10 (9–10)	65	< **0.01**
IUGR < 10th percentile	14%	20/142	16%	9/57	13%	11/85	0.82
Postnatal steroid exposure	10%	14/141	19%	11/57	4%	3/84	< **0.01**
NSAID exposure	6%	9/142	14%	8/58	1%	1/84	< **0.01**
Preoperative data							
Intubation time before surgery (d)	0 (0–1)	143	0 (0–8)	59	0 (0–0)	84	< **0.001**
Biological measures							
Hemoglobin (g/L)	143 (115–175)	132	124 (106–150)	56	160 (125–177)	76	< **0.001**
Hematocrit (%)	41 (34–51)	132	38 (30–44)	56	47 (37–51)	76	< **0.01**
Leukocytes (G/L)	13.6 (9.8–17.3)	112	13.9 (9.7–17.6)	49	13.3 (9.9–17.1)	63	0.51
Neutrophils (abs.) (G/L)[a]	6.8 (3.9–9.9)	98	6.8 (4.3–9.4)	45	6.7 (2.8–10.8)	53	0.82
Lymphocytes (G/L)[a]	4.4 (2.9–5.5)	97	4.4 (3–5.6)	44	4.4 (2.8–5.5)	53	0.97
Platelets (G/L)	280 (191–394)	108	223 (137–348)	48	307 (230–445)	60	< **0.01**
CRP (mg/L)[a]	10 (4–15)	72	10 (4–41)	33	10 (3–10)	39	0.08
Lactates (mmol/L)	1.6 (1.3–2.3)	127	1.6 (1.2–2.4)	54	1.6 (1.3–2.2)	73	0.94
Diagnosis		144		59		85	<0.001
Malformation/obstruction	64%	92	41%	24	80%	68	< **0.001**
NEC/intestinal perforations	19%	27	39%	23	5%	4	< **0.001**
Laparoschisis/omphalocele	10%	15	14%	8	8%	7	0.41
Other	7%	10	7%	4	7%	6	1
Relaparotomy	6%	8/144	8%	5/59	4%	3/85	0.27

Table 1 (*Continued*)

Characteristics	Entire cohort ($N = 144$)		Preterm newborns ($N = 59$)		Full-term newborns ($N = 85$)		*p*-Value
Intraoperative data							
Minimal O_2 sat during surgery (%)	95 (91–98)	127	95 (91–98)	48	95 (92–97)	79	0.89
FiO_2 at the end of surgery (%)	21 (0–33)	121	30 (20–35)	49	0 (0–30)	72	< **0.001**
Use of amines during surgery	45%	62/138	61%	33/54	35%	29/84	< **0.01**
Blood transfusion during surgery	31%	42/135	44%	23/52	23%	19/83	**0.02**
Operating time (min)	151 (92–233)	138	151 (101–235)	55	147 (89–229)	83	0.43
Surgical details							
Suture: fascia (running suture)	46%	43/93	41%	17/41	50%	26/52	0.54
Suture: skin (running suture)	73%	89/122	65%	33/51	79%	56/71	0.13
Suture material: fascia							
Slowly absorbable	100%	139	100%	57	100%	82	
Suture material: skin		137		55		82	< **0.01**
Slowly absorbable	64%	88	56%	31	70%	57	0.16
Rapidly absorbable	24%	33	20%	11	27%	22	0.48
Nonabsorbable	12%	16	24%	13	4%	3	< **0.001**
Ostomy	25%	34/143	41%	23/59	14%	11/84	< **0.001**
Ostomy placement within the incision	58%	19/33	55%	12/22	64%	7/11	0.72
Incision orientation		142		59		83	0.07
Horizontal	77%	109	86%	51	70%	58	**0.03**
Vertical	3%	4	2%	1	4%	3	0.64
Umbilical	20%	29	12%	7	26%	22	**0.04**
Postoperative data							
Amines (within 5 d post-op)	17%	25/144	29%	17/59	9%	8/85	< **0.01**
Intubation (within 5 d post-op)	56%	79/142	83%	48/58	37%	31/84	< **0.001**
Wound							
Redness	38%	50/131	49%	25/51	31%	25/80	0.06
Abscess	6%	8/137	11%	6/54	2%	2/83	0.06
Positive bacteriological cultures (wound)	10%	15/143	17%	10/58	6%	5/85	< **0.05**
Surgical wound dehiscence	11%	16/144	22%	13/59	4%	3/85	< **0.001**

Abbreviations: abs., absolute; CRP, C-reactive protein; FiO_2, inspiratory oxygen fraction; IUGR, intrauterine growth restriction; NEC, necrotizing enterocolitis; NSAID, nonsteroidal anti-inflammatory drug.
Note: All values are presented as percentages or medians (Q1–Q3).
[a] > 30% missing data.

Patients with and without Wound Dehiscence

Data of 144 pre- and full-term neonates were included; 16 (11%) presented with SWD. SWD incidence was significantly increased in preterm newborns (13/59, 22%) compared with full-term newborns (3/85, 4%; $p < 0.001$).

►Table 2 summarizes characteristics of the patients with and without SWD. Gestational age was found to be significantly associated with SWD (shown in ►Fig. 2), as were birth weight, Apgar score at 10 minutes, and postnatal steroid and NSAID exposures. Among the preoperative data, intubation

Table 2 Patients with vs. without wound dehiscence

Characteristics	Patients with wound dehiscence ($N = 16$)		Patients without wound dehiscence ($N = 128$)		*p*-Value
Patient information					
Preterm newborns	81%	13/16	36%	46/128	< **0.001**
Age at surgery (d)	13 (9–45)	16	6 (1–30)	128	< **0.01**
Gestational age at birth (wk)	$26^{6/7}$ ($25^{4/7}$–$33^{3/7}$)	16	38 (35–$39^{3/7}$)	128	< **0.001**
Sex		16		128	0.26
Female	19%	3	36%	46	
Male	81%	13	64%	82	
Birth weight (kg)	1 (0.7–1.9)	15	2.8 (2.2–3.3)	124	< **0.001**
Apgar score at 10 min	8 (7–9)	14	10 (9–10)	105	< **0.001**
IUGR < 10th percentile	27%	4/15	13%	16/127	0.23
Postnatal steroid exposure	60%	9/15	4%	5/126	< **0.001**
NSAID exposure	25%	4/16	4%	5/126	< **0.01**
Preoperative data					
Intubation time before surgery (d)	10 (2–14)	16	0 (0–0)	127	< **0.001**
Biological measures					
Hemoglobin (g/L)	115 (100–130)	16	147 (118–177)	116	< **0.001**
Hematocrit (%)	35 (28–38)	16	42 (35–51)	116	< **0.001**
Leukocytes (G/L)	10.7 (6.5–15)	16	14.2 (10.1–17.6)	96	0.05
Neutrophils (abs.) (G/L)[a]	4.4 (2.9–6.6)	15	7.2 (4–10.4)	83	< **0.05**
Lymphocytes (G/L)[a]	3.2 (2.2–4.2)	14	4.5 (3–5.6)	83	0.13
Platelets (G/L)	127 (59–210)	16	295 (213–413)	92	< **0.001**
CRP (mg/L)[a]	38 (10–133)	12	10 (3–10)	60	< **0.01**
Lactates (mmol/L)	1.8 (1.5–2.9)	15	1.6 (1.3–2.2)	112	0.15
Diagnosis		16		128	< **0.001**
Malformation/obstruction	6%	1	71%	91	< **0.001**
NEC/intestinal perforations	81%	13	11%	14	< **0.001**
Laparoschisis/omphalocele	0%	0	12%	15	0.22
Other	13%	2	6%	8	0.31
Relaparotomy	25%	4/16	3%	4/128	< **0.01**
Intraoperative data					
Minimal O_2 sat during surgery (%)	89 (85–97)	12	95 (92–98)	115	0.05
Use of amines during surgery	62%	8/13	43%	54/125	0.25
Blood transfusion during surgery	58%	7/12	28%	35/123	< **0.05**
Operating time (min)	142 (96–180)	14	151 (93–235)	124	0.61
Surgical details					
Suture: skin (running suture)	50%	7/14	76%	82/108	0.08
Suture material: fascia slowly absorbable	100%	14	100%	125	

Table 2 (*Continued*)

Characteristics	Patients with wound dehiscence ($N = 16$)		Patients without wound dehiscence ($N = 128$)		*p*-Value
Suture material: skin		14		123	< **0.01**
Slowly absorbable	50%	7	66%	81	0.38
Rapidly absorbable	7%	1	26%	32	0.19
Nonabsorbable	43%	6	8%	10	< **0.001**
Ostomy	69%	11/16	18%	23/127	< **0.001**
Ostomy placement within the incision	36%	4/11	68%	15/22	0.14
Incision orientation		14		128	0.10
Horizontal	100%	14	74%	95	**0.04**
Vertical	0%	0	3%	4	1
Umbilical	0%	0	23%	29	0.07
Postoperative data					
Amines (within 5 d post-op)	44%	7/16	14%	18/128	< **0.01**
Intubation (within 5 d post-op)	81%	13/16	52%	66/126	**0.03**
Wound					
Redness	92%	11 /12	33%	39/119	< **0.001**
Abscess	23%	3/13	4%	5/124	**0.03**
Positive bacteriological cultures (wound)	50%	8/16	6%	7/127	< **0.001**

Abbreviations: abs., absolute; CRP, C-reactive protein; IUGR, intrauterine growth restriction; NEC, necrotizing enterocolitis; NSAID, nonsteroidal anti-inflammatory drug.
Note: All values are presented as percentages or medians (Q1–Q3).
[a] > 30% missing data.

time was significantly increased in patients with SWD. SWD incidence was higher in patients with decreased levels of hemoglobin, hematocrit, and platelets (shown in ►**Fig. 2**). In the blood sample of patients with SWD, a trend (> 30% missing data) of decreased absolute neutrophil count and increased CRP levels were seen. Since it can be assumed that in patients with a noninflammatory condition (and thus missing data) these variables were normal, the results can be interpreted as significant. In the group with SWD, there were significantly more patients with the diagnosis of necrotizing enterocolitis (NEC)/intestinal perforations. As for perioperative data, significant more cases with SWD had a relaparotomy. They also had significantly more blood transfusion during surgery. In terms of surgical technique, nonabsorbable suture material was significantly more often used in patients who developed SWD and patients with SWD had significantly more ostomies. Whether the ostomy was placed within the incision or not did not appear to be significant. Within 5 days after surgery, amines and intubation were significantly more frequently found in patients with SWD. The postoperative wound among patients with SWD showed significantly increased redness, abscesses, and positive local bacteriological cultures.

Wound Dehiscence in Patients with NEC/Intestinal Perforations

The majority of patients developing SWD had NEC: 13/16 of all newborns and 12/13 preterm newborns. Upon analysis of this subgroup, postnatal steroid use, decreased leukocyte levels, and intubation time before surgery were significantly associated with SWD. The presence of ostomy in these patients was not associated with increased SWD, as was the placement of the ostomy inside or outside of the incision (►**Table 3**).

Discussion

In the present study, more than 10% of neonates who underwent laparotomy developed SWD. This is, as expected, a threefold higher incidence than in the adult population.[2–5] Indeed, this study showed that prematurity plays a central role in the development of SWD. Surrogate variables for prematurity are gestational age, birth weight, and the 10-minute Apgar score, all of those having been shown to be significant risk factors for SWD. These findings are in line with other studies, which also identified age as an independent and major risk factor for SWD.[6,19] Indeed, preterm newborns differ from full-term newborns in a number of physiological mechanisms. The *immune* immaturity of preterm newborns results in increased vulnerability to infections.[20–22] Their *dermatological* immaturity might also favor SWD, since skin increases its thickness and keratinization with age.[23] The skin of preterm newborns is therefore a less resistant and more permeable barrier compared with that of older babies.[24,25]

Interestingly, age at surgery was also associated with SWD: patients with SWD were older at the time of surgery. This might be due to the fact that the majority of patients

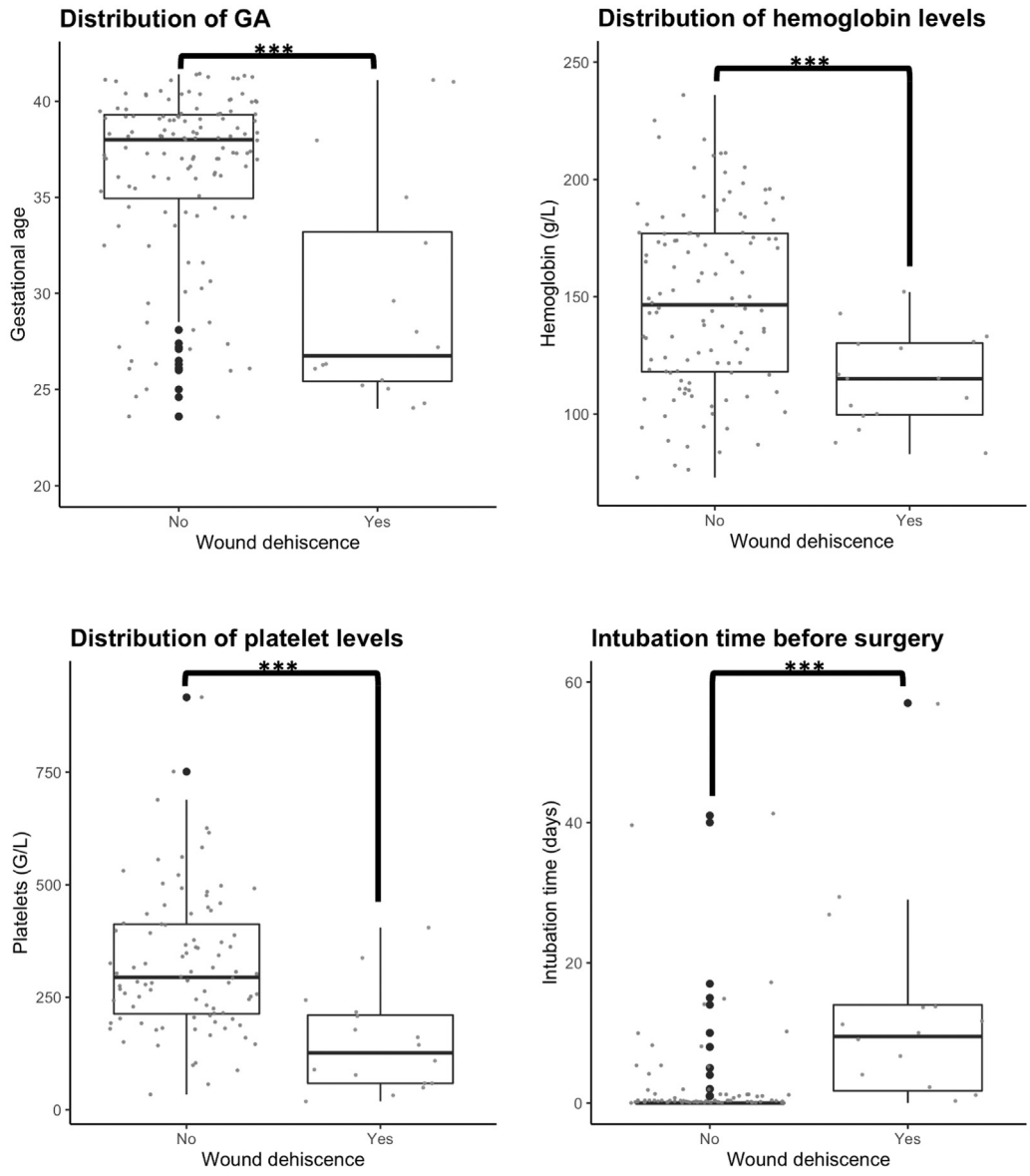

Fig. 2 Comparison of some variables representative of the child's general condition among patients with and without surgical wound dehiscence. Surgical wound dehiscence was significantly associated with gestational age ($p < 0.001$; median: 26 6/7 vs. 38), decreased levels of hemoglobin ($p < 0.001$; median: 115 g/L vs. 147 g/L), platelets ($p < 0.001$; median: 127 G/L vs. 295 G/L), and increased intubation time before surgery ($p < 0.001$; median: 10 days vs. 0 day) (Mann–Whitney *U* test).

developing SWD had a NEC, the latter usually arising after the first postnatal week.

Other risk factors such as steroid and NSAID exposure were identified, which come along with severe prematurity and its comorbidities. Long-term corticosteroid use has already been identified as a risk factor in adults[8,26,27] and has also been independently associated with SWD in the pediatric population,[28] explained by the resulting impaired wound healing.[29] On the other hand, several studies have shown that NSAID use has a controversial impact on wound healing. Experimental research on rats showed that NSAID use has an impact on bone wound healing by decreasing bone mineral density under parecoxib and indomethacin.[30] Their use has also been associated with a higher occurrence of anastomotic leakage.[31–33] This contradicts another experimental study conducted under diclofenac and ketorolac.[34] Other groups deny the impact of NSAID use on anastomotic leakage.[35–37] Our study shows an association of SWD with NSAID use, which can be explained not only by patient comorbidities but also by the histopathological effect of NSAIDs.[38] Indeed, inflammation and its associated production of prostaglandins are critical for adequate wound healing.[39] Furthermore, the application of prostaglandin (PGE2) has been used as a therapeutic strategy to enhance tissue repair.[40,41]

In this study, intubation time before and after surgery was also identified risk factors for SWD. They are correlated to the patients' comorbidities and vulnerability and might thus be used as indicators of hemodynamic instability and consequently contribute to the development of SWD.

Low hemoglobin/hematocrit levels and blood transfusions during surgery were associated with SWD, which is

Table 3 Wound dehiscence in patients with NEC/intestinal perforations

Characteristics	Patients with NEC/ intestinal perforations with surgical wound dehiscence ($N = 13$)		Patients with NEC/intestinal perforations without surgical wound dehiscence ($N = 14$)		*p*-Value
Patient information					
Preterm newborns	92%	12/13	79%	11/14	0.60
Age at surgery (d)	13 (9–56)	13	9 (4–27)	14	0.08
Gestational age at birth (wk)	$26^{3/7}$ ($25^{2/7}$–28)	13	$27^{1/7}$ ($25^{2/7}$–$34^{4/7}$)	14	0.54
Sex		13		14	0.38
Female	15%	2	36%	5	
Male	85%	11	64%	9	
Birth weight (kg)	0.8 (0.7–1.1)	12	0.9 (0.6–2.4)	14	0.66
Apgar score at 10 min	8 (7–8.3)	12	9 (8–10)	13	0.10
IUGR < 10th percentile	25%	3/12	0%	0/13	0.08
Postnatal steroid exposure	67%	8/12	7%	1/14	< **0.01**
NSAID exposure	31%	4/13	21%	3/14	0.68
Preoperative data					
Intubation time before surgery (d)	10 (4–14)	13	0 (0–7)	14	< **0.01**
Biological measures					
Hemoglobin (g/L)	115 (99–131)	13	109 (100–128)	13	0.92
Hematocrit (%)	35 (27–38)	13	30 (28–37)	13	0.96
Leukocytes (G/L)	9.7 (5.8–15)	13	17.6 (13–23.6)	11	< **0.05**
Neutrophils (abs.) (G/L)	4.3 (2.7–5.8)	12	9.7 (4.7–12.6)	11	0.06
Lymphocytes (G/L)	3.2 (2.3–5.8)	11	4.2 (2.2–5)	11	1
Platelets (G/L)	109 (59–178)	10	163 (92–213)	10	0.40
CRP (mg/L)[a]	75 (21–152)	10	6 (4–109)	9	0.09
Lactates (mmol/L)	2 (1.7–3.4)	12	1.5 (1.3–2.3)	13	0.31
Relaparotomy	23%	3/13	0%	0	0.10
Intraoperative data					
Use of amines during surgery	70%	7/10	62%	8/13	1
Operating time (min)	146 (103–200)	11	150 (117–184)	12	0.89
Surgical details					
Suture: skin (running suture)	45%	5/11	58%	7/12	0.68
Suture material: fascia - slowly absorbable	100%	12	100%	13	
Suture material: skin		11		13	0.83
Slowly absorbable	45%	5	54%	7	1
Rapidly absorbable	9%	1	0%	0	0.46
Nonabsorbable	45%	5	46%	6	1
Ostomy	85%	11/13	64%	9/14	0.38
Ostomy placement within the incision	36%	4/11	44%	4/8	0.66
Incision orientation		12		14	0.48
Horizontal	100%	12	86%	12	0.48
Vertical	0%	0	14%	2	0.48
Umbilical	0%	0	0%	0	1

(*Continued*)

Table 3 (*Continued*)

Characteristics	Patients with NEC/ intestinal perforations with surgical wound dehiscence ($N = 13$)		Patients with NEC/intestinal perforations without surgical wound dehiscence ($N = 14$)		*p*-Value
Postoperative data					
Amines (within 5 d post-op)	54%	7/13	36%	5/14	0.45
Intubation (within 5 d post-op)	92%	12/13	93%	13/14	1
Wound					
Redness	100%	10/10	42%	5/12	< **0.01**
Abscess	30%	3/10	17%	2/12	0.62
Positive bacteriological cultures (wound)	62%	8/13	29%	4/14	0.13

Abbreviations: abs., absolute; CRP, C-reactive protein; IUGR, intrauterine growth restriction; NEC, necrotizing enterocolitis; NSAID, nonsteroidal anti-inflammatory drug.
Note: All values are presented as percentages or medians (Q1–Q3).
[a] > 30% missing data.

consistent with other studies identifying anemia as a major risk factor for SWD,[42] both in adults[5,11] and in children.[6,18] The supply of oxygen is crucial to ensure the proper healing of tissues given its role in adenosine triphosphate synthesis, destruction of bacteria, cell multiplication, angiogenesis, and collagen production.[43,44] Postoperative amine use was also significantly associated with SWD. We hypothesize that this is due to the vasoconstrictor effect of amines, which subsequently reduces abdominal wall and skin perfusion.

Surgical details such as orientation were not identified in the present series as risk factors, unlike in the study of Waldhausen and Davies reporting the higher association of vertical incisions in children with SWD.[45] Of note, the vast majority of patients at our institution had horizontal incisions according to the surgeons' preference. This approach is in line with the study of Campbell and Swenson, supporting transverse incisions in the prevention of wound dehiscence.[46] Yet, in our series, all patients presenting wound dehiscence had horizontal incisions. This can be explained by the increased number of NEC/perforations in this group who mostly had horizontal and obviously never umbilical incision. Umbilical incisions were mostly performed in the context of hypertrophic pyloric stenosis or laparoschisis and do not concern this specific population of NEC patients or patients with intestinal perforation. Operating time was not shown to be a significant risk factor for SWD either; this in contrary to the study of Gowd et al identifying time as a linear risk factor of SWD after open reduction and fixation of ankle fractures,[47] a type of surgery rather not comparable to our analyzed cohort.

However, the need for an ostomy was a significant risk factor for the development of SWD. This is not surprising, given that ostomies increase wound complications[48–50] and structurally weaken the abdominal wall. Yet we showed that it was not a risk factor to place the ostomy within the incision. This has already been shown by Kronfli et al, who revealed in a study of 113 stoma formations in 106 neonates that stomas sited adjacently within the laparotomy did not increase postoperative complications.[51]

As for suture material, the use of nonabsorbable sutures for the skin closure increased the risk for SWD. It has been described that absorbable sutures allow for reduced tension of the incision and a higher proximity of wound borders,[52] probably contributing to a better wound healing. Nonabsorbable suture material has been shown to create an increased inflammatory reaction, with excessive fibrous tissue and thus poor scarring.[53] This finding is of importance for surgeons and may lead to change in practice, since the use of nonabsorbable suture material is still recommended in many clinics in the situation of a contaminated wound such as patients with NEC.

Unsurprisingly, SWD was highly associated with local infections and its classical findings of wound redness, abscess formation, and positive local bacteriological cultures. These findings are in line with the literature.[6,8,17,54,55] A generalized inflammatory condition of the patient, reflected by low neutrophils and platelet levels and high CRP levels, was also associated with SWD. Since platelets play an important role in the first phase of wound healing,[56,57] their decrease can potentially impair the wound healing process. This finding was in contrast with a study conducted by Szpaderska et al on thrombocytopenic mice concluding that "the presence of platelets may influence wound inflammation, but that platelets do not significantly affect the proliferative aspects of repair, including wound closure, angiogenesis, and collagen synthesis."[58] It is important to note that all patients were treated with antibiotics according to hospital guidelines.

Finally, it should be noted that the three cases of SWD in full-term neonates were complex situations usually encountered in tertiary centers only: a patient after neonatal liver transplantation, a patient with neonatal liver failure needing liver biopsies, and a patient with an NEC, thus all newborns with a context of extraordinary laparotomies or diagnoses.

Limitations of the Study

The two main limitations of the present study are its retrospective design and the limited number of patients. Thus, no multivariate logistic regression analyses were performed, and the study was limited to univariate analyses, thus potentially leading to biases and confounding factors.

Considerations for the Pediatric Surgeon

Despite the rather small study size, we observe a clear pattern of patients developing SWD: the most vulnerable patient is the infected, very sick, premature baby needing an ostomy. In one of five cases, this neonate will develop an SWD. Unfortunately, our study did not reveal substantial risk factors related to the surgery itself. Nevertheless, there are three measures the pediatric surgeon can take to reduce the risk of SWD. First, it appears that the use of absorbable suture material for skin closure is superior over nonabsorbable, creating better wound edge approximation and less inflammation. Second, there seems to be a trend to have less SWD in patients where the skin was closed with interrupted stitches, compared with running sutures. And third, since the sick baby who will develop SWD typically is in a weak general condition with poor tissue oxygenation, the surgeon may want to actively stimulate wound healing by applying a vacuum-assisted closure (VAC), thus reducing edema and infection and increasing local blood flow and consequently promoting healing and potentially reducing SWD. There are numerous reports suggesting that the pediatric surgeon might increasingly use VAC also in neonates.[59–61] Although placement of the stoma inside or outside the incision does not appear to be associated with SWD, it may be preferable to place it outside to facilitate VAC.

Conclusion

This study supports the hypotheses that preterm newborns have a higher risk of developing SWD than full-term newborns and that the premature newborns' bad general condition is a major risk factor. Some of the identified risk factors can help physicians recognize and respond to at-risk patients and provide better counseling for parents.

Author Contributions

Study conception and design: BEW, TBSM. Data acquisition: TBSM. Analysis and data interpretation: TBSM, BEW. Drafting of the manuscript: TBSM, BEW. Critical revision: PI, OB.

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Conflict of Interest

None declared.

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