

Uterine closure after cesarean delivery: surgical principles, biological rationale, and clinical implications

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Normal uterine function depends on cyclical regeneration and the capacity to sustain pregnancy. A cesarean incision, however, represents an injury to this remarkable organ. Although the uterus possesses exceptional healing potential, cesarean delivery increases the risk of secondary infertility, pain, uterine rupture, and abnormal placentation in later pregnancies. The method of closure can profoundly influence future uterine function. The 2 most important determinants of successful hysterotomy healing after cesarean delivery are the location of the incision and the surgical technique used for closure. The anatomic site of entry—whether the corpus, lower uterine segment, or cervix—defines the tissue composition, vascularity, and contractility at the wound margins, which in turn influence how the scar remodels and withstands subsequent pregnancies. Surgical technique is also important. A robust body of experimental and clinical evidence demonstrates that restoring anatomic integrity by reapproximating uterine layers while excluding the endometrium produces stronger scars and reduces late complications. The rationale for excluding the endometrium is to prevent displacement of endometrial tissue into the myometrium and to avoid mucosal tearing against a foreign body such as suture material, both of which predispose defective healing. When the endometrium is incorporated, healing is often impaired, leading to niches or isthmoceles, adenomyosis-like invasion, and endometriosis at the scar site. Over time, these defects have been recognized as contributors to abnormal bleeding, pelvic pain, infertility, uterine rupture, and placenta accreta spectrum disorders. Despite this evidence, single-layer closures that incorporate endometrium became widely adopted in many centers because of their speed and simplicity, while their long-term sequel was initially underappreciated. This has prompted renewed scrutiny of closure techniques, including comparisons of single-layer vs double-layer closure, locking vs nonlocking sutures, type of sutures, and the direction of suture. Collectively, the data show that optimal closure respects uterine anatomy, restores the natural alignment of tissues, and achieves hemostasis without compromising perfusion or strangulating tissue. Building on these principles, we herein describe a refined 3-layer closure. The first layer approximates decidua and junctional myometrium while excluding surface endometrium to prevent tissue entrapment and bacterial contamination. The second layer restores anatomic wall integrity by reapproximating the bulk of the myometrium, thereby reinforcing strength and distributing tension across the scar. The third layer reapproximates superficial myometrium and serosa, smoothing the uterine surface and reducing adhesions. This technique is not simply a return to traditional double-layer methods or an extension of single-layer practice, but rather a refinement that integrates lessons from visceral surgery and contemporary obstetric data. Its rationale is to restore anatomy, secure hemostasis without ischemia, and preserve long-term uterine function. While short-term safety appears comparable across closure methods, evidence increasingly indicates that long-term reproductive outcomes depend on how closure respects tissue biology. We argue that proper repair is more important than a fast repair: meticulous restoration of uterine anatomy should take precedence over operative speed, as long-term reproductive outcomes depend on how closure respects tissue biology. Further experimental and clinical studies are required to inform one of the most important aspects of the most common surgical procedure worldwide, cesarean delivery, that profoundly shapes women's reproductive health.

Key words: adenomyosis, animal experimentation, cervical dilation, cesarean, cesarean scar pregnancy, chorioamnionitis, decidua, decidual myometrial junction, electrosurgery, endometrium, endometritis, endometriosis, healing time, hysterotomy, hysterosonography, hysterosalpingography, intraperitoneal adhesions, isthmocoele, labor, locked suture, lower uterine segment, myometrium, pelvic pain, placenta accreta spectrum disorders, post menstrual bleeding, preterm delivery, purse string suture, residual myometrial thickness, secondary infertility, single layer, suture, three layer, two layer, uterine rupture, uterine dehiscence, uterine scar defect, uterine scar niche, ultrasound, uterus closure

Introduction

Closure of the hysterotomy during cesarean delivery is often considered a routine step. Yet, it is a surgical and biologically consequential act that influences not only immediate operative outcomes but also long-term gynecologic health, fertility, and risks in future pregnancies (Table). Two factors are

fundamental to successful healing: the site of the incision and the method of closure. The anatomic location of the hysterotomy determines the nature of the tissue incised—whether it involves the uterine body, the lower uterine segment, or the cervix—each characterized by distinct structural and vascular properties. The chosen closure

technique then dictates how these tissues are reapproximated: whether the endometrium is excluded, whether vascular perfusion is preserved, and whether the serosal surface is restored. Together, these elements determine the structural integrity of the uterine wall, the quality of the cesarean scar, and its far-reaching clinical implications.

TABLE

Long-term complications following cesarean delivery

Complications	Frequency	Remarks	References
Pelvic pain	11%–35% ^a	Increase of dysmenorrhea, dyspareunia, chronic pelvic pain, and suprapubic pain.	1–7
Postmenstrual spotting	33% ^a	Observed in up to 60% of women with uterine scar niche.	1,2,5,8,9
Endometriosis/adenomyosis	0%–89% ^a	Uterine scar endometriosis is common in presence of a scar niche.	3,10–13
Secondary infertility	5%–13% ^a	Impaired uterine healing is associated with delayed conception.	12,14–19
Abdominal adhesions	24%–46%	Increased at each subsequent cesarean and associated with longer operative time.	19–23
Cesarean scar pregnancy	0.05%–0.2% ^a	Related to uterine scar niche and best diagnosed at 6–8 weeks.	24–39
Placenta accreta spectrum	0.3%–6.8% ^a	In case of placenta previa, frequency and perinatal morbidity are greatly increased.	34,39–49
Spontaneous preterm birth	8%–28% ^a	Significantly increased with prior second-stage cesarean.	50–55,58,59
Uterine rupture	0.1%–3.4% ^a	More frequent among women undergoing a trial of labor after cesarean.	60–71

^a Higher frequencies in presence of uterine scar niche.

This review integrates experimental observations, histologic and imaging studies, and surgical experience to examine the biology of uterine scar formation after cesarean delivery. We trace the evolution of closure techniques, identify factors that contribute to optimal or defective healing, and discuss the implications for future reproductive outcomes. Our objective is to provide clinicians with a biologically informed

and surgically practical framework for uterine closure that minimizes short-term complications and reduces the burden of long-term sequelae.

A substantial body of research has examined the biology of uterine healing, yet this knowledge is rarely integrated into everyday clinical practice. To bridge this gap, this review includes a series of concise summary boxes that highlight key biologic and surgical concepts, offering a quick

reference to foundational studies and practical insights that inform optimal closure techniques.

How does the uterine scar heal and why is it important?

Healing of a hysterotomy unfolds in 3 overlapping phases: inflammation, repair, and remodeling. The inflammatory phase begins immediately and typically lasts 3 to 5 days, characterized by

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BOX 1**Endometrial reepithelialization and lessons for cesarean scar healing****Physiologic reepithelialization**

After menstruation, the denuded surface is rapidly recovered (within 3–5 days) by migration and sheet expansion of epithelial cells from residual basal glands, with proliferation reinforcing the new layer.^{164–166} Scanning electron microscopy shows epithelial “tongues” extending from glandular stumps, explaining why repair is typically scar-free.

Postpartum reepithelialization

After delivery, particularly at the placental bed, repair follows the same principle on a larger scale. Classic pathology and electron microscopy demonstrated that reepithelialization arises from basal glands spreading across a provisional fibrin scaffold, coordinated with vascular involution and stromal remodeling.^{164,167–169} Nonplacental areas are recovered within ~1 to 2 weeks, while placental-site repair may extend to 6 weeks.

Animal lineage-tracing confirms that mesenchymal–epithelial transition can supplement epithelial repair in menstruation.^{170,87}

Cesarean scar implications

A cesarean incision interrupts these processes. Healing requires preservation of basal glands, avoidance of endometrial inclusion in sutures, minimization of cautery or crush injury, and prevention of infection. When these are compromised, incomplete reepithelialization can predispose to impaired healing and its related complications.^{95,171} Thus, surgical technique can be biologically important for long-term uterine health.

Role of epithelial tension

Recent work in the intestinal epithelium shows that epithelial integrity depends on a tension-based “tug of war”: cells unable to sustain basal actomyosin tension are extruded by neighbors, preserving barrier function.¹⁷² By analogy, the endometrium may also rely on tension-mediated extrusion of damaged cells during repair, a concept not yet studied but highly relevant to uterine scars.

hemostasis, leukocyte infiltration, and activation of cytokine networks.^{72–74} The reparative phase follows from around day 4 through 2 to 3 weeks, with fibroblast proliferation, angiogenesis, and deposition of extracellular matrix. Remodeling begins by 3 to 4 weeks and may continue for months to a year, marked by collagen reorganization and gradual recovery of tensile strength. Endometrial reepithelialization plays a crucial role in maintaining the integrity of uterine function and can be disrupted by a hysterotomy and its repair (Box 1). Unlike cutaneous wounds, however, uterine repair occurs in the unique context of involution and profound hormonal changes. The rapid fall in estrogen and progesterone after delivery, combined with myometrial contraction and a catabolic state, creates a biologic environment unlike any other site of surgical healing. These biological phases have direct clinical relevance. For example, short interpregnancy intervals increase the likelihood of uterine rupture and abnormal placentation, most likely because conception occurs before scar remodeling is complete.^{75–77} The prolonged nature of the remodeling phase highlights why adequate spacing between deliveries is important, and why the technique of hysterotomy closure has implications not only for immediate

repair but also for outcomes in subsequent pregnancies.

Evolution of knowledge on hysterotomy incision healing

Systematic investigation of uterine scar healing began in the early twentieth century, motivated by the occurrence of uterine rupture after cesarean delivery and Cragin’s dictum, “once a cesarean, always a cesarean”.⁷⁸ At the Harvard Surgical Laboratory, Mason and Williams (1910) combined animal experiments and clinical observations to demonstrate that with careful suturing, the uterus could withstand subsequent pregnancy and labor, and that rupture nearly always occurred along the scar rather than through intact myometrium.⁷⁹ Histologic descriptions from Spalding (1917) and Losee (1917) provided early evidence that cesarean scars consisted mainly of fibrous tissue with limited muscle regeneration and that healing was impaired when infection or placental implantation involved the incision site.^{80,81}

Further progress came from Washington University, St. Louis, where Schwarz and Paddock (1925) studied both human and experimental material. They found that healed incisions were composed largely of fibrous tissue with minimal myocyte regeneration,

establishing that the scar was biologically distinct from normal myometrium.⁸² In 1938, Schwarz et al confirmed these findings using mechanical testing: scarred uteri ruptured at lower intraluminal pressures than unscarred controls, correlating biomechanical weakness with disorganized fibrotic architecture.⁸³

The focus then turned to minimizing inflammation from suture material and improving tissue approximation. In 1942, Potter and Elton proposed an interrupted closure technique that excluded the endometrium and brought only the external myometrium into accurate apposition to reduce ischemia and foreign-body reaction in vertical incisions.⁸⁴ In 1954, Potter and Johnston applied similar principles to low transverse hysterotomy, using interrupted silk sutures through the outer third of the myometrium and fine plain catgut for the peritoneal flap.⁸⁵ These studies advanced the concept that optimal repair requires the use of the smallest amount of nonreactive suture necessary to ensure accurate apposition and hemostasis while avoiding excessive tension that could lead to ischemia.

An important contribution came from the work of Leslie O.S. Poidevin (1961), whose doctoral thesis at the University of Adelaide combined animal experiments and clinical hysterography.^{11,86,88} He

BOX 2

Key animal studies in the evolution of the uterine closure technique

- Schwarz and Paddock, 1925 (guinea pig): This study demonstrated that fibroblast proliferation is the fundamental mechanism of uterine scar healing and that endometrial inclusion, although occasional, may interfere with orderly myometrial repair.⁸²
- Poidevin, 1961 (cat & rabbit): This work established that the quality of uterine scar healing after cesarean delivery depends primarily on surgical technique and that including the endometrium in the suture line is the main factor leading to scar dehiscence and niche formation.^{86,88}
- Csúcs, 1970 (rabbit): In this experimental cesarean model, suturing only the outer myometrial layer while excluding the endometrium produced optimal healing, supporting the principle that precise tissue apposition, not multilayer closure, is key to uterine scar integrity.^{89,90}
- Dunnihoop et al, 1989 (rabbit): In this experimental cesarean model, eversion during uterine closure altered scar histology by exposing endometrial cells on the surface, while the choice between interrupted and continuous sutures did not affect scar strength.¹⁷³
- Einarsson J.I. et al, 2011 (sheep): In a nonpregnant sheep uterine incision model, barbed and conventional Vicryl sutures used for myometrial closure resulted in similar degrees of adhesion formation at necropsy, indicating no significant difference in postoperative adhesions.¹⁷⁴
- Lapointe-Milot et al, 2014 (sheep): In a randomized trial, comparing single vs double layers, uterine healing was compromised when the endometrium was included in the suture line, and a second layer did not compensate for this defect, highlighting the importance of correct tissue apposition rather than layer number alone in optimizing cesarean scar repair.¹⁷⁵
- Api et al, 2015 (rat): In the rat myomectomy model, barbed sutures caused greater inflammatory cell infiltration, fibroblast proliferation, and collagen deposition than Vicryl leading to more pronounced adhesion formation on the uterine serosa.¹⁷⁶
- Li et al, 2020 (mouse): In a mouse model of uterine scarring, the authors showed that fibrotic remodeling and persistent inflammation blunt the endometrium's response to ovarian steroids. Scarred uteri displayed reduced progesterone and estrogen receptor expression, downregulation of implantation-related genes (*Hoxa10*, *Hoxa11*, *Lif*, *Bmp2*), and defective decidualization. Functionally, this led to fewer implantation sites, abnormal placentation, and higher pregnancy loss, demonstrating that uterine scarring compromises fertility by impairing steroid-mediated endometrial receptivity.¹⁷⁷
- Debras et al, 2025 (rabbit): The investigators first created a cesarean scar in rabbits, allowed healing, and then—in a later experiment—induced uterine distension with a balloon to mimic the mechanical stress of labor. Rupture occurred in 47% of cases, most frequently at the prior scar site, confirming that polarimetric inhomogeneity (disordered collagen organization) corresponded to reduced mechanical strength.¹⁷⁸

showed that healing was strongest when closure achieved muscle-to-muscle apposition and excluded endometrium, whereas inclusion of endometrium led to weak, collagen-rich scars and pouch-like defects—later recognized as niches or

isthmocèles. His research established the biologic rationale for endometrium-excluding techniques (details are described in the next section).

Csúcs et al (1970) in Hungary proposed a single-layer closure limited to

the superficial myometrium, allowing the endometrium and deeper layers to heal spontaneously.^{89,90} In rabbits, this method provided healing comparable to 2-layer closure, and clinical observations suggested its feasibility in humans.

BOX 3

Summary of recent studies of hysterotomy wound healing

Recent research has advanced our understanding of the biology of cesarean scar formation, using histology, imaging, molecular markers, and experimental therapies. Key findings include:

- Hysterectomy specimens from women with prior cesarean showed scars dominated by fibrous tissue, reduced smooth muscle, and marked disorganization.¹⁷⁹
- Quantitative analyses with immunohistochemistry and electron microscopy demonstrated increased collagen types I and III, altered collagen ratios, and ultrastructural myocyte disruption. Cesarean scars were collagen-dense and architecturally distinct from normal myometrium.¹⁸⁰
- Myofibroblast activity (α -smooth muscle actin staining and elastin) remains consistent in scars beyond a period of 13 months following cesarean suggesting a limited window of active remodeling.¹⁸¹
- Immunohistochemical data indicate that TGF- β 1 promotes fibroblast activation, collagen deposition, and contraction, whereas TGF- β 3 is associated with more regenerative healing. Reduced TGF- β 3 expression has been reported in cesarean scar defects, suggesting a shift toward fibrosis.¹⁸²
- Clusters of adipocytes were identified within some human cesarean scars, with transient adipocyte presence also noted in animal uterine scars. These findings raise the possibility of metabolic-immune interactions in scar biology.¹⁸³
- Transplantation of human umbilical cord—derived mesenchymal stem cells in rat models promoted scar healing, with reduced fibrosis, improved vascularization, and enhanced myometrial regeneration. Effects were linked to modulation of the TGF- β /Smad pathway.¹⁸⁴
- Human umbilical cord—derived mesenchymal stem cells combined with a collagen scaffold enhanced regeneration of full-thickness uterine scars in rat models, improved collagen remodeling, and restored fertility.⁵⁶
- A phase 1 clinical trial of human umbilical cord—derived mesenchymal stem cell infusion in women with poor uterine healing after surgical injury showed early improvement in symptoms and tissue repair, although larger controlled studies are needed.⁵⁷

This study is one of several that have been conducted using animal models to investigate surgical techniques for uterine closure (Box 2).

In the 1970s, locked single-layer closure including the endometrium gained popularity because of technical simplicity and shorter operative time (details of the debate are described in the next section). However, accumulating evidence now links this method to higher rates of scar defects and increased risk of uterine rupture in subsequent pregnancies.^{91–94} Three main mechanisms have been proposed for the increased risk of defective scars with single-layer techniques: 1) incomplete apposition of the inner myometrial layer (Figure 1); 2) malalignment or strangulation of myometrium leading to ischemia (Figure 2); and 3) implantation of endometrial cells into the suture line, resulting in ectopic endometrial tissue within the scar (Figure 3) that is not resolved with a second layer (Figure 4).^{3,11,95,96}

In summary, over the past century, experimental, histologic, and clinical investigations have revealed that uterine healing is a complex process influenced

by anatomic site, infection, labor, hormonal state, and surgical technique. Recognition of these factors has reshaped the understanding of why some scars remain strong and asymptomatic, while others predispose to rupture, abnormal bleeding, infertility, or placental invasion disorders in future pregnancies.⁹⁷ Box 3 summarizes recent studies on uterine wound healing and emerging therapeutic approaches.

The debate over single-layer vs double-layer closure.

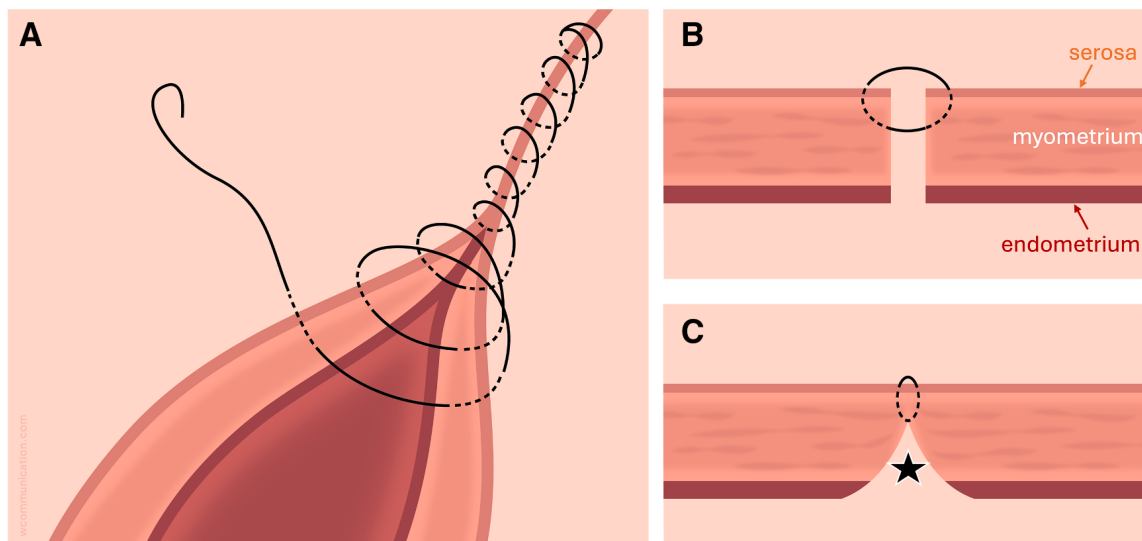
For much of the twentieth century, the uterine incision at cesarean delivery was routinely closed in 2 layers, following Kerr's 1926 description of the low transverse hysterotomy and the guidance of successive editions of *Williams Obstetrics*.^{98–107} In 1976, Pritchard and MacDonald observed that “the uterine incision may be closed with either one or the more traditional 2 layers of continuous chromic suture,” noting that a thin lower uterine segment could often be satisfactorily approximated with one layer.¹⁰⁸ This statement marked a turning point that prompted modern evaluation of the optimal closure method.

The first randomized trial, by Hauth et al published in 1992, compared a single locked continuous layer with a 2-layer closure.¹⁰⁹ The single-layer technique reduced operative time without increasing hemorrhage, infection, or extra hemostatic sutures. In the follow-up of 145 subsequent pregnancies (70 with single-layer and 75 with double-layer closure), no uterine ruptures were observed.¹¹⁰

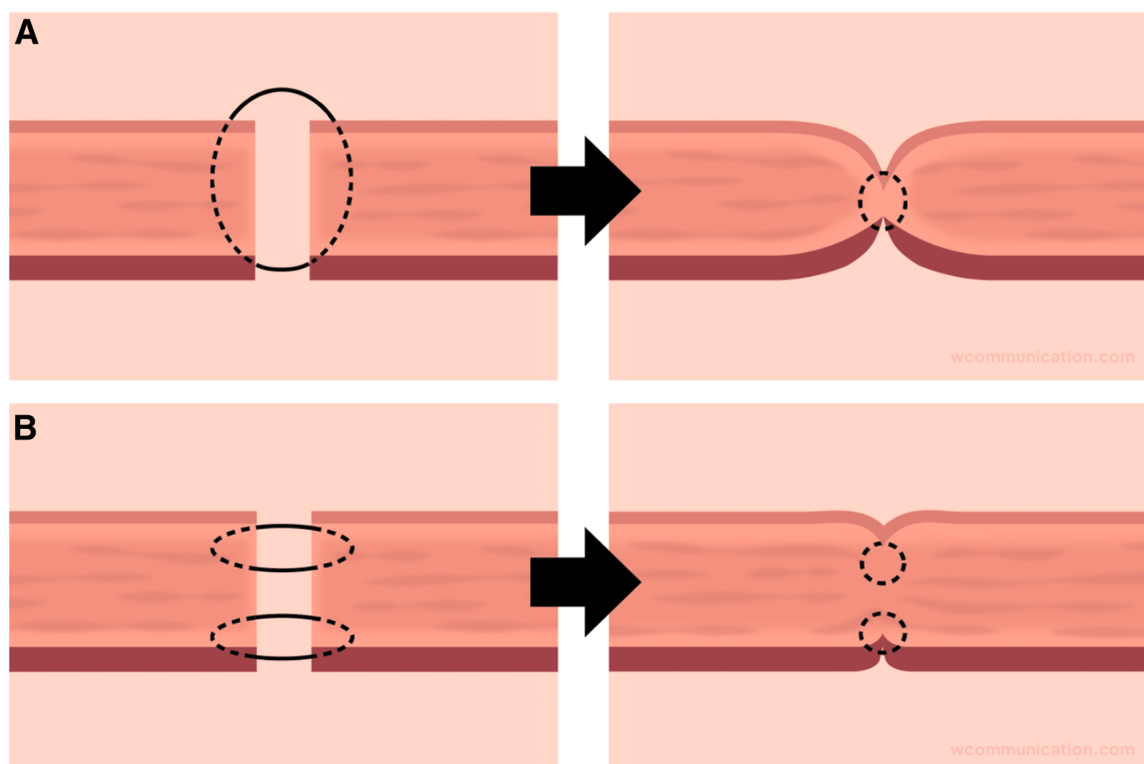
Subsequent studies produced conflicting results. Bujold et al^{93,94} reported that single-layer closure was associated with a higher risk of rupture during trial of labor after cesarean, whereas Roberge et al clarified that the excess risk was limited to locked single-layer closures that included endometrium, while unlocked single-layer closures were not associated with rupture.⁹¹ In a meta-analysis (2014), Roberge et al found that double-layer closure resulted in a thicker residual myometrium (+2.6 mm; 95% confidence interval [CI], 2.2–3.1) and that an unlocked first layer produced a thicker scar than a locked one (+2.5 mm; 95% CI, 1.8–3.2).⁹² Reviews that did not distinguish these technical variations found no differences in clinical outcomes.^{111,112}

FIGURE 1

First hypothesis for the mechanism of uterine scar defect: incomplete approximation of the myometrium



(A) The figure shows a superficial closure of the uterine wall in a single layer, not including the endometrium (darker). Including less tissue (B) may reduce strangulation but could cause incomplete approximation of the myometrium (C). The black star shows where the myometrium has not been appropriately approximated.

FIGURE 2**Second hypothesis: tissue strangulation is increased in single-layer compared to double-layer**

The figure illustrates that a single-layer closure encompassing the entire myometrium may cause tissue contraction and strangulation of the myometrium, by tightening the suture firmly, even with the avoidance of the endometrium (A), whereas a 2-layer closure, with more limited inclusion, permits better approximation and reduces the risk of tissue contraction and strangulation.

Blumenfeld et al later showed an increased risk of bladder adhesions after single-layer closure (odds ratio, 7.0; 95% CI, 1.7–28.1).¹¹³

Among major randomized trials, the Caesarean section surgical techniques: a randomised factorial trial (CAESAR)¹¹⁴ and Caesarean section surgical techniques (CORONIS) trial^{115–118} studies demonstrated no difference in short-term or long-term maternal outcomes between single-layer and double-layer closure, although specific suture techniques were not standardized. In contrast, the Cesarean-scar Thickness and Closure Technique trial by Bamberg et al.^{119,120} found greater residual myometrial thickness with a double-layer closure (7.9 mm; 95% CI, 6.4–10.2) than with either locked (6.7 mm; 95% CI, 5.1–8.8) or unlocked (6.6 mm; 95% CI, 5.0–8.8) single-layer methods ($P=.04$) among women who underwent primary cesarean. In the Niche In CEsaean Scar

Trial (NICEST) trial,¹²¹ double-layer closure produced fewer severe scar niches and thicker residual myometrium at 6 and 12 months, while in the 2Close study [a multicenter randomized controlled trial that compared single-versus double-layer closure of the uterus in the prevention of gynaecological symptoms in relation to niche development],^{122–125} no differences in niche frequency, gynecologic symptoms, or fertility were observed. However, when the endometrium was excluded within the single-layer closure group, the prevalence of niche formation was significantly reduced (59% [150/253] vs 72% [471/656]; relative risk [RR], 0.83; 95% CI, 0.74–0.93; $P=.001$).¹²⁴

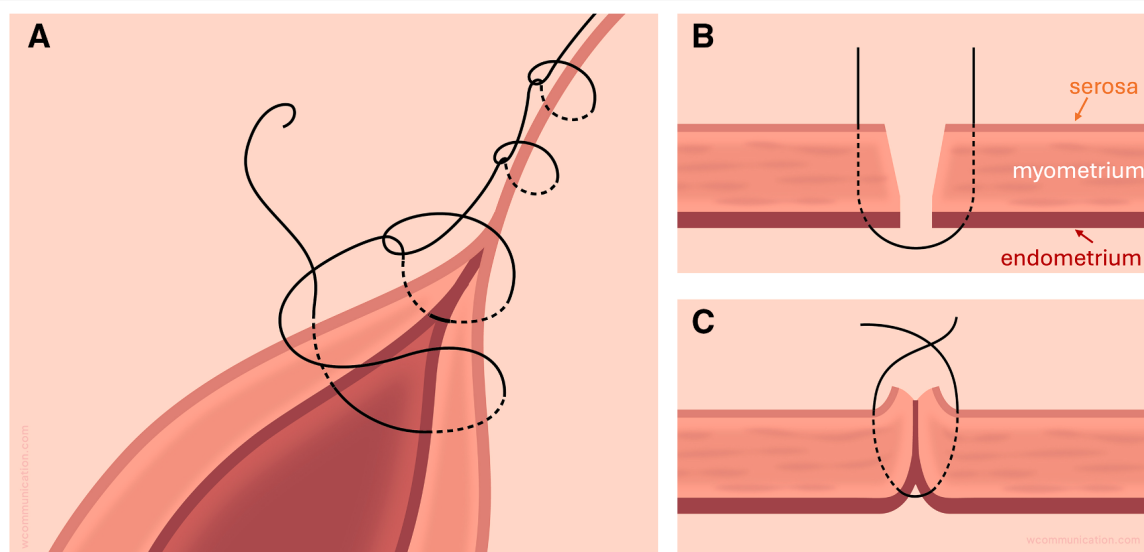
In summary, current evidence suggests that while a second layer may improve residual myometrial thickness, the critical factor for optimal healing is exclusion of the endometrium/decidua. The number of layers alone does not

ensure an intact scar unless myometrial approximation is achieved and endometrial inclusion is avoided.^{122,126,127}

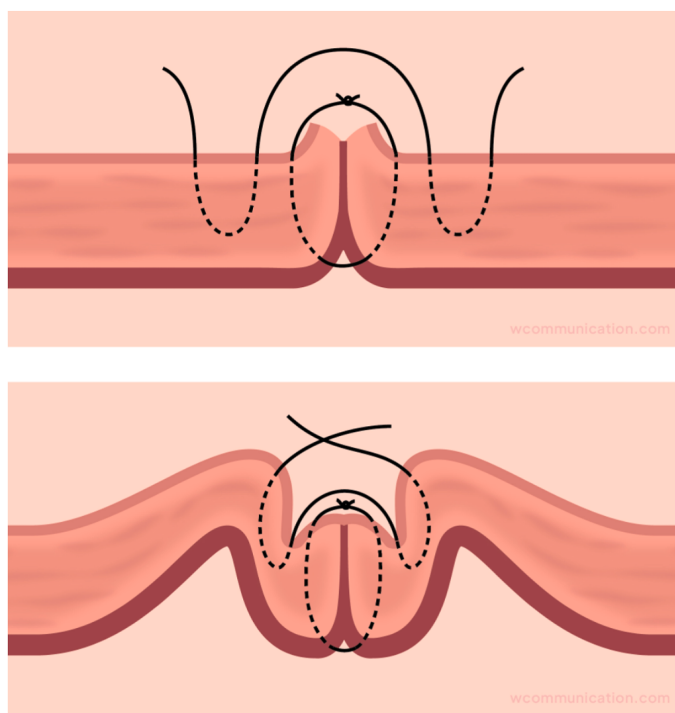
The story of inclusion and exclusion of the endometrium

From the nineteenth century onward, surgeons understood that incorporating the uterine lining into a hysterotomy closure was detrimental. In his classical report in 1891, Howard A. Kelly described the essential “do’s and don’ts” of cesarean technique and explicitly described exclusion of the endometrium.¹²⁸

Early obstetric surgeons were trained in general surgery, and their approach to cesarean repair reflected the principles of visceral closure established in operations on the bowel and stomach. In such procedures, the mucosal layer was excluded from the muscular suture line to prevent infection, leakage, or fistula formation. By analogy, the endometrium uterine mucosal lining was

FIGURE 3**Third hypothesis: inclusion of endometrial cells with locked single-layer, including the entire uterine wall**

(A) The figure shows full closure of the uterine wall in a single layer, including the endometrium (darker). Including all layers in a single layer, especially if the endometrium is included (B), leads to tissue strangulation, poor approximation of similar tissues, and inclusion of endometrial cells in the suture (C).

FIGURE 4**The effect of adding a second layer over a first layer including all uterine layers**

The figure shows the addition of a second layer covering the first, suggesting that the endometrium (dark) remains trapped inside the myometrium and that the second layer brings 2 distinct surfaces of the uterine peritoneum closer together.

considered a delicate and potentially contaminated surface that should not be incorporated into the sutures. This principle guided early cesarean techniques, ensuring apposition of myometrium to myometrium while avoiding decidual inclusion.

This concept persisted until the latter half of the twentieth century, when the introduction of single-layer continuous closure led some surgeons to include the endometrium in the suture line for simplicity and speed. However, careful experimental and clinical work by Leslie O.S. Poidevin at the University of Adelaide (1961) demonstrated that inclusion of the endometrium impaired healing.¹¹ In animal experiments using cats and rabbits, he compared closure techniques in opposite uterine horns: when the suture line included endometrium, defective healing occurred in 78% (14/18), whereas exclusion of the endometrium resulted in no defects (0/18).⁸⁸

Poidevin extended these findings to humans in an observational study of 202 women.¹²⁹ On hysterosonography, scar defects were observed far more frequently when the endometrium had been included in the closure—73% (93/

127)—than when it had been excluded—8% (6/75)—and all severe defects (100%, 14/14) occurred in the endometrium-included group. Histologic examination of hysterectomy specimens further confirmed these results, showing endometrial glands deep within the fibrotic scar in 89% (8/9) of women whose closures had incorporated the endometrium.¹¹

Subsequent investigators reaffirmed Poidevin's conclusions. Antoine et al summarized the accumulating experimental and clinical evidence that inclusion of the endometrium predisposes to scar defects and abnormal placentation, explicitly crediting Poidevin's pioneering contributions.^{127,130–133} Most recently, Lino et al (2025) synthesized data from 4 randomized trials including 392 women and confirmed that endometrium-excluding techniques halved the risk of scar defect (RR, 0.53; 95% CI, 0.34–0.82; $I^2=0\%$).¹³⁴

Together, these findings reaffirm a principle first drawn from general surgical experience and now supported by modern evidence: exclusion of the endometrium is essential for durable uterine healing regardless of whether closure is performed in 1 or 2 layers.

Continuous vs interrupted sutures

Two main strategies have been used to close the hysterotomy: continuous and interrupted suturing. Poidevin¹¹ observed that when the endometrium was excluded, interrupted sutures resulted in no scar defects (0%, 0/30), whereas continuous sutures produced defects in 13% (6/45). However, when the endometrium was included, defect rates were high regardless of technique—73% (91/124) with continuous and 67% (2/3) with interrupted sutures. These data suggested that the inclusion of endometrium, rather than the choice of suture technique, was the key factor determinant of poor healing.

A randomized trial by Tsuji et al¹³⁵ confirmed these experimental findings: severe defects were observed in only 2% (2/89) of women after interrupted 2-layer closure excluding the endometrium, compared with 22% (19/88) after continuous unlocked 2-layer closure

including the endometrium ($P<.001$). Similarly, Sumigama et al¹³⁶ reported a higher risk of placenta accreta spectrum with continuous sutures (odds ratio, 6.0; 95% CI, 1.4–25.2), although this retrospective study was limited by design.

Taken together, these studies indicate that interrupted suturing that excludes the endometrium is associated with the most favorable histologic and clinical outcomes. In routine obstetric practice, however, continuous suturing remains far more common, largely because it is faster, simpler, and easier to perform.

Locked vs unlocked sutures

Locking is a frequent modification of continuous suturing in which each needle pass loops and “locks” the thread, preventing slippage and allowing tighter tension control along the suture line. Although this technique provides mechanical security, its independent effect on uterine healing remains difficult to isolate because locking is often combined with single-layer closure and inclusion of the endometrium.

From a physiological standpoint, locking may concentrate stress and compromise microvascular perfusion at the myometrial edges, whereas non-locking sutures distribute tension more evenly, reducing focal ischemia and promoting tissue viability. Evidence from other visceral and mucosal closures supports this principle: locking sutures may offer short-term security but at the cost of increased tissue compression and inflammatory response.

Tarafdari et al¹³⁷ compared locked vs unlocked first layers—both including endometrium—and found that scar defects developed in all women at 6 months (30/30 locked, 26/26 unlocked). Although mean residual myometrial thickness did not differ significantly (4.12 ± 0.48 mm vs 4.44 ± 1.07 mm, $P=.14$), scar depth was greater in the unlocked group (3.77 ± 1.11 mm vs 3.16 ± 1.10 mm, $P=.04$). A larger trial involving 435 women also found no difference between locked and unlocked single-layer closures, both including endometrium, but demonstrated that double-layer closure with an unlocked

first layer produced thicker residual myometrium.^{119,120} In an observational study of 388 women, Hudic et al¹³⁸ observed similarly high rates of complete uterine rupture after both locked and unlocked single-layer closures (2.1% [1/47] vs 2.4% [2/85], $P=.93$).

Overall, the available data suggest that locking itself is not independently harmful, but it provides no measurable benefit and may impair microcirculation when used under high tension. Consequently, unlocked continuous sutures are generally preferred for hysterotomy closure, particularly when the first layer excludes the endometrium and achieves accurate myometrial apposition.

Suture material: catgut, synthetic multifilaments, monofilaments, and antimicrobial

Suture materials used for hysterotomy closure have evolved markedly over the past century. In early days, surgeons relied on silk and plain catgut, both of which produced marked tissue inflammation and were soon replaced by chromic catgut, a treated variant intended to slow absorption and reduce reactivity. However, even chromic catgut elicits a significant inflammatory response and has been associated with poorer-quality scars and delayed healing.¹³⁹ This recognition led to the adoption of synthetic absorbable polymers, such as polyglactin (Vicryl) and poliglecaprone (Monocryl), which provide more predictable absorption and minimal tissue reaction.

In an observational study of 1613 women, Vachon-Marceau et al¹⁴⁰ found no difference in third-trimester lower uterine segment thickness between catgut and synthetic multifilament sutures, and the CORONIS trial^{116,117} similarly found no significant difference in uterine rupture risk at subsequent delivery (0.2%; $n=3/1660$) catgut vs (0.06%; $n=1/1647$) synthetic (RR, 3.1; 95% CI, 0.3–29.3). However, Hosseini et al¹⁴¹ observed higher rates of scar defects with catgut (18.2%, $n=20/110$) than with Vicryl (9.3%; $n=13/140$) and greater residual myometrial thickness

with Vicryl (5.0 ± 2.2 mm vs 3.7 ± 1.5 mm; $P < .01$).

Recent randomized trials suggest that monofilament sutures may yield slightly thicker uterine scars than multifilament sutures ($+1.1$ mm residual myometrium across 3 trials, 499 women) but require approximately 3 additional minutes of operative time.¹⁴² Saccone et al,¹⁴³ in a trial of 300 women, found no significant differences in scar thickness or symptoms between monofilament and multifilament materials. Two meta-analyses suggested that the use of barbed sutures reduced uterus closure time by approximately 2 minutes but had no impact on intraoperative complications.^{142,144} However, a recent trial observed less scar niche using a double-layer closure with barbed sutures excluding the endometrium (29.1%; $n=32/110$) compared to conventional double-layer sutures (68.2%; $n=75/110$; $P < .001$).¹⁴⁵

Because braided multifilament sutures can harbor bacteria, triclosan-coated variants have been developed to reduce surgical site infection. Large meta-analyses in general surgery—Jalalzadeh et al¹⁴⁶ and Depuydt et al¹⁴⁷—reported approximately a 25% reduction in wound infection rates with antimicrobial-coated sutures. Although these have not been specifically studied in cesarean hysterotomy closure, they may benefit patients at high risk of infection (eg, those with chorioamnionitis, prolonged rupture of membranes, or confirmed intra-amniotic infection).

Overall, current evidence supports synthetic absorbable sutures as safe and effective, with monofilament materials showing modest potential advantages for long-term scar integrity. For the serosal layer, a rapidly resorbable monofilament appears a reasonable and biologically sound choice.

Amount of tissue included in the suture: large vs small “bites”

The extent and depth of tissue captured with each suture pass may influence long-term scar quality as much as the number or type of layers used. Taking full-thickness, widely spaced sutures

(large bites) can lead to tissue strangulation and ischemia, whereas very superficial or widely gapped passes may leave residual cavities or dead space. In uterine closure, precise, closely spaced, partial-thickness sutures (ie, small bites) promote accurate reapproximation of the myometrial edges while preserving perfusion. Evidence from general surgery reinforces this principle: in the small bites versus large bites for closure of abdominal midline incisions (STITCH) trial of abdominal fascial closure, fine, closely spaced suture placement (approximately 5 mm $\times$ 5 mm) significantly reduced incisional hernia rates compared with wider placement (10 mm $\times$ 10 mm) (13%; $n=35/268$ vs 21%; 57/277 at 1 year, $P < .05$).¹⁴⁸ Although this study addressed fascial rather than uterine repair, the underlying biomechanics are similar—narrow, equidistant suture placement distributes tension evenly along the incision, reducing localized ischemia and supporting stronger healing. Figure 5 illustrates how precise, short-interval suturing facilitates uniform apposition and minimizes reliance on thread tension for wound stability.

Parallel vs perpendicular suture direction

The orientation of sutures relative to the incision line may influence wound mechanics and healing. Experimental evidence from general surgery supports this concept. In a rat laparotomy model, Rappaport et al (1990) compared sutures placed parallel and perpendicular to the incision and found that parallel placement produced greater bursting strength, less inflammation, and less tissue necrosis, likely because tension was distributed along the wound axis rather than concentrated at discrete points.¹⁴⁹ Similarly, Lear et al (2020) showed in excisional skin wounds that tension distribution—more than suture material or type—determines whether sutures “cheese-wire” through tissue; parallel orientation provided more uniform stress and resistance to tearing.¹⁵⁰

Although the uterine wall differs in composition and mechanical loading,

analogous principles may apply. Aligning sutures parallel to the hysterotomy could reduce focal ischemia and stress across myometrial fibers, enhancing healing quality. Supporting this hypothesis, Alper et al¹⁵¹ observed in 497 women undergoing primary cesarean before labor that parallel-layered closure was associated with fewer scar defects (7.9% vs 16.3%, $P = .009$) and fewer long-term gynecologic symptoms (1.5% vs 7.8%, $P = .004$) compared with perpendicular single-locked closure. The purse-string technique described below also employs a parallel suture orientation, further underscoring the potential relevance of suture direction for optimizing uterine repair.

Direct approximation vs purse-string approximation

Traditional uterine repair involves direct approximation of the upper and lower edges of the hysterotomy. An alternative approach, described by Turan et al¹⁵² in Turkey, proposed a purse-string double-layer closure designed to reduce residual scar size. This technique employs 2 layers, excludes the endometrium, and places sutures parallel to the incision. Rather than securing knots at the ends, the suture is run circumferentially and tightened centrally, producing the characteristic purse-string appearance (Figure 6).

A meta-analysis of 8 randomized trials (751 women) suggested that the purse-string technique is associated with lower uterine scar defect than conventional single-layer or double-layer closures that included the endometrium (RR, 0.45; 95% CI, 0.36–0.58; $I^2 = 0\%$).¹⁵³ While these findings are encouraging, concerns remain regarding possible circumferential ischemia and tissue strangulation, and long-term safety data are still limited.

Summary of evidence

Current evidence supports a double-layer closure using synthetic absorbable suture, unlocked, and placed parallel to the incision, with the first layer excluding the endometrium, as the configuration most likely to promote optimal uterine

healing. These principles appear especially beneficial for primary cesarean deliveries and for procedures performed before the onset of labor.

Applying the principles of surgical technique to hysterotomy closure

The goal of uterine closure after cesarean delivery is to restore the organ's structural integrity while preserving its function for future pregnancies. Halsted's principles of safe surgery—gentle handling, meticulous hemostasis, preservation of blood supply, precise apposition of tissues, elimination of dead space, and tension-free closure—remain the cornerstone of durable repair.¹⁵⁴ The uterus, although biologically distinct and structurally much

thicker, follows similar logic: avoiding incorporation of the endometrium, reapproximating myometrium to myometrium, and protecting the serosa leads to a stronger, more functional scar.

To provide clinicians with a practical framework, we propose the REPAIR mnemonic, which translates these enduring surgical principles into the specific context of cesarean hysterotomy closure (Box 4).

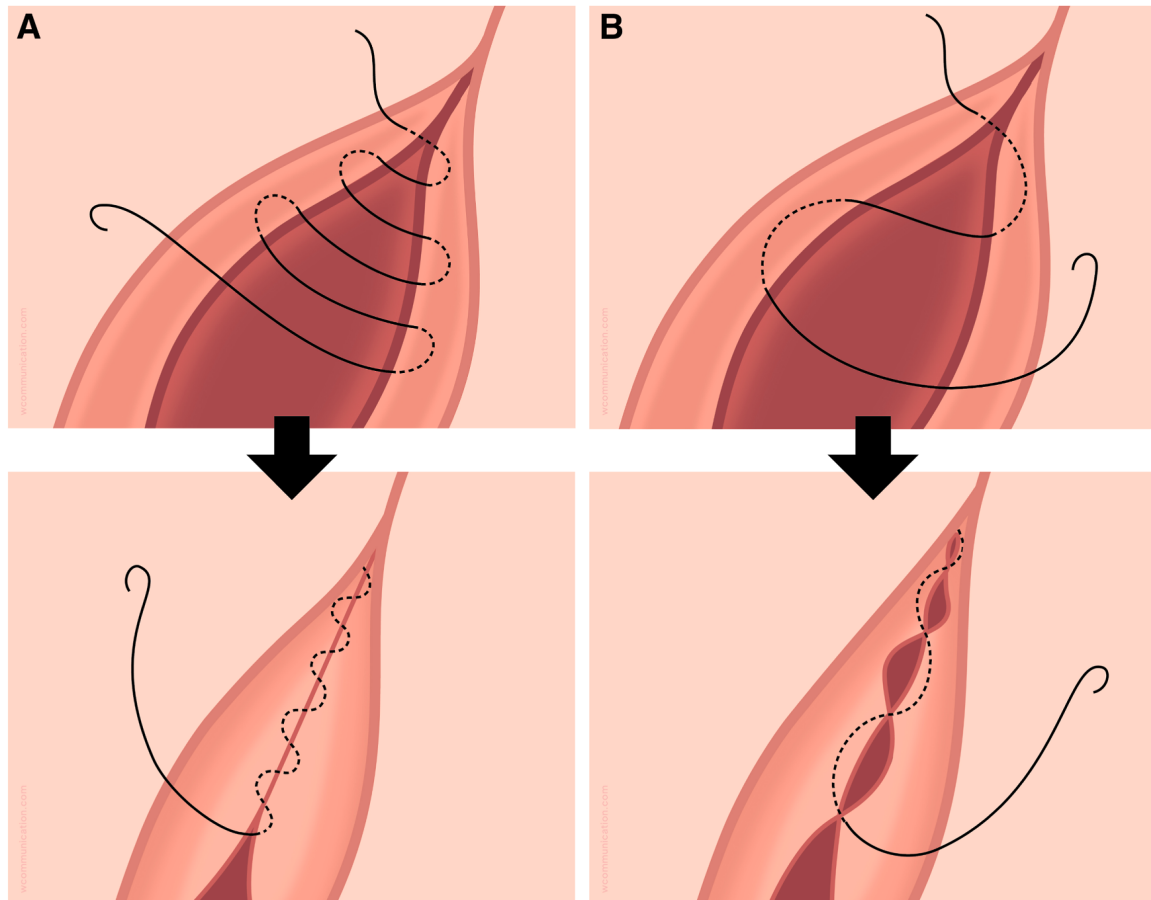
A 3-step approach for hysterotomy closure

The closure of a low transverse hysterotomy can be conceptualized as 3 distinct steps, each corresponding to a specific anatomical layer: the endometrium, the

myometrium, and the serosa (Figure 7). The first step reapproximates the endomyometrial junction while excluding the decidual surface. The second step restores uterine wall integrity by reapproximating the myometrium and minimizing dead space. The third step reapproximates the remaining superficial myometrium and serosa, ensuring coverage of exposed tissue, optimizing hemostasis, and reducing the need for cauterization.

This 3-step technique is particularly suitable for cesareans performed before or in early labor, when the lower uterine segment is relatively thick, and the different layers can be clearly distinguished. These are also the cases most at risk for scar defects and long-term

FIGURE 5
Comparison of closed vs spaced bites in continuous parallel sutures



(A) A suture with closely spaced stitches facilitates precise reapproximation and reduces reliance on suture tension. In contrast, widely spaced stitches often require greater traction on the suture, which increases the risk of tissue crushing and compromises optimal coaptation. (B) A parallel rather than a perpendicular suture reduces twisting of the tissue.

complications. In situations where the myometrium is thin, as in advanced labor, the first 2 steps can often be combined. The optimal method of closure for second-stage cesarean delivery remains uncertain, as the incision frequently extends into cervical tissue.^{50,155,156}

The first step: approximation at the endomyometrial junction

The goal of the first layer is to approximate the endomyometrial junction while avoiding incorporation of the endometrium. This prevents introducing bacteria into the wound, tearing fragile endometrium, and displacement of decidual cells into the myometrium, which may impair healing or promote adenomyosis and endometriosis. Inclusion of both myometrium and decidua increases the risk of scar defects and long-term complications.^{86,88,130,131,157} Because approximating decidua alone is technically difficult, sutures should be placed in the myometrium immediately above the junction. Sutures are generally placed parallel to the incision (Figure 8A); in friable tissue, a slight oblique angle may provide a more secure closure (Figure 8B). The aim is to

eliminate dead space while avoiding endometrial displacement into the myometrium. Figure 9 shows an example of parallel approximation. Large myometrial bites should be avoided, as they increase ischemia and tissue strangulation.

The second step: approximation of the myometrium

The second layer reapproximates myometrium to myometrium and is not intended to bury the first layer. Unless active bleeding is present, it is unnecessary to take large bites of myometrium. As in the first step, sutures placed parallel to the incision and near the myometrium–serosa junction ensure apposition with minimal tension or strangulation (Figure 10). This technique also keeps sutures beneath the uterine surface, reducing peritoneal exposure and adhesion formation. Figure 11 shows an example of myometrial approximation using a sub-serosal entry.

The third step: approximation of the superficial myometrium and serosa

The third layer aims to restore surface anatomy and optimize healing

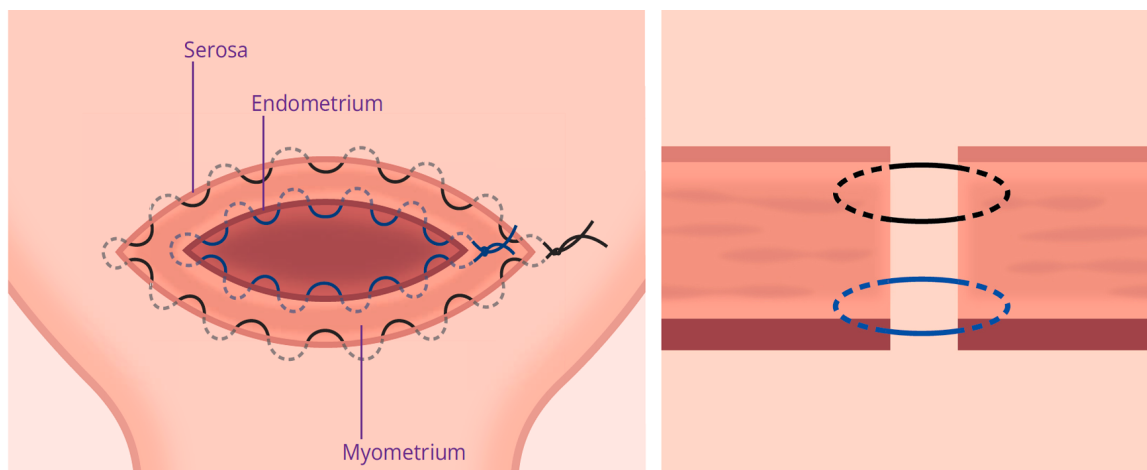
(Figure 12). This layer ensures that superficial myometrium left exposed after the second step is covered, reducing the risk of adhesions. When the myometrium is thick, the second layer should be placed deeply to avoid dead space, while the third layer closes the remaining myometrium and serosa. This layer also contributes to hemostasis, as small vessels are often present on the surface (Figure 13). Rather than relying on cautery, which may impair healing, gentle approximation with a fine absorbable suture can cover exposed myometrium and sutures, reduce bleeding, and minimize thermal injury.

Adaptation for thin myometrium

When the myometrium is thin (<5 mm), as often occurs after prolonged labor, a single first layer may be sufficient to reapproximate the entire thickness of the myometrium, with the suture positioned between the endometrium and the serosa. The next layer, in this context the equivalent of a ‘third layer’, can then be used to approximate the serosa with a fine absorbable suture, thereby reinforcing the closure in tissue that is often more fragile (Figure 14).

FIGURE 6

Purse-string double-layer closure



The purse-string technique uses 2 sutures placed parallel to the incision: the first at the endomyometrial junction (*blue suture*) and the second beneath the serosa (*black suture*). When tightened, the sutures encircle the incision and approximate all tissue layers toward the center.

Modified from Turan et al.¹⁵²

BOX 4

The REPAIR principles of uterine closure after cesarean

- **R:** Restore anatomy: This is the cardinal principle of surgical repair.
- **E:** Exclude endometrium/decidua: this tissue can interfere with wound healing, generate adenomyosis/endometriosis and carry bacteria from uterine cavity into the wound.
- **P:** Preserve tissue integrity by handling gently and using atraumatic instruments.
- **A:** Approximate both edges of the endomyometrial junction, myometrium to myometrium, and serosa to serosa.
- **I:** Ischemia prevention: use unlocked & tension-free sutures and avoid strangulation.
- **R:** Reduce dead space: Layered closure fills potential cavities, limiting hematoma formation and reducing the risk of infection.

Additional hemostatic sutures

The 3-step technique does not appear to increase the need for hemostatic sutures. When required, they can be used without compromising anatomic reapproximation and tissue handling principles. Although excessive hemostatic suturing could theoretically impair healing by distorting tissue or

entrapping decidual cells, limited use is unlikely to affect overall apposition.

Empirical evidence supporting the proposed surgical closure

Two prospective comparative studies—one quasi-randomized and one randomized—have evaluated closure techniques similar to this 3-step method, in

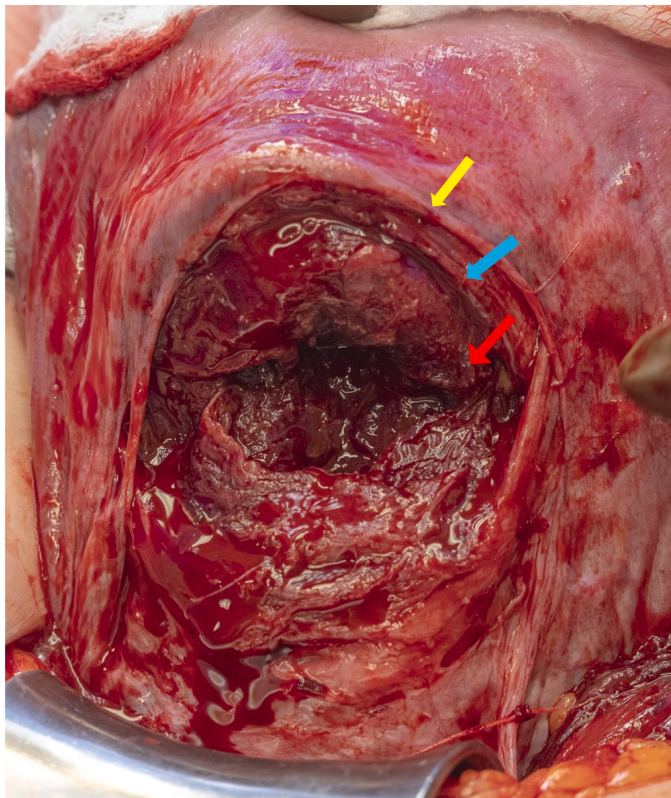
which the first layer is unlocked (or interrupted) and excludes the endometrium and the second layer reapproximates the residual myometrium. These designs differ slightly from the parallel second layer described in our proposed approach. Each trial included 2 control groups: a single-layer closure incorporating both myometrium and endometrium and a 2-layer closure in which the first layer included the endometrium and the second simply covered it.^{158,159}

In the quasi-randomized trial of 137 participants, Hayakawa et al¹⁵⁹ found significant differences in scar defect rates: 6% (2/36) for the 2-layer closure excluding the endometrium, 34% (17/50) for interrupted single-layer closure including the endometrium, and 16% (8/51) for 2-layer closure with the first layer including the endometrium ($P<.01$). In the randomized trial by Roberge et al¹⁵⁸ involving 81 participants, the corresponding rates of severe scar defect were 4% (1/26), 20% (5/25), and 5% (1/22), respectively ($P=.10$), while the residual myometrial thickness was significantly greater with the 2-layer closure excluding the endometrium (6.1 ± 2.2 mm) compared with the other 2 methods (3.8 ± 1.6 mm and 4.8 ± 1.3 mm, $P<.001$).

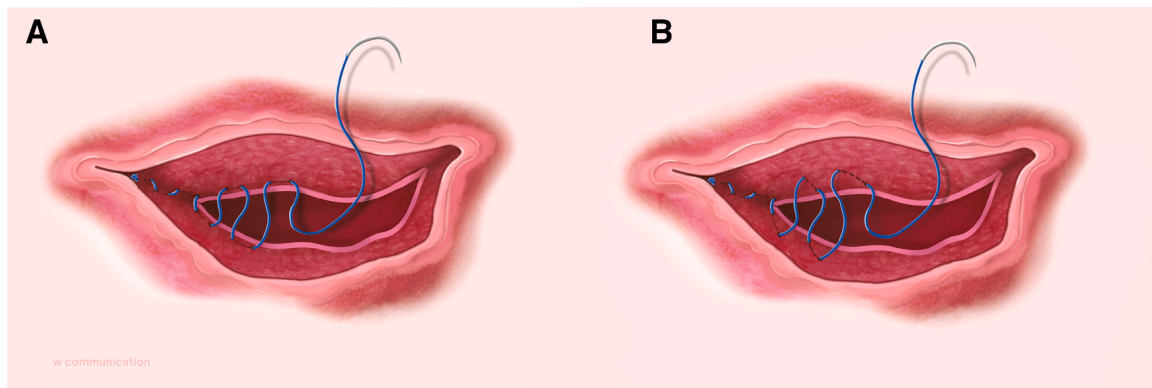
More recently, Özler et al¹⁶⁰ compared double-layer closure with an unlocked first layer avoiding the endometrium ($n=28$) to single-layer unlocked closure also avoiding the endometrium ($n=26$). At 6 months, the residual myometrial thickness was significantly greater in the double-layer group (5.1 ± 0.4 mm vs 4.1 ± 0.4 mm; $P<.001$). Interpretation of these results is limited, however, as most participants had at least one previous cesarean delivery.

FIGURE 7

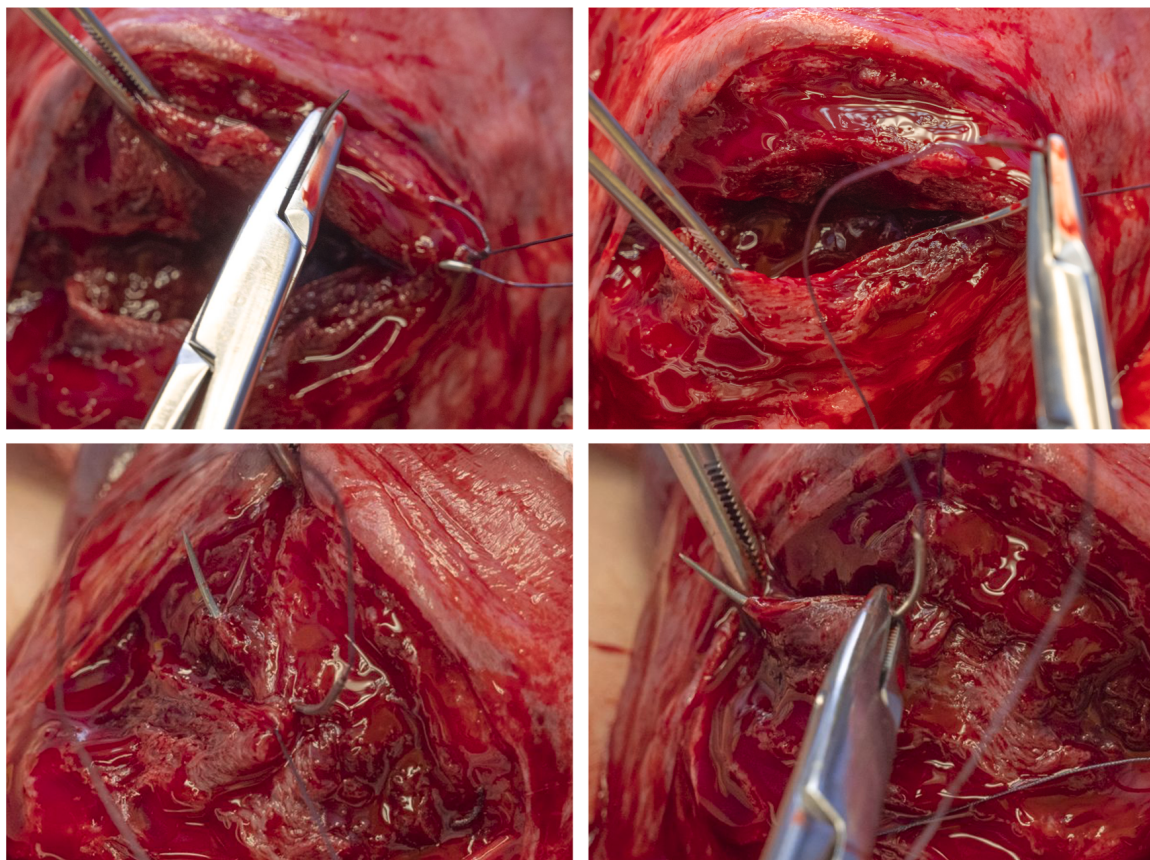
The 3 layers of the uterine wall



The image shows a low transverse hysterotomy after placental delivery. On either side of the incision, the 3 uterine layers can be distinguished: the endometrium which is the innermost, usually more purple colored and friable layer (red arrows), the myometrium which is usually the thickest of the 3 layers denoted by fibers that run horizontally and in parallel to the transverse incision (blue arrows), and the serosa, the thin, glossy superficial layer (yellow arrows).

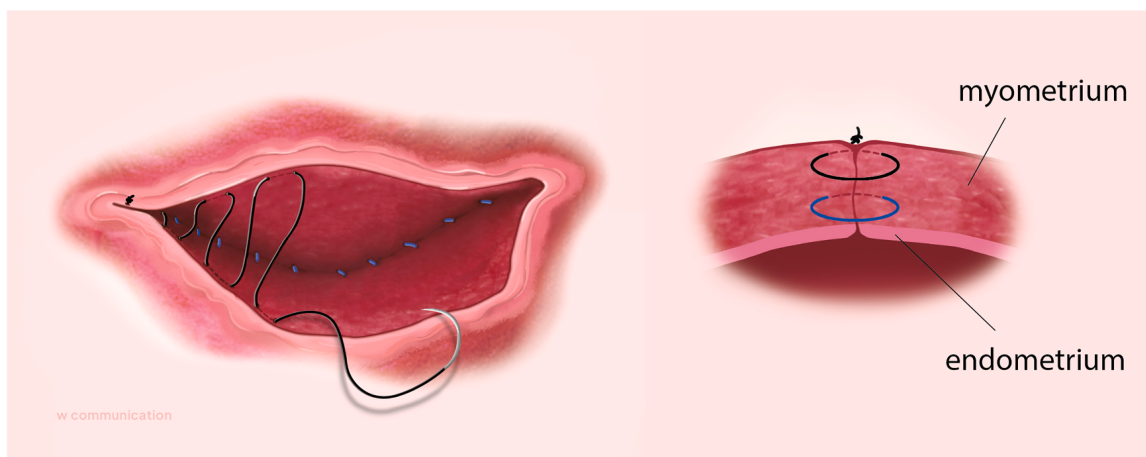
FIGURE 8**First layer for approximation of the endometrium**

(A) The suture starts at one end of the hysterotomy with closely spaced, parallel stitches along the endomyometrial junction. Applying gentle tension prevents tearing or strangulation of the tissue. (B) If the tissue appears fragile, a slightly oblique needle angle can be used to incorporate more myometrial fibres and ensure secure approximation.

FIGURE 9**Approximation of the endomyometrial junction using a suture parallel to the incision**

The figures show the first-layer closure at elective cesarean. They depict 4 stages of a parallel suture that approximates the endometrium without incorporating it by reapproximating the endomyometrial junction. The needle is passed through the myometrium, parallel to the incision, just above the endomyometrial junction.

FIGURE 10
Second layer for approximation of the myometrium



The parallel suture starts at one end of the hysterotomy and follows the upper edge of the myometrium, just below the serosa. It avoids including the surface of the uterus and the serosa in the suture.

Overall, these studies consistently demonstrate that a double-layer closure with the first layer excluding the endometrium is associated with thicker residual myometrium and lower rates of uterine scar defect.

The potential benefit of adding a third (serosal) layer remains less certain. While some observational data suggest that peritoneal closure may reduce postoperative adhesions,¹⁶¹ randomized

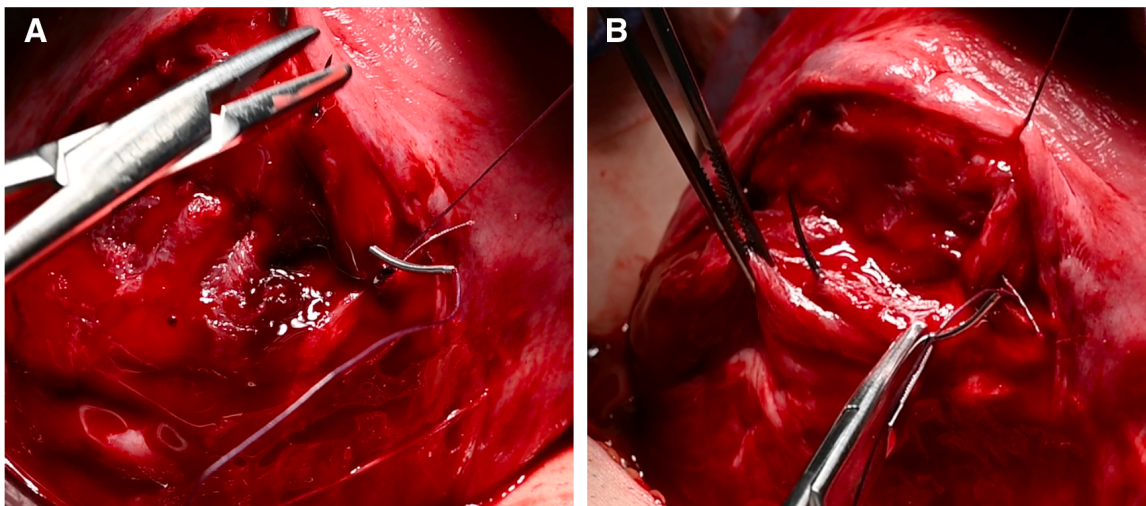
trials have not confirmed a durable advantage.¹⁶² At present, this additional step is based more on surgical judgment and established principles of tissue handling than on definitive evidence (Box 5).^{95,96,163}

Surgical technique in advanced labor and cervical dilatation

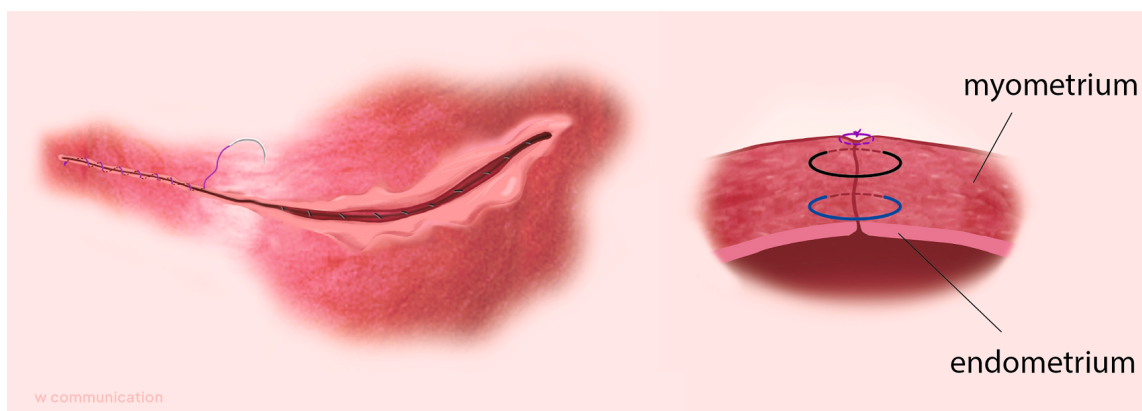
In advanced labor, the lower uterine segment becomes markedly thinned,

and the incision may extend into cervical tissue. Under these circumstances, it is often difficult to distinguish and separately reapproximate the endometrium and myometrium according to standard surgical principles. In a randomized trial of 122 participants, Vikhareva et al reported that placing the incision approximately 2 cm above the vesicouterine fold, rather than below it, may reduce the risk of subsequent scar

FIGURE 11
Approximation of the myometrium using a suture parallel to the incision



The figures show the second-layer closure at elective cesarean. They depict needle insertion into the myometrium, parallel to the incision and just beneath the serosa, on both the upper (A) and lower (B) edges of the hysterotomy.

FIGURE 12**Third layer for approximation of the myometrium edge and the serosa**

The last layer uses a rapidly absorbable thread and an unlocked continuous suture to join the remaining myometrium to the myometrium and the serosa to the serosa. This covers the non-rapidly absorbable thread that was used for the previous layer.

defects in women undergoing cesarean during advanced labor.¹⁵⁵

Nonetheless, additional studies are needed to define the optimal surgical technique in this specific context, as uterine and cervical tissues remodel substantially in the hours and days following delivery, often returning to a configuration very different from that observed intraoperatively. Based on available evidence, a slightly higher hysterotomy is advisable, as this increases the likelihood of entering the

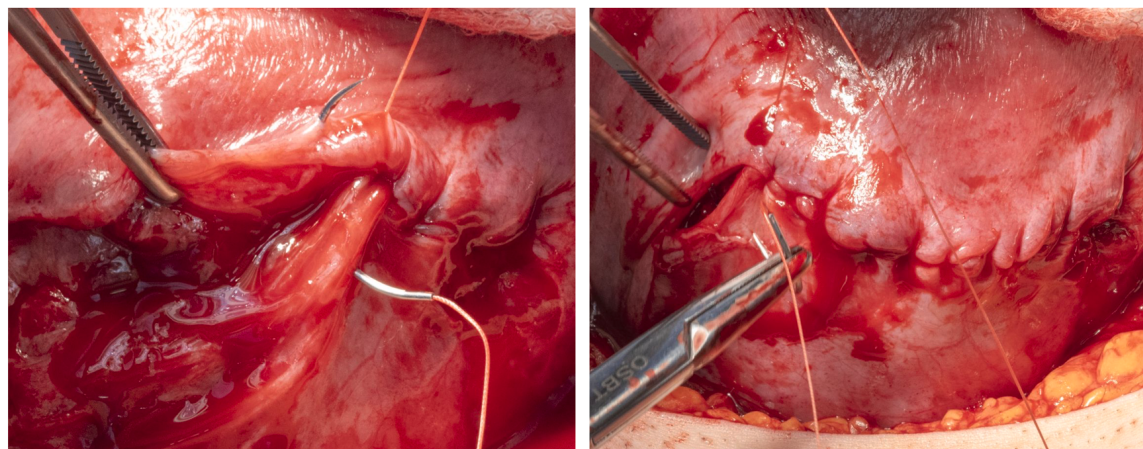
lower uterine segment rather than the cervix.

For closure, the markedly thinned myometrium usually requires modification of standard techniques. We recommend combining the first 2 parallel layers into a single layer placed parallel to the incision, thereby approximating the thin residual myometrial tissue between the endometrium and serosa. A second step should then be performed with a rapidly resorbable synthetic suture, reapproximating the

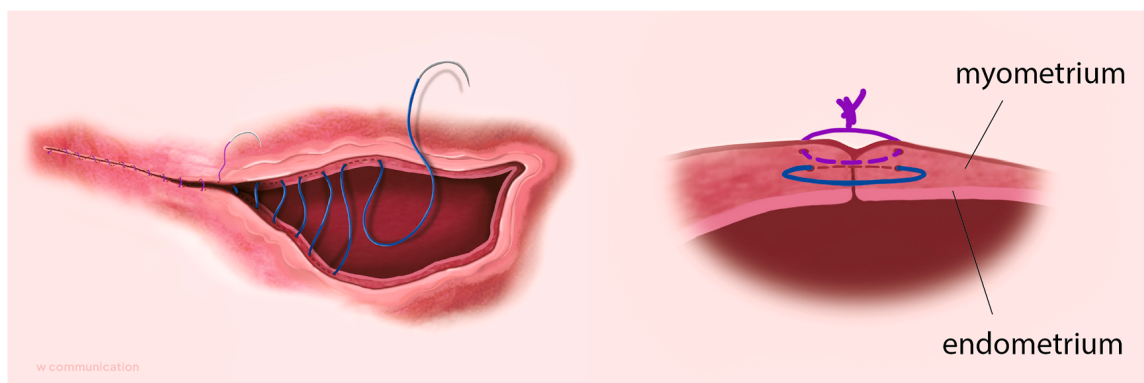
serosa while incorporating a small amount of superficial myometrium to reinforce the closure and restore the uterine surface.

Open question and future research

Key questions about the optimal method of hysterotomy closure remain unanswered and warrant renewed experimental and clinical investigation. Well-designed studies are needed to determine how variations in suture technique, tissue handling, and myometrial

FIGURE 13**Approximation of the myometrium edge and serosa**

The figures show the third-layer closure at elective cesarean. They illustrate the suture incorporating both the portion of myometrium not captured by the first layer and the serosa, providing full serosal coverage of the hysterotomy.

FIGURE 14**Adaptation of the technique for a thin lower uterine segment (myometrium)**

In the presence of a thin lower uterine segment, as is often observed in advanced labor, we suggest replacing the first 2 sutures with a single suture that approximates the thin myometrial layer (between the endometrium and the serosa) on either side of the incision. The subsequent suture then ensures complete approximation by slightly 'imbricating' the first suture, thereby reinforcing the closure in a context where the tissue is frequently more fragile.

thickness influence the quality of healing and long-term reproductive outcomes. The 3-step closure method proposed in this review applies primarily to cesarean deliveries performed before labor, or in early labor, yet the best approach for cesarean conducted in the second stage—when the lower uterine segment is extremely thin and may involve cervical tissue—has not been established.

Historically, efforts to shorten operative time have strongly influenced surgical technique. Yet, the long-term implications of a poorly healed uterine scar—such as infertility, pain, abnormal bleeding, and life-threatening complications in future pregnancies—argue for

a renewed emphasis on quality rather than speed. In an age when most cesarean deliveries are performed under regional anesthesia, the priority should be meticulous restoration of uterine anatomy, over a rapid closure. It goes without saying that if patients were asked to choose between a fast operation and one that best protects their future reproductive health, most would undoubtedly prefer the latter. Institutions and healthcare systems should ensure that maternity care is staffed and structured to support careful, deliberate surgical practice that safeguards maternal well-being beyond the immediate postoperative period.

We believe strongly that future research should extend beyond short-term surgical metrics such as operative duration or blood loss and focus on outcomes that matter most to patients: restoration of uterine structure, reproductive performance, and long-term gynecologic health. The integration of imaging, biomechanical, and molecular studies will be essential to elucidate the biological pathways that underlie successful healing.

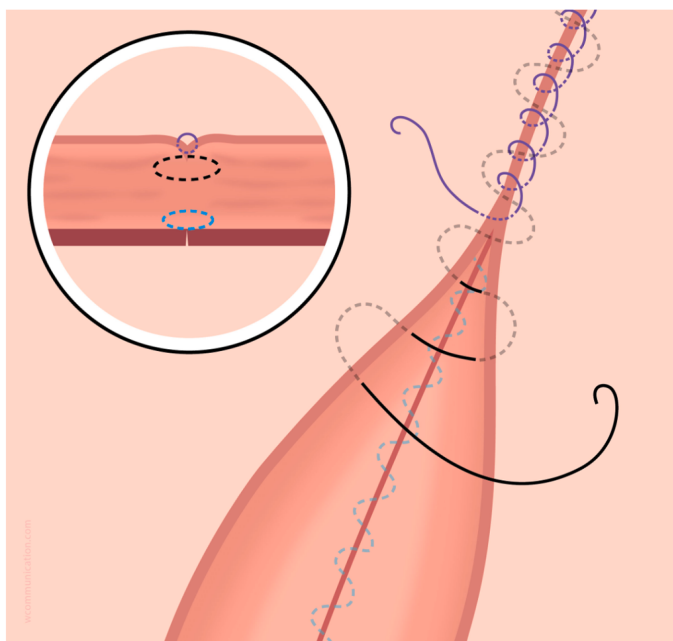
Cesarean delivery has lasting consequences for mothers and their families. Because of its global frequency and lifelong impact, research aimed at optimizing uterine closure and improving

BOX 5**Key points for surgical practice**

- Exclusion of the endometrium in the first layer is the single most important factor promoting sound uterine healing and reducing niche formation.
- Double-layer closure—with an unlocked first layer approximating the endomyometrial junction and a second layer reapproximating residual myometrium—consistently yields thicker residual myometrium and fewer scar defects.
- Fine, parallel suturing minimizes tissue strangulation and preserves perfusion; large, deep bites should be avoided.
- Serosal coverage with a third, superficial layer may help reduce adhesion formation and protect exposed myometrium, although high-level evidence is still limited.
- Synthetic absorbable sutures (preferably monofilament) are recommended; catgut should be avoided.
- The 3-step technique is most suitable for cesarean deliveries performed before or early in labor, when myometrial planes are well defined.

Summary:

Anatomically guided, tension-free closure of the uterine wall—executed in distinct layers and excluding the endometrium—builds on a century of surgical experience and emerging clinical evidence. Adoption of this technique may improve uterine healing, decrease scar defects, and potentially lower the risk of abnormal placentation in subsequent pregnancies.

FIGURE 15**Schematic representation of uterus closure in 3 steps**

The first parallel sutures located at the endomyometrial junction with closely spaced stitches approximates the endometrium/decidua, with minimal suture visible (blue). The second parallel layer beneath the serosa approximates the myometrium (black) and the third layer brings together the remaining myometrium and the serosa (violet).

maternal outcomes should be recognized as an immediate public health priority.

Conclusion

We propose that successful uterine closure after cesarean delivery depends on adherence to fundamental surgical principles: exclusion of the endometrium in the first layer, restoration of myometrial thickness with a tension-free second layer, and serosal coverage to minimize adhesions. The videos ([Supplemental Material](#)) illustrate the 3-step closure technique, which embodies these principles and provides a practical framework for routine surgical practice ([Figure 15](#)). The REPAIR mnemonic offers a concise reminder of the key elements underlying optimal closure, aligning surgical technique with the biological requirements of uterine healing. ■

REFERENCES

1. Tower AM, Frishman GN. Cesarean scar defects: an underrecognized cause of

abnormal uterine bleeding and other gynecologic complications. *J Minim Invasive Gynecol* 2013;20:562–72.

2. Min N, Thiel P, McGrattan M, et al. Cesarean scar niche and pelvic pain: a systematic review and meta-analysis. *J Minim Invasive Gynecol* 2025 [Epub ahead of print].

3. Gulz M, Vidal A, Kalaitzopoulos DR, Karrer T, Mueller MD. Endometriosis, a familiar companion of isthmocele. A systematic review and meta-analysis. *J Minim Invasive Gynecol* 2025 [Epub ahead of print].

4. Ciechanowicz S, Joy RR, Kasmirski J, Blake L, Carvalho B, Sultan P. Incidence, severity, and interference of chronic post-surgical pain after cesarean delivery: a systematic review and meta-analysis. *J Clin Anesth* 2025;104:111832.

5. Klein Meuleman SJM, Verberkt C, Barri PN, et al. Prevalence of cesarean scar disorder in patients 3 years after a first cesarean section. *Acta Obstet Gynecol Scand* 2025;104:1972–9.

6. Sousa Shimamura LK, Bettiol H, Moura da Silva AA, et al. Incidence of chronic pelvic pain after childbirth and its causal association with C-section. *Pain* 2025;166:1847–58.

7. Borges NC, de Deus JM, Guimarães RA, et al. The incidence of chronic pain following cesarean section and associated risk factors: a cohort of women followed up for three months. *PloS One* 2020;15:e0238634.

8. Bij de Vaate AJ, Brölmann HA, van der Voet LF, van der Slikke JW, Veersema S, Huime JA. Ultrasound evaluation of the cesarean scar: relation between a niche and postmenstrual spotting. *Ultrasound Obstet Gynecol* 2011;37:93–9.

9. Murji A, Sanders AP, Monteiro I, et al. Cesarean scar defects and abnormal uterine bleeding: a systematic review and meta-analysis. *Fertil Steril* 2022;118:758–66.

10. Gruber TM, Lange K, Ebeling GS, Henrich W, Mechsner S. Scar endometriosis, a form of abdominal wall endometriosis—a neglected obstetrical complication? *Arch Gynecol Obstet* 2025;312:1–8.

11. Poidevin LOS. CEASAREAN SECTION SCARS. Springfield (IL): Charles C Thomas Publisher; 1965. p.112.

12. Donnez O. Cesarean scar disorder: management and repair. *Best Pract Res Clin Obstet Gynaecol* 2023;90:102398.

13. Zhang P, Sun Y, Zhang C, et al. Cesarean scar endometriosis: presentation of 198 cases and literature review. *BMC Womens Health* 2019;19:14.

14. Bij de Vaate AJM, van der Voet LF, Naji O, et al. Prevalence, potential risk factors for development and symptoms related to the presence of uterine niches following cesarean section: systematic review. *Ultrasound Obstet Gynecol* 2014;43:372–82.

15. Gurol-Urganci I, Bou-Antoun S, Lim CP, et al. Impact of caesarean section on subsequent fertility: a systematic review and meta-analysis. *Hum Reprod Oxf Engl* 2013;28:1943–52.

16. Brennan L, Bujold E, Maheux-Lacroix S, Sanders AP, Bedaiwy MA, Murji A. Clinical consensus no. 463: diagnosis and management of cesarean scar niche. *J Obstet Gynaecol Can* 2025;47:103143.

17. Evers EC, McDermott KC, Blomquist JL, Handa VL. Mode of delivery and subsequent fertility. *Hum Reprod Oxf Engl* 2014;29:2569–74.

18. Kjerulf KH, Paul IM, Weisman CS, et al. Association between mode of first delivery and subsequent fecundity and fertility. *JAMA Netw Open* 2020;3:e203076.

19. Vissers J, Hehenkamp W, Lambalk CB, Huime JA. Post-caesarean section niche-related impaired fertility: hypothetical mechanisms. *Hum Reprod Oxf Engl* 2020;35:1484–94.

20. Morales KJ, Gordon MC, Bates GW. Postcesarean delivery adhesions associated with delayed delivery of infant. *Am J Obstet Gynecol* 2007;196:461.e1–6.

21. Tulandi T, Agdi M, Zarei A, Miner L, Sikirica V. Adhesion development and morbidity after repeat cesarean delivery. *Am J Obstet Gynecol* 2009;201:56.e1–6.

22. Post BL, Verberkt C, van Veen D, et al. The feasibility and effectiveness of using an adhesion barrier in preventing dysmenorrhea, pain, and niche-related problems after cesarean

sections: a multicenter randomized pilot study. *Am J Obstet Gynecol MFM* 2025;7:101742.

23. Suganathan K, Kumari RS, Perumal SR, Murugesan A. Diagnostic utility of the ultrasound sliding sign in predicting intra-abdominal adhesions in repeat caesarean delivery: a prospective study. *J Ultrasound* 2025 [Epub ahead of print].

24. Morlando M, Buca D, Timor-Tritsch I, et al. Reproductive outcome after cesarean scar pregnancy: a systematic review and meta-analysis. *Acta Obstet Gynecol Scand* 2020;99:1278–89.

25. Timor-Tritsch I, Buca D, Di Mascio D, et al. Outcome of cesarean scar pregnancy according to gestational age at diagnosis: a systematic review and meta-analysis. *Eur J Obstet Gynecol Reprod Biol* 2021;258:53–9.

26. Society for Maternal-Fetal Medicine (SMFM), Miller R, Gyamfi-Bannerman C; Publications Committee. Society for maternal-fetal medicine consult series #63: cesarean scar ectopic pregnancy. *Am J Obstet Gynecol* 2022;227(3):B9–20.

27. Noël L, Thilaganathan B. Caesarean scar pregnancy: diagnosis, natural history and treatment. *Curr Opin Obstet Gynecol* 2022;34:279–86.

28. Knapman BL, Forgues MAS, Abbott JA, Maheux-Lacroix S. Other treatments for CSP. *Best Pract Res Clin Obstet Gynaecol* 2023;90:102367.

29. Maheux-Lacroix S, Li F, Bujold E, Nesbitt-Hawes E, Deans R, Abbott J. Cesarean scar pregnancies: a systematic review of treatment options. *J Minim Invasive Gynecol* 2017;24:915–25.

30. Jurkovic D, Hillaby K, Woelfer B, Lawrence A, Salim R, Elson CJ. First-trimester diagnosis and management of pregnancies implanted into the lower uterine segment cesarean section scar. *Ultrasound Obstet Gynecol* 2003;21:220–7.

31. Noël I, Ghesquiere L, Guerby P, Maheux-Lacroix S, Bujold E, Moretti F. Clinical risk factors for Placenta accreta or placenta percreta: a case-control study. *J Obstet Gynaecol Can* 2024;46:102294.

32. Timor-Tritsch IE, Monteagudo A, Goldstein SR. Early first-trimester transvaginal ultrasound screening for cesarean scar pregnancy in patients with previous cesarean delivery: analysis of the evidence. *Am J Obstet Gynecol* 2024;231:618–25.

33. Timor-Tritsch IE, Monteagudo A, Santos R, Tsybmal T, Pineda G, Arslan AA. The diagnosis, treatment, and follow-up of cesarean scar pregnancy. *Am J Obstet Gynecol* 2012;207:44.e1–13.

34. Timor-Tritsch IE, Monteagudo A, Cali G, et al. Cesarean scar pregnancy is a precursor of morbidly adherent placenta. *Ultrasound Obstet Gynecol* 2014;44:346–53.

35. Jordans IPM, de Leeuw RA, Stegwee SI, et al. Sonographic examination of uterine niche in non-pregnant women: a modified Delphi procedure. *Ultrasound Obstet Gynecol* 2019;53:107–15.

36. Jordans IPM, Verberkt C, De Leeuw RA, et al. Definition and sonographic reporting system for cesarean scar pregnancy in early gestation: modified Delphi method. *Ultrasound Obstet Gynecol* 2022;59:437–49.

37. Timor-Tritsch IE, D'Antonio F, Monteagudo A, Kaelin Agten A, Melcer Y, Maymon R. Cesarean scar pregnancy spectrum: a proposed standardized classification and terminology for the reporting of pregnancy developing in uterine cesarean scar. *J Ultrasound Med* 2025 [Epub ahead of print].

38. Timor-Tritsch IE, Monteagudo A. Unforeseen consequences of the increasing rate of cesarean deliveries: early Placenta accreta and cesarean scar pregnancy. A review. *Am J Obstet Gynecol* 2012;207:14–29.

39. Timor-Tritsch IE, Monteagudo A, Cali G, et al. Cesarean scar pregnancy and early Placenta accreta share common histology. *Ultrasound Obstet Gynecol* 2014;43:383–95.

40. Palacios-Jaraquemada JM. Diagnosis and management of Placenta accreta. *Best Pract Res Clin Obstet Gynaecol* 2008;22:1133–48.

41. Lim BH, Palacios-Jaraquemada JM. The morbidly adherent placenta—a continuing diagnostic and management challenge. *BJOG Int J Obstet Gynaecol* 2015;122:1673.

42. Palacios-Jaraquemada JM. Cesarean section in cases of Placenta praevia and accreta. *Best Pract Res Clin Obstet Gynaecol* 2013;27:221–32.

43. Palacios-Jaraquemada JM, Fiorillo A, Hamer J, Martínez M, Bruno C. Placenta accreta spectrum: a hysterectomy can be prevented in almost 80% of cases using a resective-reconstructive technique. *J Matern-Fetal Neonatal Med* 2022;35:275–82.

44. Pinto PV, Freitas G, Vieira RJ, Aryananda RA, Nieto-Calvache AJ, Palacios-Jaraquemada JM. Placenta accreta spectrum disorder: a systematic review and meta-analysis on conservative surgery. *Int J Gynaecol Obstet* 2025 [Epub ahead of print].

45. Jauniaux E, Jurkovic D, Hussein AM, Burton GJ. New insights into the etiopathology of Placenta accreta spectrum. *Am J Obstet Gynecol* 2022;227:384–91.

46. Javanani A, Qaderi S, Hessami K, et al. Delivery outcomes in the subsequent pregnancy following the conservative management of Placenta accreta spectrum disorder: a systematic review and meta-analysis. *Am J Obstet Gynecol* 2024;230:485–92.e7.

47. Palacios-Jaraquemada J. How to reduce the incidence of Placenta accreta spectrum independently of the number of cesarean? *Matern-Fetal Med* 2019;1:68–9.

48. Silver RM, Landon MB, Rouse DJ, et al. Maternal morbidity associated with multiple repeat cesarean deliveries. *Obstet Gynecol* 2006;107:1226–32.

49. Farquhar CM, Li Z, Lensen S, et al. Incidence, risk factors and perinatal outcomes for Placenta accreta in Australia and New Zealand: a case-control study. *BMJ Open* 2017;7:e017713.

50. van der Krogt L, Shennan A. Cervical cesarean damage as a growing clinical problem: the association between in-labour cesarean section and recurrent preterm birth in subsequent pregnancies. *PLoS Med* 2024;21:e1004497.

51. Wood SL, Tang S, Crawford S. Cesarean delivery in the second stage of labor and the risk of subsequent premature birth. *Am J Obstet Gynecol* 2017;217:63.e1–10.

52. Levine LD, Sammel MD, Hirshberg A, Elovitz MA, Srinivas SK. Does stage of labor at time of cesarean delivery affect risk of subsequent preterm birth? *Am J Obstet Gynecol* 2015;212:360.e1–7.

53. Levine LD, Srinivas SK. Length of second stage of labor and preterm birth in a subsequent pregnancy. *Am J Obstet Gynecol* 2016;214:535.e1–4.

54. Watson HA, Carter J, David AL, Seed PT, Shennan AH. Full dilation cesarean section: a risk factor for recurrent second-trimester loss and preterm birth. *Acta Obstet Gynecol Scand* 2017;96:1100–5.

55. Acker S, Hoffmann CH, Hansen LK, Glavind J, Jeppgaard M, Krebs L. Risk of spontaneous preterm birth in a subsequent pregnancy after full dilatation caesarean birth: a nationwide cohort study. *BJOG Int J Obstet Gynaecol* 2025;132:1585–93.

56. Xu L, Ding L, Wang L, et al. Umbilical cord-derived mesenchymal stem cells on scaffolds facilitate collagen degradation via upregulation of MMP-9 in rat uterine scars. *Stem Cell Res Ther* 2017;8:84.

57. Huang J, Li Q, Yuan X, Liu Q, Zhang W, Li P. Intrauterine infusion of clinically graded human umbilical cord-derived mesenchymal stem cells for the treatment of poor healing after uterine injury: a phase I clinical trial. *Stem Cell Res Ther* 2022;13:85.

58. Kirubarajan A, Thangavelu N, Rottenstreich M, Muraca GM. Operative delivery in the second stage of labor and preterm birth in a subsequent pregnancy: a systematic review and meta-analysis. *Am J Obstet Gynecol* 2024;230:295–307.

59. Offringa Y, Paret L, Vayssiere C, Parant O, Loussett L, Guerby P. Second stage cesarean section and the risk of preterm birth in subsequent pregnancies. *Int J Gynaecol Obstet* 2022;159:783–9.

60. Jastrow N, Chaillet N, Roberge S, Morency AM, Lacasse Y, Bujold E. Sonographic lower uterine segment thickness and risk of uterine scar defect: a systematic review. *J Obstet Gynaecol Can* 2010;32:321–7.

61. Bashiri A, Burstein E, Rosen S, Smolin A, Sheiner E, Mazor M. Clinical significance of uterine scar dehiscence in women with previous cesarean delivery: prevalence and independent risk factors. *J Reprod Med* 2008;53:8–14.

62. Rozenberg P, Goffinet F, Phillippe HJ, Nisand I. Ultrasonographic measurement of lower uterine segment to assess risk of defects of scarred uterus. *Lancet Lond Engl* 1996;347:281–4.

63. Marchant I, Lessard L, Bergeron C, et al. Measurement of lower uterine segment thickness to detect uterine scar defect: comparison of transabdominal and transvaginal ultrasound. *J Ultrasound Med* 2023;42:1491–6.
64. Lydon-Rochelle M, Holt VL, Easterling TR, Martin DP. Risk of uterine rupture during labor among women with a prior cesarean delivery. *N Engl J Med* 2001;345:3–8.
65. Bujold E, Gauthier RJ. Neonatal morbidity associated with uterine rupture: what are the risk factors? *Am J Obstet Gynecol* 2002;186:311–4.
66. Chaillet N, Dumont A, Abrahamowicz M, et al. A cluster-randomized trial to reduce cesarean delivery rates in Quebec. *N Engl J Med* 2015;372:1710–21.
67. Chaillet N, Mâsse B, Grobman WA, et al. Perinatal morbidity among women with a previous caesarean delivery (PRISMA trial): a cluster-randomised trial. *Lancet Lond Engl* 2024;403:44–54.
68. Bujold E, Dubé E, Girard M, Chaillet N. Lower uterine segment thickness to predict uterine rupture: a secondary analysis of PRISMA cluster randomized trial. *Am J Obstet Gynecol MFM* 2024;6:101543.
69. Landon MB, Hauth JC, Leveno KJ, et al. Maternal and perinatal outcomes associated with a trial of labor after prior cesarean delivery. *N Engl J Med* 2004;351:2581–9.
70. McMahon MJ, Luther ER, Bowes WA, Olshan AF. Comparison of a trial of labor with an elective second cesarean section. *N Engl J Med* 1996;335:689–95.
71. Guise JM, McDonagh MS, Osterweil P, Nygren P, Chan BKS, Helfand M. Systematic review of the incidence and consequences of uterine rupture in women with previous caesarean section. *BMJ* 2004;329:19–25.
72. Gurtner GC, Werner S, Barrandon Y, Longaker MT. Wound repair and regeneration. *Nature* 2008;453:314–21.
73. Singer AJ, Clark RA. Cutaneous wound healing. *N Engl J Med* 1999;341:738–46.
74. Diegelmann RF, Evans MC. Wound healing: an overview of acute, fibrotic and delayed healing. *Front Biosci J Virtual Libr* 2004;9:283–9.
75. Bujold E, Gauthier RJ. Risk of uterine rupture associated with an interdelivery interval between 18 and 24 months. *Obstet Gynecol* 2010;115:1003–6.
76. Schlensker KH, Bolte A. [Rupture of the uterus. Analysis of 42 cases of rupture during the years from 1955-1975 (author's transl)]. *Arch Gynakol* 1977;223:55–74.
77. Bujold E, Mehta SH, Bujold C, Gauthier RJ. Interdelivery interval and uterine rupture. *Am J Obstet Gynecol* 2002;187:1199–202.
78. Cragin EB. Conservatism in obstetrics? *N Y Med J* 1916;104:1–3.
79. Mason D, Silliams J. The strength of the uterine scar after cesarean section: an experimental and clinical study. *N Engl J Med* 1910;162:301–9.
80. Losee JR. The cesarean scar, an anatomical study. *Am J Obstet Gynecol* 1917;76:1–11.
81. Spalding AB. Cesarean section scars. A histologic study of four specimens. *JAMA* 1847;69:1847–55.
82. Schwartz O, Paddock R. The cesarean scar. *Am J Obstet Gynecol* 1925;10:153–71.
83. Schwartz O, Paddock R, Bortnick A. The cesarean section scar: an experimental study. *Am J Obstet Gynecol* 1938;36:962–74.
84. Potter M, Elton NW. An improved method of uterine closure in high classical cesarean section. *Am J Obstet Gynecol* 1941;43:303–8.
85. Potter M, Johnston DC. Uterine closure in cesarean section. *Am J Obstet Gynecol* 1954;67:760–7.
86. Poidevin LO. The value of hystero-graphy in the prediction of cesarean section wound defects. *Am J Obstet Gynecol* 1961;81:67–71.
87. Kirkwood PM, Gibson DA, Shaw I, et al. Single-cell RNA sequencing and lineage tracing confirm mesenchyme to epithelial transformation (MET) contributes to repair of the endometrium at menstruation. *eLife* 2022;11:e77663.
88. Poidevin LO. Histopathology of caesarean section wounds. An experimental study. *J Obstet Gynaecol Br Emp* 1961;68:1025–9.
89. Csúcs L, Kött I, Solt I. [Single layer suturing of the uterus in cesarean section]. *Orv Hetil* 1970;111:813–4.
90. Csúcs L, Kött I, Solt I. [Mono-layer sutures of uterine incision in cesarean section based on clinical experience and animal experiments]. *Zentralbl Gynakol* 1972;94:1121–6.
91. Roberge S, Chaillet N, Boutin A, et al. Single- versus double-layer closure of the hysterotomy incision during cesarean delivery and risk of uterine rupture. *Int J Gynaecol Obstet* 2011;115:5–10.
92. Roberge S, Demers S, Berghella V, Chaillet N, Moore L, Bujold E. Impact of single- vs double-layer closure on adverse outcomes and uterine scar defect: a systematic review and metaanalysis. *Am J Obstet Gynecol* 2014;211:453–60.
93. Bujold E, Bujold C, Hamilton EF, Harel F, Gauthier RJ. The impact of a single-layer or double-layer closure on uterine rupture. *Am J Obstet Gynecol* 2002;186:1326–30.
94. Bujold E, Goyet M, Marcoux S, et al. The role of uterine closure in the risk of uterine rupture. *Obstet Gynecol* 2010;116:43–50.
95. Vervoort AJ, Uittenbogaard LB, Hehenkamp WJ, Brölmann HA, Mol BW, Huime JA. Why do niches develop in caesarean uterine scars? Hypotheses on the aetiology of niche development. *Hum Reprod Oxf Engl* 2015;30:2695–702.
96. Sholapurkar SL. Etiology of cesarean uterine scar defect (Niche): detailed critical analysis of hypotheses and prevention strategies and peritoneal closure debate. *J Clin Med Res* 2018;10:166–73.
97. Klein Meuleman SJM, Murji A, van den Bosch T, et al. Definition and criteria for diagnosing cesarean scar disorder. *JAMA Netw Open* 2023;6:e235321.
98. Hellman LM, Pritchard JA. Cesarean section. In: Williams Obstetrics, 14th ed. New York: Appleton-Century-Crofts; 1971. p. 1163–90.
99. Kerr JMM. The technic of cesarean section, with special reference to the lower uterine segment incision. *Am J Obstet Gynecol* 1929;12:729–34.
100. Williams JW. Cesarean section and symphysectomy. In: Williams Obstetrics, 6th ed. New York: Appleton; 1930. p. 530–66.
101. Stander HJ. Cesarean section, symphysectomy, and pubiotomy. In: Williams obstetrics, 7th ed. New York: Appleton-Century; 1936. p. 596–629.
102. Stander HJ. Cesarean section. In: Williams Obstetrics, 8th ed. New York: Appleton-Century; 1941. p. 1193–226.
103. Stander HJ. Cesarean section. In: Williams Obstetrics, 9th ed. New York: Appleton-Century; 1945. p. 1077–108.
104. Eastman NJ. Cesarean section. In: Williams Obstetrics, 10th ed. New York: Appleton-Century-Crofts; 1950. p. 1097–125.
105. Eastman NJ. Cesarean section. In: Williams Obstetrics, 11th ed. New York: Appleton-Century-Crofts; 1956. p. 1133–54.
106. Eastman NJ, Hellman LM. Cesarean section. In: Williams Obstetrics, 12th ed. New York: Appleton-Century-Crofts; 1961. p. 1179–205.
107. Eastman NJ, Hellman LM. Cesarean section. In: Williams Obstetrics, 13th ed. New York: Appleton-Century-Crofts; 1966. p. 1122–48.
108. Pritchard JA, MacDonald PC. Cesarean section and cesarean hysterectomy. In: Williams Obstetrics, 15th ed. New York: Appleton-Century-Crofts; 1976. p. 903–23.
109. Hauth JC, Owen J, Davis RO. Transverse uterine incision closure: one versus two layers. *Am J Obstet Gynecol* 1992;167(4 Pt 1):1108–11.
110. Chapman SJ, Owen J, Hauth JC. One-versus two-layer closure of a low transverse cesarean: the next pregnancy. *Obstet Gynecol* 1997;89:16–8.
111. Dominoni M, Torella M, Moliterno R, et al. Single-versus double-layer uterine closure at the time of cesarean delivery and risk of uterine scar niche: a systematic review and meta-analysis of randomized trials. *Arch Gynecol Obstet* 2025;312:1095–106.
112. Di Spiezio Sardo A, Saccone G, McCurdy R, Bujold E, Bifulco G, Berghella V. Risk of cesarean scar defect following single- vs double-layer uterine closure: systematic review and meta-analysis of randomized controlled trials. *Ultrasound Obstet Gynecol* 2017;50:578–83.
113. Blumenfeld YJ, Caughey AB, El-Sayed YY, Daniels K, Lyell DJ. Single- versus double-layer hysterotomy closure at primary caesarean delivery and bladder adhesions. *BJOG Int J Obstet Gynaecol* 2010;117:690–4.

- 114.** CAESAR study collaborative group. Caesarean section surgical techniques: a randomised factorial trial (CAESAR). *BJOG Int J Obstet Gynaecol* 2010;117:1366–76.
- 115.** CORONIS Trial Collaborative Group. The CORONIS trial. International study of caesarean section surgical techniques: a randomised fractional, factorial trial. *BMC Pregnancy Childbirth* 2007;7:24.
- 116.** Abalos E, Addo V, Brocklehurst P, et al. Caesarean section surgical techniques (CORONIS): a fractional, factorial, unmasked, randomised controlled trial. *Lancet Lond Engl* 2013;382:234–48.
- 117.** Abalos E, Addo V, Brocklehurst P, et al. Caesarean section surgical techniques: 3 year follow-up of the CORONIS fractional, factorial, unmasked, randomised controlled trial. *Lancet Lond Engl* 2016;388:62–72.
- 118.** Abalos E, Oyarzun E, Addo V, et al. CORONIS - International study of caesarean section surgical techniques: the follow-up study. *BMC Pregnancy Childbirth* 2013;13:215.
- 119.** Bamberg C, Hinkson L, Dudenhausen JW, Bujak V, Kalache KD, Henrich W. Longitudinal transvaginal ultrasound evaluation of caesarean scar niche incidence and depth in the first two years after single- or double-layer uterotomy closure: a randomized controlled trial. *Acta Obstet Gynecol Scand* 2017;96:1484–9.
- 120.** Bamberg C, Dudenhausen JW, Bujak V, et al. A prospective randomized clinical trial of single vs. double layer closure of hysterotomy at the time of caesarean delivery: the effect on uterine scar thickness. *Ultraschall Med Stuttg Ger* 2018;39:343–51.
- 121.** Nguyen HTT, Duong GTT, Do DT, et al. Single- vs double-layer uterine closure of the caesarean scar in niche development: the nicest study. *AJOG Glob Rep* 2025;5:100507.
- 122.** Verberkt C, Stegwee SI, Huirne JAF. Hysterotomy closure at caesarean, beyond the number of layers; a response. *Am J Obstet Gynecol* 2024;231:e45–6.
- 123.** Verberkt C, Stegwee SI, Van der Voet LF, et al. Single-layer vs double-layer uterine closure during caesarean delivery: 3-year follow-up of a randomized controlled trial (2Close study). *Am J Obstet Gynecol* 2024;231:346.e1–11.
- 124.** Stegwee SI, van der Voet LF, Ben AJ, et al. Effect of single- versus double-layer uterine closure during caesarean section on post-menstrual spotting (2Close): multicentre, double-blind, randomised controlled superiority trial. *BJOG Int J Obstet Gynaecol* 2021;128:866–78.
- 125.** Stegwee SI, Jordans IPM, van der Voet LF, et al. Single- versus double-layer closure of the caesarean (uterine) scar in the prevention of gynaecological symptoms in relation to niche development - the 2Close study: a multicentre randomised controlled trial. *BMC Pregnancy Childbirth* 2019;19:85.
- 126.** Maheux-Lacroix S, Bujold E. Hysterotomy closure at caesarean: beyond the number of layers. *Am J Obstet Gynecol* 2024;231:e44.
- 127.** Antoine C. Beyond single- vs double-layer closure: optimizing uterine repair in cesarean delivery with endometrium-free technique. *Am J Obstet Gynecol* 2025;232:e108.
- 128.** Kelly H. The steps of the cesarean section - the do's and the don'ts. *Am J Obstet Gynecol*. 1891;21:532–544.
- 129.** Poidevin LO, Bockner VY. A hysterographic study of uteri after caesarean section. *J Obstet Gynaecol Br Emp* 1958;65:278–83.
- 130.** Antoine C, Meyer JA, Silverstein J, Buldo-Licciardi J, Lyu C, Timor-Tritsch IE. Endometrium-free closure technique during cesarean delivery for reducing the risk of niche formation and Placenta accreta spectrum disorders. *Obstet Gynecol* 2025;145:674–82.
- 131.** Antoine C, Meyer JA, Silverstein JS, Alexander J, Oh C, Timor-Tritsch IE. The impact of uterine incision closure techniques on post-cesarean delivery niche formation and size: sonohysterographic examination of nonpregnant women. *J Ultrasound Med* 2022;41:1763–71.
- 132.** Antoine C, Pimentel RN, Reece EA, Oh C. Endometrium-free uterine closure technique and abnormal placental implantation in subsequent pregnancies. *J Matern-Fetal Neonatal Med* 2021;34:2513–21.
- 133.** Meyer JA, Silverstein J, Timor-Tritsch IE, Antoine C. The effect of uterine closure technique on cesarean scar niche development after multiple cesarean deliveries. *J Perinat Med* 2024;52:150–7.
- 134.** Lino GM, Galvão PVM, da Silva MLF, Conrado GAM. Not closing compared with closing the endometrial layer during cesarean delivery: a systematic review and meta-analysis. *Obstet Gynecol* 2025;146:e55–63.
- 135.** Tsuji S, Katsura D, Tokoro S, et al. Two-layer interrupted versus two-layer continuous sutures for preventing cesarean scar defect: a randomized controlled trial. *BMC Pregnancy Childbirth* 2025;25:248.
- 136.** Sumigama S, Sugiyama C, Kotani T, et al. Uterine sutures at prior caesarean section and Placenta accreta in subsequent pregnancy: a case-control study. *BJOG Int J Obstet Gynaecol* 2014;121:866–74.
- 137.** Tarafdari A, Nazarpour M, Zargardzadeh N, Hantoushzadeh S, Parsaei M. Comparing cesarean scar defect incidence after locked and unlocked repair methods among primiparous patients: a randomized double-blinded trial. *J Fam Reprod Health* 2024;18:146–53.
- 138.** Hudic I, Bujold E, Fatusic Z, Roberge S, Mandzic A, Fatusic J. Risk of uterine rupture following locked vs unlocked single-layer closure. *Med Arch Sarajevo Bosnia Herzeg* 2012;66:412–4.
- 139.** Bérubé L, Ariel M, Gagnon G, Brassard N, Boutin A, Bujold E. Factors associated with lower uterine segment thickness near term in women with previous caesarean section. *J Obstet Gynecol Can JOGC* 2011;33:581–7.
- 140.** Vachon-Marceau C, Demers S, Bujold E, et al. Single versus double-layer uterine closure at cesarean: impact on lower uterine segment thickness at next pregnancy. *Am J Obstet Gynecol* 2017;217:65.e1–5.
- 141.** Hosseini R, Mansoorli S, Pirjani R, Eslamian L, Rabiee M. A comparison of the effects of two suture materials on isthmocele formation: a cohort study. *J Gynecol Obstet Hum Reprod* 2021;50:101933.
- 142.** Khanuja K, Burd J, Ozcan P, Peleg D, Saccone G, Berghella V. Suture type for hysterotomy closure: a systematic review and meta-analysis of randomized controlled trials. *Am J Obstet Gynecol MFM* 2022;4:100726.
- 143.** Saccone G, De Angelis MC, Zizolfi B, et al. Monofilament vs multifilament suture for uterine closure at the time of cesarean delivery: a randomized clinical trial. *Am J Obstet Gynecol MFM* 2022;4:100592.
- 144.** Raischer HB, Massalha M, Iskander R, Izhaki I, Salim R. Knotless barbed versus conventional suture for closure of the uterine incision at cesarean delivery: a systematic review and meta-analysis. *J Minim Invasive Gynecol* 2022;29:832–9.
- 145.** Maki J, Mitoma T, Ooba H, et al. Barbed vs conventional sutures for cesarean uterine scar defects: a randomized clinical trial. *Am J Obstet Gynecol MFM* 2024;6:101431.
- 146.** Jalalzadeh H, Timmer AS, Buis DR, et al. Triclosan-containing sutures for the prevention of surgical site infection: a systematic review and meta-analysis. *JAMA Netw Open* 2025;8:e250306.
- 147.** Depuydt M, Van Egmond S, Petersen SM, Muysoms F, Henriksen N, Deerenberg E. Systematic review and meta-analysis comparing surgical site infection in abdominal surgery between triclosan-coated and uncoated sutures. *Hernia J Hernias Abdom Wall Surg* 2024;28:1017–27.
- 148.** Deerenberg EB, Harlaar JJ, Steyerberg EW, et al. Small bites versus large bites for closure of abdominal midline incisions (STITCH): a double-blind, multicentre, randomised controlled trial. *Lancet Lond Engl* 2015;386:1254–60.
- 149.** Rappaport W, Allen R, Chvapil M, Benson D, Putnam C. A comparison of parallel versus perpendicular placement of retention sutures in abdominal wound closure. *Am Surg* 1990;56:618–23.
- 150.** Lear W, Roybal LL, Kruzic JJ. Forces on sutures when closing excisional wounds using the rule of halves. *Clin Biomech Bristol Avon* 2020;72:161–3.
- 151.** Alper E, Aksakal E, Usta I, Urman B. The novel parallel closure technique compared to single-layer closure of the uterus after primary cesarean section decreases the incidence of isthmocele formation and increases residual

- myometrial thickness. *Cureus* 2024;16:e60932.
152. Turan C, Büyükbayrak EE, Yılmaz AO, Karsidag YK, Pirimoglu M. Purse-string double-layer closure: a novel technique for repairing the uterine incision during cesarean section. *J Obstet Gynaecol Res* 2015;41:565–74.
 153. Nabighadim M, Vaezi M, Maghalian M, Mirghafourvand M. Ultrasound outcomes and surgical parameters of the double-layer purse-string uterine closure technique in cesarean delivery: a systematic review and meta-analysis of randomized trials. *BMC Surg* 2025;25:60.
 154. Chen C. The art of bowel anastomosis. *Scand J Surg SJS Off Organ Finn Surg Soc Scand Surg Soc* 2012;101:238–40.
 155. Vikhareva O, Rickle GS, Lavesson T, Nedopekina E, Brandell K, Salvesen KÅ. Hysterotomy level at cesarean section and occurrence of large scar defects: a randomized single-blind trial. *Ultrasound Obstet Gynecol* 2019;53:438–42.
 156. O'Brien S, Sharma K, Simpson A, et al. Learning from experience: development of a cognitive task list to perform a caesarean section in the second stage of labour. *J Obstet Gynaecol Can JOGC* 2015;37:1063–71.
 157. Bujold E. The optimal uterine closure technique during cesarean. *North Am J Med Sci* 2012;4:362–3.
 158. Roberge S, Demers S, Girard M, et al. Impact of uterine closure on residual myometrial thickness after cesarean: a randomized controlled trial. *Am J Obstet Gynecol* 2016;214:507.e1–6.
 159. Hayakawa H, Itakura A, Mitsui T, et al. Methods for myometrium closure and other factors impacting effects on cesarean section scars of the uterine segment detected by the ultrasonography. *Acta Obstet Gynecol Scand* 2006;85:429–34.
 160. Özler MR, Al RA. A prospective comparative study of single-layer versus double-layer uterine closure techniques on cesarean scar formation. *BMC Pregnancy Childbirth* 2025;25:868.
 161. Shi Z, Ma L, Yang Y, et al. Adhesion formation after previous caesarean section-a meta-analysis and systematic review. *BJOG Int J Obstet Gynaecol* 2011;118:410–22.
 162. Gialdini C, Chamillard M, Diaz V, et al. Evidence-based surgical procedures to optimize caesarean outcomes: an overview of systematic reviews. *EClinicalMedicine* 2024;72:102632.
 163. Hafner A, Pohle MC, Rauh M, Schnabel A, Meyer S, Königer A. Contrast hysterosonographic evaluation of niche prevalence following a standardized suturing technique for caesarean sections. *Geburtshilfe Frauenheilkd* 2024;84:737–46.
 164. Critchley HOD, Maybin JA. Molecular and cellular causes of abnormal uterine bleeding of endometrial origin. *Semin Reprod Med* 2011;29:400–9.
 165. Ludwig H, Metzger H. The re-epithelization of endometrium after menstrual desquamation. *Arch Gynakol* 1976;221:51–60.
 166. Ludwig H, Spornitz UM. Microarchitecture of the human endometrium by scanning electron microscopy: menstrual desquamation and remodeling. *Ann N Y Acad Sci* 1991;622:28–46.
 167. Anderson WR, Davis J. Placental site involution. *Am J Obstet Gynecol* 1968;102:23–33.
 168. Sharman A. Post-partum regeneration of the human endometrium. *J Anat* 1953;87:1–10.
 169. Ludwig H. Surface structure of the human term placenta and of the uterine wall post partum in the screen scan electron microscope. *Am J Obstet Gynecol* 1971;111:328–44.
 170. Wang Z, Davenport KM, Behura SK, Patterson AL. Mesenchymal-epithelial transition serves to rapidly, yet transiently, restore the endometrial epithelium during postpartum murine uterine regeneration. *BioRxiv Prepr Serv Biol* 2025 [Epub ahead of print].
 171. Jauniaux E, Collins S, Burton GJ. Placenta accreta spectrum: pathophysiology and evidence-based anatomy for prenatal ultrasound imaging. *Am J Obstet Gynecol* 2018;218:75–87.
 172. Krueger D, Spoelstra WK, Mastebroek DJ, et al. Epithelial tension controls intestinal cell extrusion. *Science* 2025;389:eadr8753.
 173. Dunnihoo DR, Otterson WN, Mailhes JB, Lewis DF, Grafton WD, Brown CC. An evaluation of uterine scar integrity after cesarean section in rabbits. *Obstet Gynecol* 1989;73(3 Pt 1):390–4.
 174. Einarsson JI, Grazul-Bilska AT, Vonnahme KA. Barbed vs standard suture: randomized single-blinded comparison of adhesion formation and ease of use in an animal model. *J Minim Invasive Gynecol* 2011;18:716–9.
 175. Lapointe-Milot K, Rizcallah E, Takser L, Abdelouahab N, Duvareille C, Pasquier JC. Closure of the uterine incision with one or two layers after caesarean section: a randomized controlled study in sheep. *J Matern-Fetal Neonatal Med* 2014;27:671–6.
 176. Api M, Boza A, Cikman MS, Aker FV, Onenerk M. Comparison of barbed and conventional sutures in adhesion formation and histological features in a rat myomectomy model: randomized single blind controlled trial. *Eur J Obstet Gynecol Reprod Biol* 2015;185:121–5.
 177. Li Z, Bian X, Ma Y, et al. Uterine scarring leads to adverse pregnant consequences by impairing the endometrium response to steroids. *Endocrinology* 2020;161:bqaa174.
 178. Debras E, Maudot C, Allain JM, et al. Development of a rabbit model of uterine rupture after caesarean section, histological, biomechanical and polarimetric analysis of the uterine tissue. *Reprod Fertil* 2025;6:e250018.
 179. Pollio F, Staibano S, Mascolo M, et al. Uterine dehiscence in term pregnant patients with one previous cesarean delivery: growth factor immunoexpression and collagen content in the scarred lower uterine segment. *Am J Obstet Gynecol* 2006;194:527–34.
 180. Paping A, Basler C, Ehrlich L, et al. Uterine scars after caesarean delivery: from histology to the molecular and ultrastructural level. *Wound Repair Regen* 2023;31:752–63.
 181. Ziętek M, Świątkowska-Feund M, Ciećwiedz S, Machałowski T, Szczuko M. Uterine cesarean scar Tissue-An immunohistochemical study. *Med Kaunas Lith* 2024;60:651.
 182. Debras E, Capmas P, Maudot C, Chavatte-Palmer P. Uterine wound healing after caesarean section: a systematic review. *Eur J Obstet Gynecol Reprod Biol* 2024;296:83–90.
 183. Tikhonova N, Milovanov AP, Aleksankina VV, et al. Adipocytes in the uterine wall during experimental healing and in cesarean scars during pregnancy. *Int J Mol Sci* 2023;24:15255.
 184. Sun Q, Zhang D, Ai Q, et al. Human umbilical cord mesenchymal stem cells improve uterine incision healing after cesarean delivery in rats by modulating the TGF- β /Smad signaling pathway. *Arch Gynecol Obstet* 2024;310:103–11.