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ORIGINAL RESEARCH

The technique and results of fenestrated laparoscopic-assisted internal Ring-rrhaphy (FLAIR) for boys with a high risk of recurrence inguinal hernia

Anas Shikha[1] · **Win Sabai Phyu Han**[1] · **Janice Wong**[1]

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Abstract

Introduction The laparoscopic percutaneous inguinal hernia repair has gained popularity. One of the more popular percutaneous techniques involves hydrodissection and anterior diathermy. However, because these maneuvers may lead to injury and lack snugging of large hernias, a modified technique was meant to eliminate the diathermy and hydrodissection, create multiple needle injuries, incorporate transversalis fascia in the closure, and always skip over the vas deferens and vessels.

Aim and method An aggregational modified technique, based on the international collective experience and the available evidence, was defined and called Fenestrated Laparoscopic-Assisted Internal Ring-rrhaphy (FLAIR). The study provides a challenge to the FLAIR technique using it only in boys with a high risk for recurrence (HRH). Boys with HRH are defined to be patients younger than 1-year, strangulated hernia at any age, recurrent hernia after an open repair, or those with a very large hernia. Between July 2016 and December 2018 FLAIR was performed for HRH and cases were followed up until June 2021. Operative findings and complications were documented alongside any complications or complaints during follow-up.

Results 73 HRH hernias were repaired with FLAIR. The HRH category was found to be 42 patients younger than 1-year-old, 16 strangulated hernias, 12 large hernias, and 3 recurrent hernias after an open repair. No intraoperative complications were encountered. The mean follow-up period was 38 months (24–52 months). No recurrence or testicular atrophy was encountered during the follow-up period. 3 patients were found to have a hydrocele at 6-week follow-up which resolved on the subsequent follow-up. The palpable subcutaneous knot was the complaint of 18% of the patients at the 6-week follow-up, but none caused concern at the 5-month follow-up.

Conclusions The FLAIR technique is reliable and safe with no recurrence or complications over the mid-term follow-up.

Keywords FLAIR · Percutaneous herniorrhaphy · Laparoscopic herniorrhaphy · High risk for recurrence hernia · Minimally invasive herniotomy

Introduction

Inguinal herniotomy (IH) is one of the most common procedures done by a pediatric surgeon. The principle of *high ligation of the patent processus vaginalis (PPV)* remains the backbone of most known corrective surgeries.

Laparoscopic percutaneous extraperitoneal closure (LPEC) was first described by Takehara et al in 2000 [1, 2]. In this procedure, the extraperitoneal suturing was done using a 19-gauge LPEC needle (needle with wire loop within) and the knot was tied extracorporeally and buried subcutaneously [Fig. 1]. The procedure was aided with an additional laparoscopic instrument.

Harrison et al. [3, 4] illustrated the subcutaneous endoscopically assisted ligation (SEAL) of the internal ring in 2005. The essential difference is the use of a suture on a large needle which results in the inclusion of all layers of the abdominal wall at least on the anterior quarter of the ring [Fig. 2].

Patkowski et al. [5] described the Percutaneous Internal Ring Suturing (PIRS) in 2006 as a modified technique, where a conventional 18-gauge injection needle was used implementing the lasso technique to complete the internal ring closure [Fig. 1].

✉ Anas Shikha
dr.a.n.shikha@gmail.com

[1] Unit of Pediatric Surgery, RIPAS Hospital, Jalan Putera Al-Muhtadee Billah, Bandar Seri Begawan BA1712, Brunei

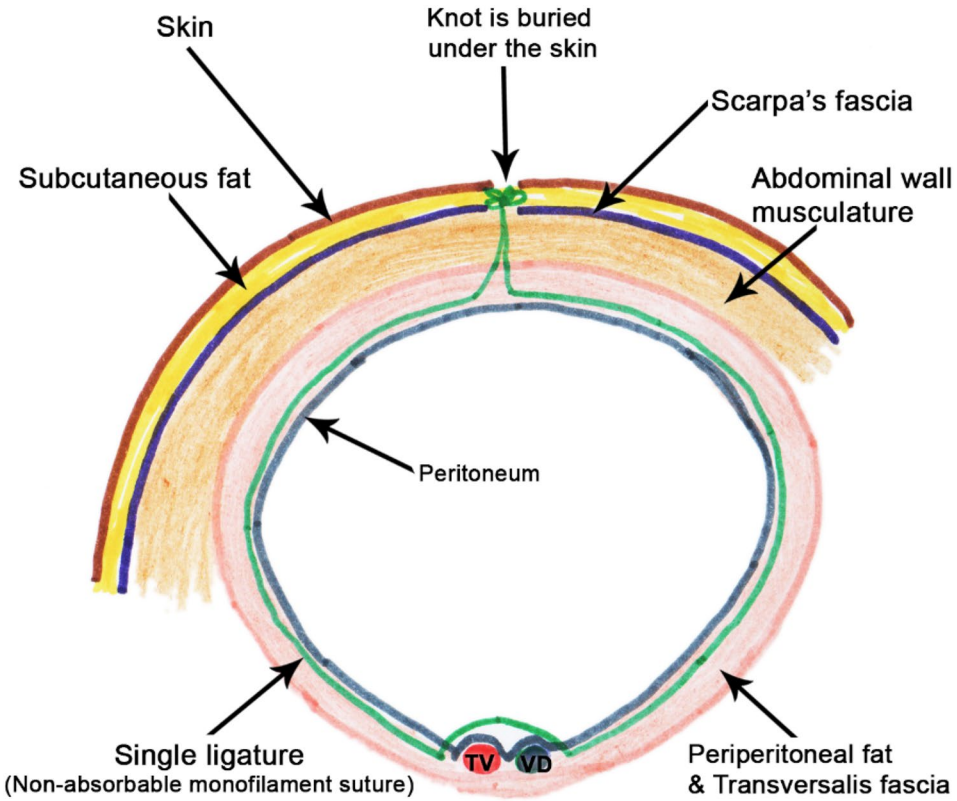


Fig. 1 Left internal ring in LPEC and PIRS techniques

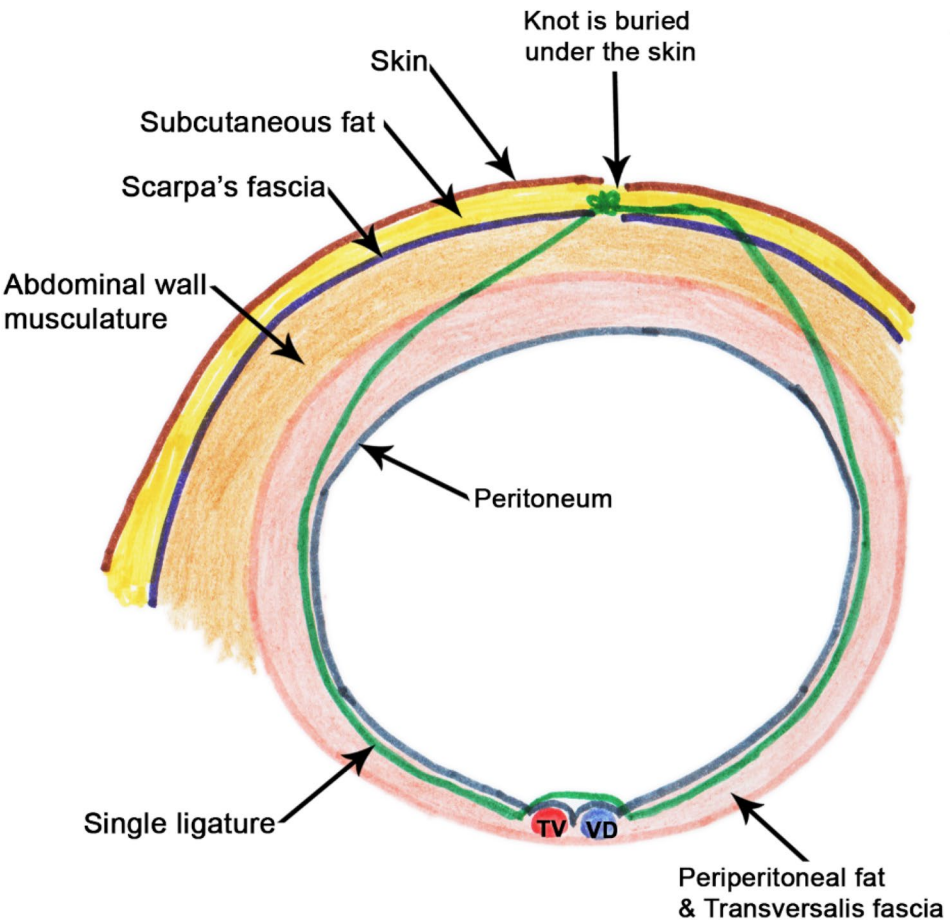


Fig. 2 Left internal ring in SEAL technique

Both Takehara et al. and Patkowski et al. techniques used a monofilament non-absorbable single suture to encircle the PPV at the level of internal ring crossing over the vas deferens (VD) and testicular vessels (TV), whereas Harrison et al. reported the use of both absorbable and non-absorbable sutures.

Another two modifications were presented by Muensterer and Georgeson [6] in 2011 by introducing a preperitoneal hydrodissection to achieve full ring closure, in addition to the use of a double braided suture instead of a single monofilament suture. The technique was called hernia repair by Single-Incision Pediatric Endosurgery (SIPES) [Fig. 3].

The latest modification was described by Ponsky TA [7, 8] in 2013 based on his work on the hernia model in rabbits [9, 10], where the peritoneal diathermic injury was added to the procedure to obtain better fusion at the level of the internal ring [Fig. 4]. Ponsky's technique is one of the most popular techniques in many centers.

The anatomy of the internal ring in children, especially the younger ones, is very compact and surrounded by many vital structures [Figs. 5, 6]. Hence, considering the possibility of injury to the cord structures, surrounding nerves, and vessels, in addition to the knowledge of the causative factors of recurrence in open technique, the author has incorporated parts of the techniques described above with some modifications into the Fenestrated Laparoscopic Assisted Internal Ring-rrhaphy (FLAIR). This technique is essentially a trial towards perfection by utilizing the international collective experience in both open and laparoscopic percutaneous techniques with some modifications. The nuance differences between the aforementioned techniques are summarized in Table 1.

As a challenge to this technique, FLAIR was utilized only in boys with a high risk for recurrence. This study aims to describe the technique and its complications followed by a thorough discussion of the justification behind the proposed technique in the light of the available evidence.

Materials and methods

Boys with high risk for recurrence hernias (HRH) were selected to undergo FLAIR, while other cases are still being done by open technique.

The Selection criteria for male patients going for FLAIR are.

- *Category-1 (CAT1):*

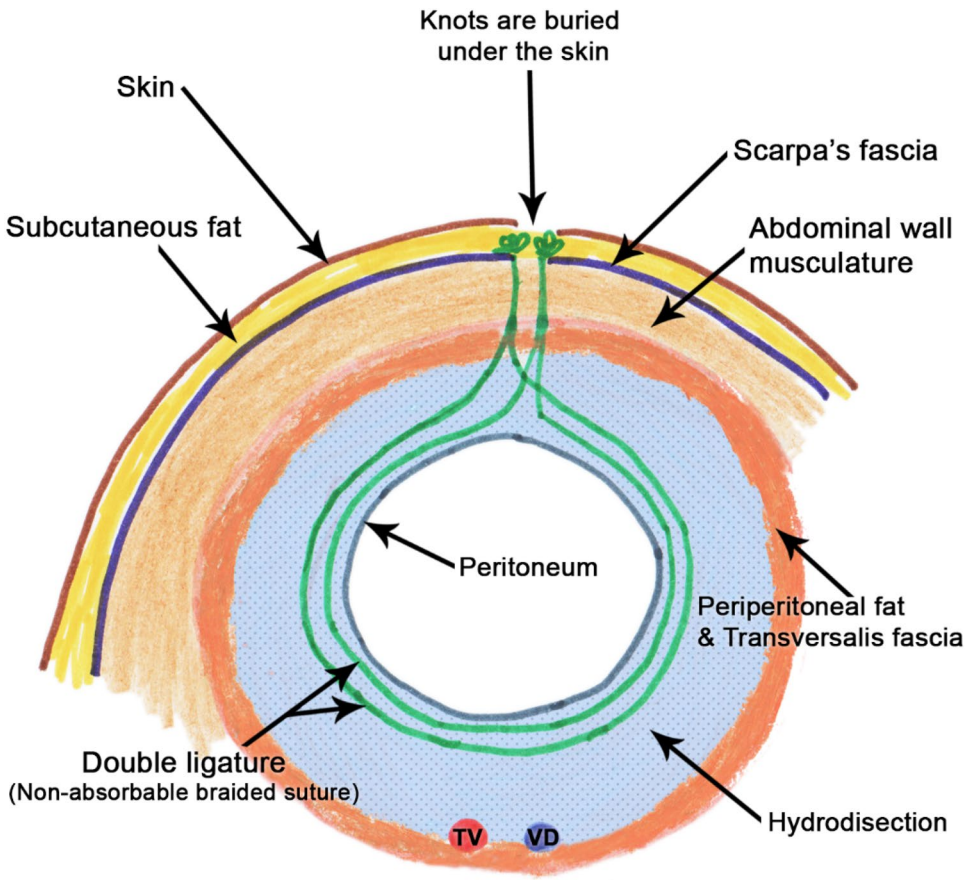


Fig. 3 Left internal ring in the SIPES technique

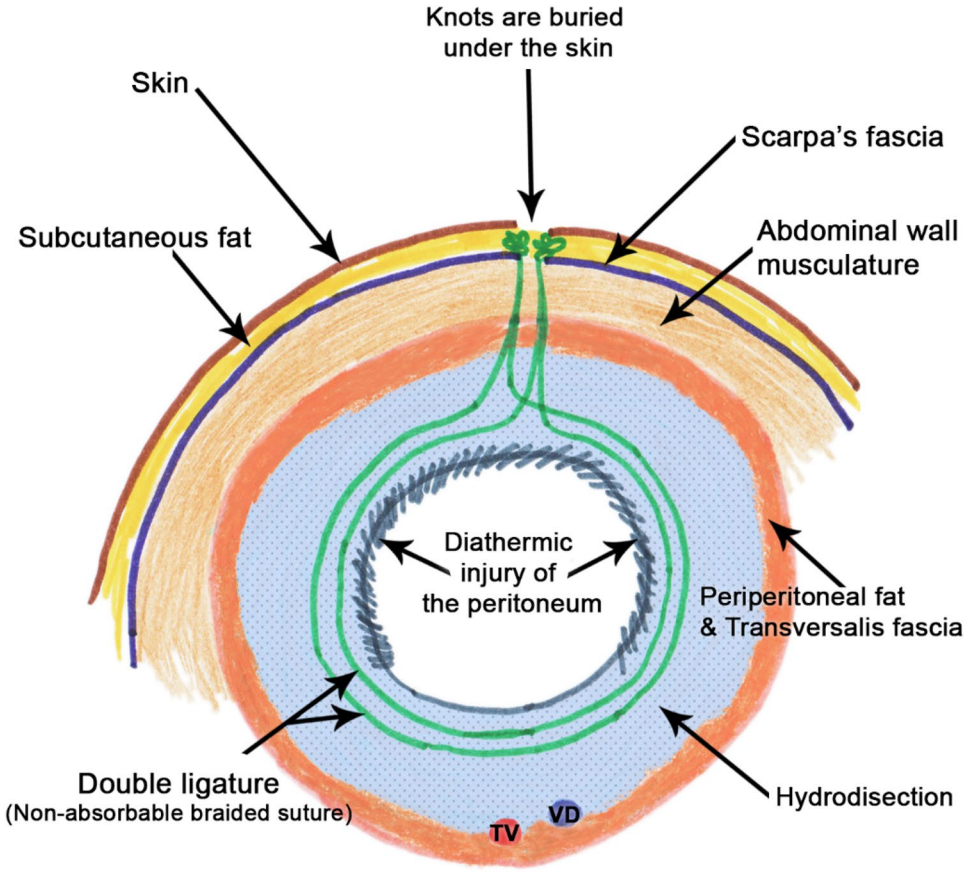
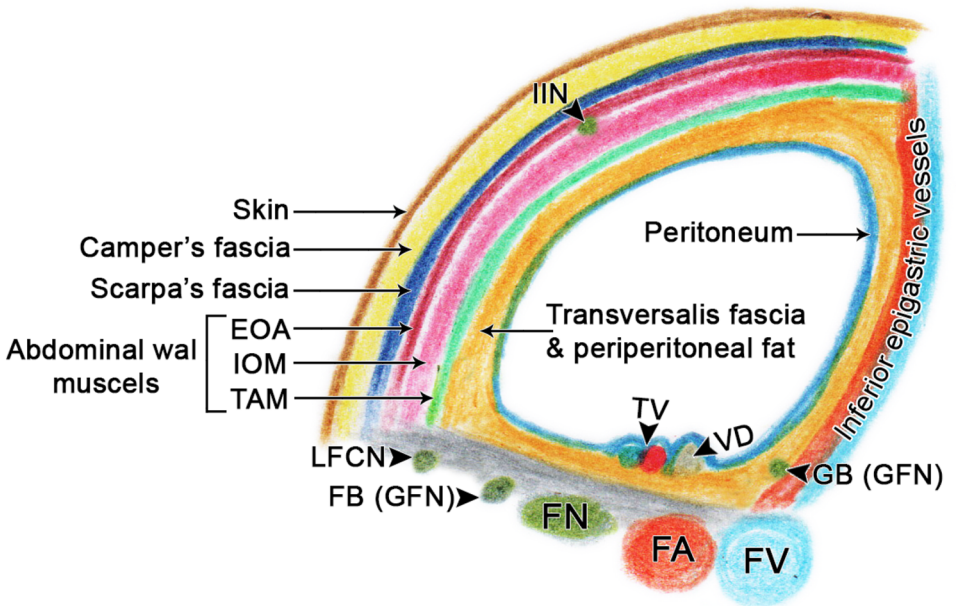


Fig. 4 Left internal ring in Ponsky's technique



EOA: External oblique apponeurosis, IOM: Internal oblique muscle, TAM: Transversus abdominis muscle, FA: Femoral artrery, FV: Femoral vein, TV: Testicular vessels, VD: Vas deferense, LFCN: Lateral Femoral Cutaneous Nerve, GFN: Genitofemoral Nerve, GB: Genital Branch, FB: Femoral branch, FN: Femoral nerve.

Fig. 5 Schematic cross-sectional anatomy of a left inguinal hernia at the level of the internal ring (infant)

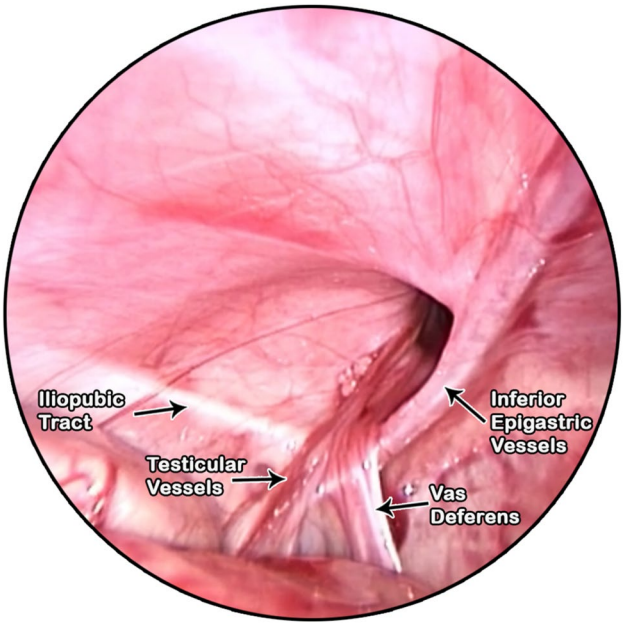


Fig. 6 Laparoscopic view of a left inguinal hernia at the level of the internal ring

Young patients with age < 1 year. Hernias were classified in this category only if they are not strangulated or recurrent regardless of the size of the hernia.

- *Category-2 (CAT2):*

  Strangulated hernias at any age.

- *Category-3 (CAT3):*

  Recurrent hernias after open repair at any age, regardless of the size of the hernia and the presence of strangulation.

- *Category-4 (CAT4):*

Patients with *Large hernias* who are *older than 1 year*. A large hernia is defined as a hernia that is present all the time and causes a significant inguinoscrotal discrepancy.

Patients who underwent FLAIR for HRH between 1st July 2016 and 31 December 2018 were included. None of them were excluded.

The incidental contralateral PPV found intraoperatively were included only if they fit in one of the HRH categories, otherwise, they were excluded.

Postoperatively, the follow-up was done at 6 weeks, 5 months, and then yearly. The reported follow-up period was carried on until June 2021.

Description of FLAIR technique

Preparation

The following are prepared before the procedure is started:

1. An 18-gauge cannula needle. The bevel is bent slightly without obliterating the lumen.
2. Two loops of 3/0 polypropylene. The loop itself is compressed at its tip to ease its passage into the shaft without it being snipped or cut by the sharpness of the bevel. The loop is passed through the needle and kept just proximal to the bevel. The other loop is prepared to be passed through the same needle later on during the procedure.
3. Heavy braided polyester suture without the needle. Size 0 for patients > 6 kg and 2/0 for patients < = 6 kg are used.
4. 5 mm 30 degrees telescope with 5 mm laparoscopic port.
5. 3 mm laparoscopic grasper is prepared in case it is needed during the procedure.
6. A blade 11 scalpel.
7. Suitable braided absorbable suture to close the umbilical fascia.

Procedure

The procedure is done under general anesthesia with endotracheal intubation. The patient is positioned supine, the monitor is located on the left side of the patient and the surgeon stands on the right side. The following steps are followed [Video-01]:

1. A trans-umbilical incision is made, deepened into the fascia, and the abdomen is entered.
2. 5 mm cannula is inserted bluntly and the intraabdominal position is confirmed. Carbon dioxide is insufflated with the pressure of 8–10 mmHg and flow of 1.5–2.0 L/min.
3. The telescope is introduced and both internal rings are checked.
4. The midpoint of the anterior aspect of the internal ring is identified externally under the vision of the telescope. A nick incision is made at that point and bluntly deepened well below the Scarpa's fascia to create a deep pocket that can accommodate the knots well below the fascia.
5. Through the nick incision, the pre-prepared 18-gauge needle is passed just below the peritoneum and multiple fenestrations are created by popping into the peritoneal cavity a few times. This is done at the anterior,

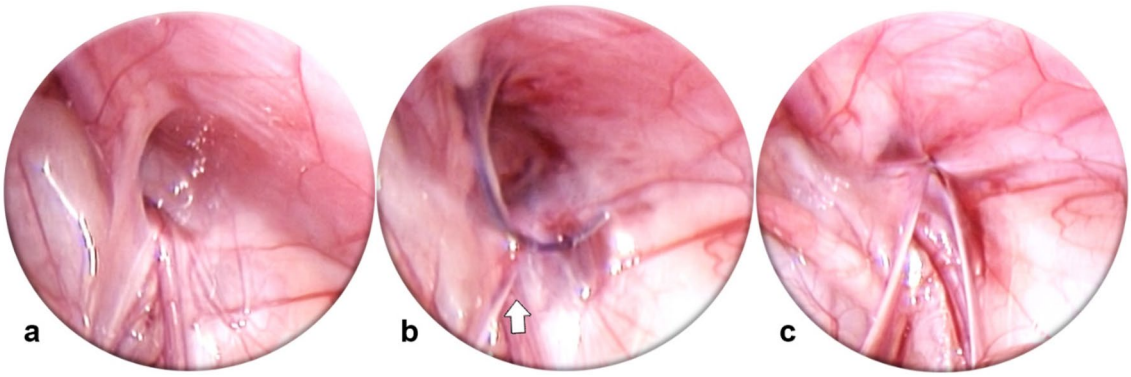


Fig. 7 FLAIR for right inguinal hernia with adjacent VD and TV. **a** Patent PPV with adjacent VD and TV. **b** Visible suture near the VD and TV indicates the inclusion of the peritoneum only, whereas the rest of the ring suture is not visible, because it is beneath the transversalis fascia. The white arrow indicates the excluded peritoneum covering the VD and TV. **c** Right internal ring after completion of FLAIR. Note the well-snugged ring

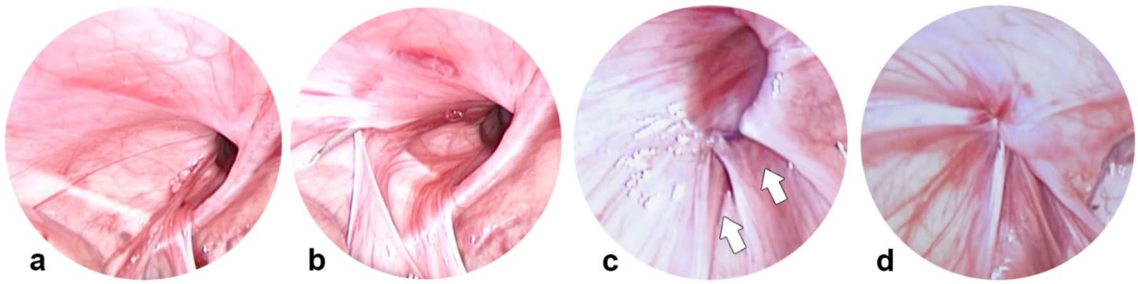


Fig. 8 FLAIR for large left inguinal hernia with VD and TV far apart from each other. **a** Large left PPV with many peritoneal folds between the VD and TV. **b** Peritoneum is stretched to show the distance between the VD and TV. **c** Suture skips over the VD and TV individually. The white arrows indicate the excluded peritoneum covering the VD and TV. Note that the suture is not visible over the superior half of the internal ring indicating a good inclusion of the transversalis fascia. **d** Left internal ring after completion of FLAIR. Note the well-snugged ring despite the large PPV

lateral, and medial aspects of the internal ring sparing the posterior aspect.

6. The Needle is withdrawn and passed again but slightly deeper through the anterior half of the ring's circumference, whereas only beneath the PPV for the other half. The needle should not pass too deep into the musculature or through the iliopubic tract. The aim here is to include the preperitoneal fat and transversalis fascia but not deep into the muscles laterally, inferior epigastric vessels medially, or through the iliopubic tract posteriorly. A difficult passage, bleeding or loss of the needle's indentation are the indicators of a deep passage that should be rectified by withdrawing the needle and passing it through the right plane. Of note, in most infants, this inclusion is likely to be possible on the anterolateral aspect of the internal ring, while the medial aspect (over the epigastric vessels) has very thin fat and fascia to be included.
7. Always skipping over the vas and vessels, either as one block or separately when these structures are widely spaced. This is to keep the VD and TV totally out of the closure along with their covering peritoneum.
8. Once the needle reaches half of the circumference (usually lateral to the TV), the loop of polypropylene is pushed into the abdomen and the external ends are held with a hemostat to the adjacent drapes.
9. The other loop of polypropylene is passed through the 18-gauge needle. After which, the latter is inserted through the same midpoint of the anterior aspect of IR and then is passed through the medial aspect of the internal ring (IR). The exit point is just medial to the VD if a single skip of VD and TV is appropriate, otherwise, the peritoneum between the spaced VD and TV should be included after skipping over the VD, where the exit point will be lateral to the VD [Figs. 7, 8].

10. The needle is negotiated into the first loop (of step 8), then the second loop of polypropylene is pushed into the abdominal cavity.
11. The first loop (of step 8) is pulled out to deliver the second loop (of step 10) through the inguinal stab incision, hence the second loop will be encircling most of the PPV at the level of the internal ring.
12. The polypropylene loop (of step 11) is replaced with a heavy braided polyester loop. This is done by passing a loop of the latter into the loop of the former.
13. The polyester loop is divided into two separate lines and each is tied down and buried into the deep pocket below the fascia. Care is taken to ensure a deep burial of the knot is achieved.
14. The umbilical fascia and subcutaneous tissue are approximated with an absorbable suture and the inguinal nick incision is covered with a waterproof adhesive.

An additional 3 mm portless grasper is inserted in case of a very floppy PPV that is difficult to handle by needle alone. In addition, it may be inserted for strangulated hernias to aid the reduction.

The same steps are followed for the contralateral PPV if it is present.

After the procedure, the patient is discharged within 24 h and followed up after 6 weeks, 5 months then yearly.

During the follow-up period, complications (recurrence, hydrocele, granuloma, palpable knot, and testicular atrophy) or any complaints from the parents were documented.

Results

73 HRH in 59 patients were repaired with the FLAIR technique. All hernias were indirect and in two cases there was an additional direct component.

High-risk category

- CAT1 was found in 39 hernias (mean age of 4.4 months, [0,11]), of those, 19 hernias were large ones.
- CAT2 was found in 18 hernias (mean age of 11.4 months, [2,34]), 8 of them were younger than 1 year.
- CAT3 was found in 3 hernias (mean age of 19 months, [2,32]), one of them was younger than 1 year and presented with strangulation.
- CAT4 was found in 13 hernias (mean age 51 months, [24,91]).

Intraoperative findings

19 patients (32%) with a clinically unilateral hernia (11 left and 8 right) were found to be having a contralateral PPV intraoperatively. In patients younger than 1 year, the contralateral PPV was found in 50%. Only 14 contralateral PPV were included (CAT1), while the remaining 5 were excluded as they did not fall into any of the HRH categories. The morphology of the internal ring of the contralateral PPV was found to be cavernous in 13 (68%) and slit-like in 6 (32%).

Six patients have a large umbilical hernia (> 1.5 cm) and all of them were in CAT1 (21% of patients in CAT1). The umbilical hernia was repaired under the same anesthesia.

14 hernias (19%) required additional working instruments to aid the inclusion of a 'floppy' redundant PPV at the level of the internal ring.

In 31 hernias (42%) the skip over the VD and TV was done individually (two skips), while the rest of the hernias (58%) were done in a single skip.

The mean operative time was 23 min [12—50].

Fifty-one hernias (70%) were done by the 1st author, while 30% were done by a senior trainee (2nd author). The senior trainee has assisted in 7 hernias followed by doing 6 hernias in girls, then 6 hernias in boys with some assistance, and was able to do it independently afterward.

Post-operative follow-up

The mean follow-up period was 38 months [24, 52]. All patients had been followed up for a minimum of 24 months. Two patients lost the follow-up and were last seen at 26 and 29 months postoperatively.

4 patients had a documented preoperative testicular atrophy on the ipsilateral side of the hernia which had recovered at 5-month follow-up. Three of these patients were CAT4 and one CAT2.

2 patients (3%) developed a simple umbilical granuloma that had resolved with a single application of silver nitrate.

No recurrence or testicular atrophy was encountered during the follow-up period.

Three hernias (4%) were found to have a residual hydrocele at 6-week follow-up which resolved on further follow-ups without any recurrence. All three hernias were in CAT2.

One patient developed bilateral retractile testis that was noted at the 5-month follow-up after bilateral FLAIR. On 1-year follow-up, the case remained unchanged but total resolution was noted at 2-year follow-up with normal testicular growth.

The deep inguinal knot was still palpable in 39 hernias at 6-week follow-up (53%). At the 5-month follow-up, the number of palpable knots had fallen to 28 (38%), and at the 1-year follow-up, only 5 knots were 'barely' felt on examination (7%). Of note, none of the palpable knots at 1-year

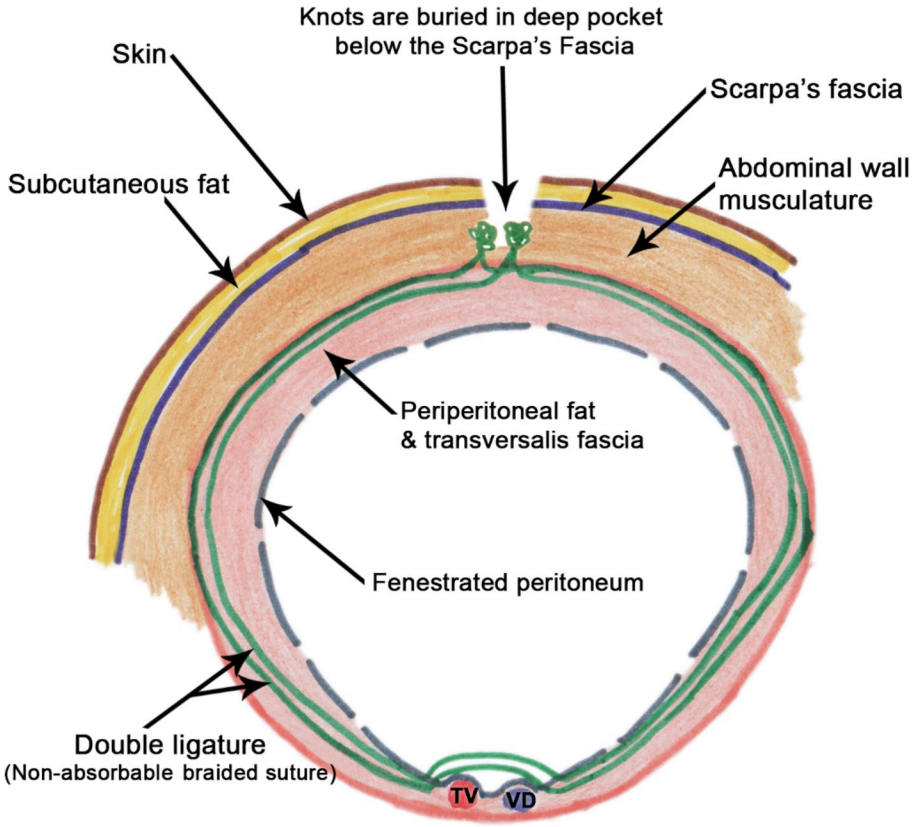


Fig. 9 Left internal ring in FLAIR (skipping over the VD and TV as one unit)

follow-up were causing skin salience and can only be found when the examiner actively searches for it. As for parents and during the 6-week follow-up, 13 of them (22%) raised the concern of the feeling of a 'tiny subcutaneous node' referring to the palpable knot, but none of them mentioned any concern at the 5-month follow-up. No granuloma, erythema, or suture site infection was encountered in any of these patients during the follow-up period.

Discussion

The enthusiasm behind this congregational modified technique has come together to perfect the technique to avoid recurrence and possible injuries. In comparison to Ponsky's technique, FLAIR eliminates both the hydrodissection and the diathermic injury, introduces needle injury to the PPV (fenestration), skips over the VD and TV, and buries the knot well below Scarpa's fascia [Figs. 9, 10].

In the following discussion, the authors' justification for FLAIR in comparison to the open technique, Takehara's original technique, and the other described percutaneous techniques will be discussed.

Early recurrence

Based on the established experience in open herniotomy, the causes of early recurrence are well addressed by many authors. Grosfeld et al. [11] addressed the factors causing recurrence in 72 recurrent inguinal hernias;

Inadequate high ligation of the PPV

In all laparoscopic-assisted techniques (including FLAIR), the level of ligation is 100% assured to be at the level of the internal ring, since it is done under direct vision of the laparoscope.

Wound infection and groin hematoma

Like any laparoscopic surgery, there is no actual wound or muscular incision. The closure is done through a small nick incision which theoretically should have far less chance, if any, for a significant wound infection and hematoma that may lead to recurrence.

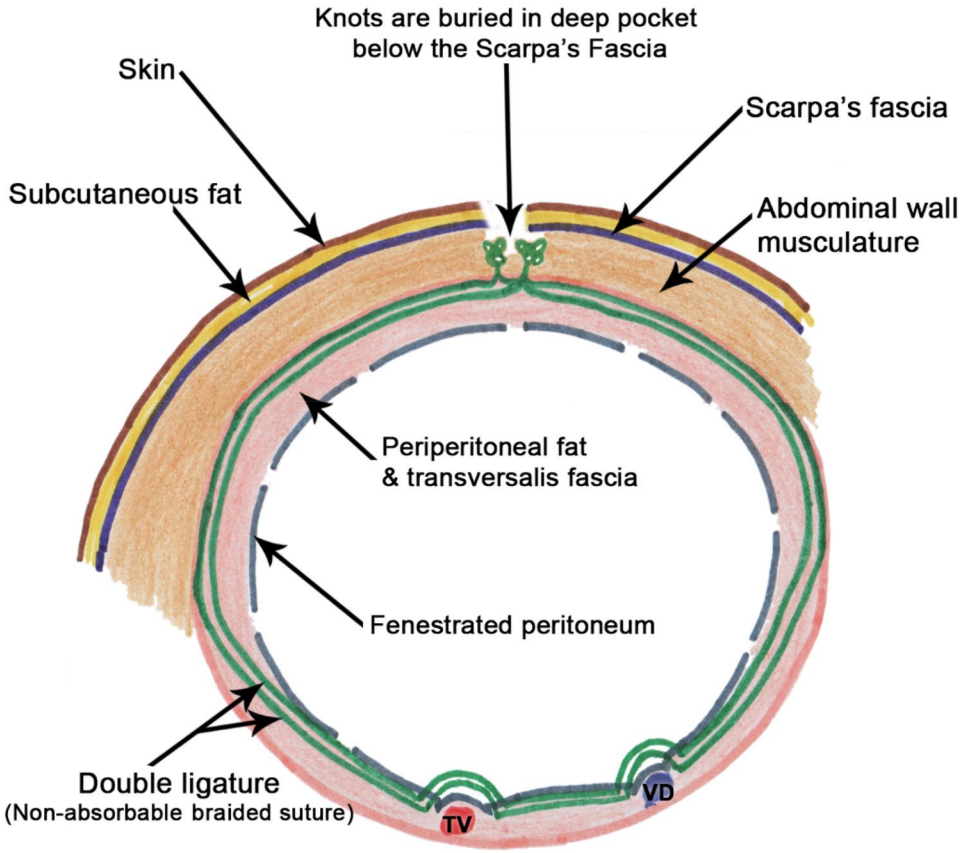


Fig. 10 Left internal ring in FLAIR (skipping over the VD and TV individually)

The direct hernias

Grosfeld et al. [11] reported 30% recurrence as direct hernias. This may be related to injury to the inguinal floor during open repair, where the PPV is dissected and excised. Fortunately, in most laparoscopic-assisted techniques, no dissection is being done, rather all the work is being done at the level of the internal ring. Furthermore, the authors believe that leaving the PPV behind might be beneficial to support the floor, especially in big hernias, where the musculature around the PPV is stretched and weakened. It is well known in open herniotomy that a large PPV (particularly in infants) is thick and occasionally adherent to surrounding musculature, when the PPV is dissected, it leads to a further weakening of the surrounding musculature, whereas if the PPV is left in situ, it will not only prevent weakening the inguinal floor but may serve, the author assumes, like an auto biological mesh once it fuses to itself after the closure of the internal ring.

Incarceration

It is known that open herniotomy for an incarcerated hernia is not an easy task because of edema and inflammation that clouds the anatomy. In contrast, working laparoscopically, the internal ring will look relatively the same whether the hernia is incarcerated or not. Furthermore, Laparoscopy can actively help in reducing and examining the viability of the incarcerated contents.

Young age

This is a factor due to anatomical difficulty, particularly in young infants with huge PPV, where the inguinal anatomy is well distorted. Once again in laparoscopy, the internal ring will look the same at any age despite the fact that the PPV is usually floppy in younger ages which may justify the need for an extra instrument to aid the inclusion of the majority of a floppy PPV at the level of the internal ring.

Failure to snug large internal ring

Grosfeld et al. emphasized snuggling the big-looking IR to prevent a recurrence. To cover this risk factor, FLAIR is unique by the inclusion of the transversalis fascia in the closure. This inclusion will drag the attached muscles and provide anterolateral support to the closed ring instead of closing the peritoneum only. If only the peritoneum is closed and

the muscles are widely stretched, it may set the ground for recurrence. In the SEAL technique [3], the anterior muscles (and maybe part of the lateral ones as well) may be included in full-thickness; however, the authors feel it is risky for two reasons. The first, including a big chunk of muscles, put both the suture and the muscle under tension and eventually predisposes to recurrence which may explain the reported 4.3% recurrence in this technique [3]. The second, doing such inclusion predisposes entrapment of one or more of the nerves that runs in between the abdominal wall musculature, especially in babies, where all structures are in very close proximity [Fig. 5].

Late recurrence

This is beyond the scope of this study, since this mandates a longer follow-up into adulthood. Zendejas et al. [12] reported 8.4% recurrence at 50-year follow-up. Of these, one-third were ipsilateral operations and the remaining two-thirds were contralateral. Unfortunately, the operative notes were not available for almost half of these which makes it difficult to speculate the mechanism (direct vs. indirect). The authors speculate that removing the PPV might put the stretched inguinal floor at risk of developing a direct inguinal hernia especially if the patient develops comorbidity that leads to increased intra-abdominal pressure, whereas keeping it in situ might be beneficial as explained above. Moreover, if a mesh is required for a direct hernia later in life, it is best to be placed on a pristine inguinal area which is the case if the hernia is managed by closing the internal ring only without incising any of the inguinal tissue as is done in open technique.

In other words, leaving the PPV behind may prove beneficial, nevertheless, the author cannot make a strong argument on the latter point in the absence of clear evidence and longer term follow-up.

Manipulation of VD and TV

Transection of the VD is reported in open herniotomy between 0.1 and 0.53% [13], yet the long-term effect of *handling* the VD is poorly studied. Janik and Shandling et al. [14] had shown that the VD grasping with non-toothed forceps or clamping with a hemostat can cause irreversible damage in rat models. This might have a significant impact, especially for bilateral hernias or those undergoing open contralateral exploration. FLAIR completely avoids the VD by skipping over it. More importantly, preserving the covering peritoneum of the VD acts as a barrier between the braided suture and the VD beneath. Ultimately, VD will be spared from any handling, injury, traction, or later fibrosis caused by the permanent braided suture.

The skip-over TV is also meant to avoid any possible injury or adhesions in case the inflammatory reaction to the suture material is overly expressed.

Skipping over the VD and TV is carried out either in one skip or individually when these structures are spaced out (common observation in large hernias). The other described techniques aim either to encircle the whole circumference (techniques with hydrodissection) or skip over both VD and TV as a single unit which may leave a significant space in case VD and TV are widely spaced out. The only concern of skipping over the VD and TV is the risk of developing a hydrocele. Fortunately, this was not an issue, where only 4% showed such hydrocele in the early follow-up period which completely resolves without any recurrence.

The intentional injury of PPV at the level of the internal ring

Based on the important work on the rabbit model by Ponsky TA et al. [9, 10] it was clear that the closure is not necessarily dependent on the suture itself, and in fact, suture-independent closure mandates an inflammatory process to induce immediate and delayed fusion of the PPV at the level of the internal ring.

As per Ponsky TA et al. [7, 8], the immediate inflammatory process is done by causing diathermic injury to the PPV avoiding the posterior wall (where the vas and vessels reside). In FLAIR, the diathermic injury is replaced with needle injury to avoid any possible energy transmission to adjacent vital structures (VD, TV, and surrounding nerves). The author cannot make a strong argument as this is still a theoretical risk and needs further long-term studies to compare those with a diathermic injury with their counterpart, but since the physics of energy transmission within a small space cannot guarantee the safety of the vital structures, the author opted for such an approach in FLAIR. The author assumes that intentional fenestration injuries used in FLAIR should cause enough inflammation to emulate the same results of intentional diathermic injury.

The delayed inflammatory process is achieved using material that both lasts long and induces enough inflammation. To achieve that a heavy braided non-absorbable material is used. It has been shown by Ponsky TA [9, 10] that using a non-absorbable braided suture keeps the ring closed even after removing the suture at a rate that is far superior to any other suture material used in the experiment.

Hydrodissection

The introduction of hydrodissection by Muensterer and Georgeson [6] is a great adjunct to lift the peritoneum off the VD and TV to achieve full circumferential closure of

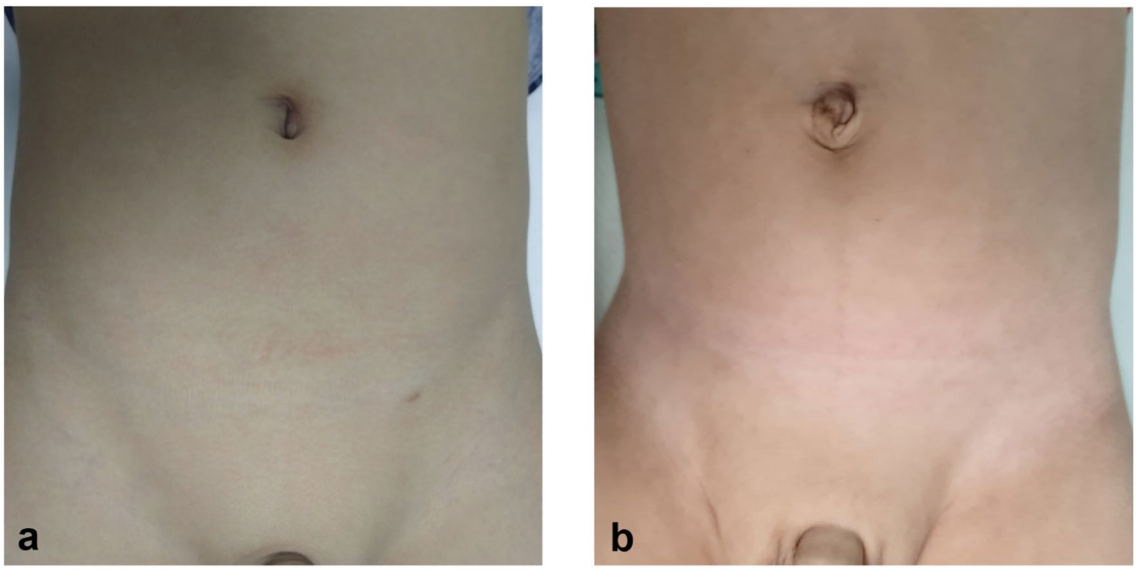


Fig. 11 Cosmetic results after FLAIR. **a** Two-year-old boy after Left FLAIR (CAT2). Barely visible scar after 6 weeks. **b** Seven-month-old boy after bilateral FLAIR (CAT1). There are no visible scars after 5 months

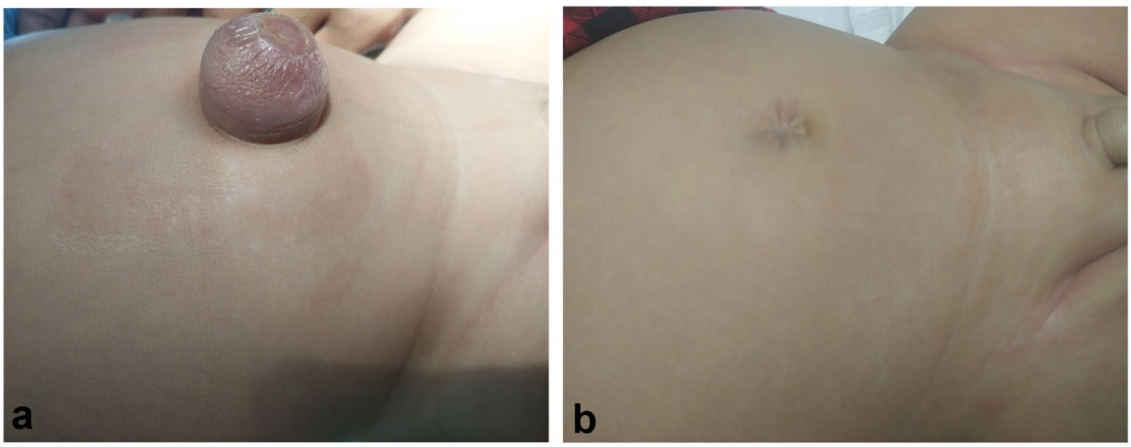


Fig. 12 One-month-old baby boy with left inguinal hernia (CAT1) and large umbilical hernia. Left FLAIR and Umbilicoplasty were performed under the same general anesthesia. **a** Preoperative picture. **b** Scars after 5 months

the PPV and to avoid injury to these vital structures. FLAIR didn't adopt the hydrodissection for two reasons. The first is to keep the anatomy clear to safely include the transversalis fascia (which cannot be done if the hydrodissection is present due to the obscured vision). The second is to keep the peritoneal layer covering both VD and TV as a barrier to prevent any direct contact between the suture and those structures, especially while exchanging the monofilament suture with the braided one.

Contralateral PPV

A prospective meta-analysis by Wenk K et al. [15] concluded the rarity of metachronous inguinal hernia (6%) on a follow-up of a maximum of 3 years in all groups. Zendejas et al. [12] report of 50-year follow-up showed a delayed contralateral recurrence in 5.6% of the patients. In the light of the available evidence, the old argument persists on whether to close the contralateral PPV or not. In the view of the author, this argument may be legitimate considering the higher risk of complications in an open inguinal hernia repair, but in the majority of laparoscopic-assisted techniques, these risks are virtually absent, and thus mandates the provision of the best

Table 1 .

Procedure	Location of the Knot	Ligated structure	Skipping over VD and TV	Suture material	Extra Instrument	Intentional Injury to PPV
LPEC	Subcutaneous	PPV	Yes	Single monofilament non-absorbable	Yes	Nil
PIRS	Subcutaneous	PPV	Yes	Single monofilament non-absorbable	No	Nil
SEAL	Subcutaneous	PPV + Full-thickness muscles (anteriorly)	Yes	Single monofilament non-absorbable/ absorbable	No	Nil
SIPES	Subcutaneous	PPV	No (protected by hydrodissection)	Double ligature, braided non-absorbable	Yes	Nil
Ponsky	Subcutaneous	PPV	No (protected by hydrodissection)	Double ligature, braided non-absorbable	Yes	Done with diathermy
FLAIR	***Well below Scarpa's fascia***	***PPV and transversalis Fascia***	Yes	Double ligature, braided non-absorbable	Occasional	***Done with needle fenestrations***

procedure to eliminate any possibility of re-operation in the future. Furthermore, the reported 6% of metachronous hernia [15] should not be taken as a rule to defer the closure of the contralateral PPV, because the reported groups have heterogeneous risk stratifications and that should be taken into consideration. Kalantary et al. [16] reported a 20% recurrence of metachronous hernia in premature infants, whereas Hoshino et al. [17] reported 11.8% in those younger than 1 year.

In our HRH, we found contralateral PPV in 32% of the patients, and all of them were closed with FLAIR principles regardless of their morphology (slit-like PPV vs. cavernous PPV).

The location of the knot

The presence of the knot in the subcutaneous tissue below the tiny inguinal incision may predispose to the development of granuloma, especially with the use of a permanent braided suture. Yi Chen et al. [18] reported a suture reaction between 0 and 3.3% in a meta-analysis of techniques involving laparoscopic-assisted internal ring closure for hernias and hydroceles. For this reason, FLAIR includes a mandatory step of creating a deep pocket well below Scarpa's fascia to ensure that the knots are well buried away from the skin and subcutaneous tissue to avoid the development of granuloma or altering wound healing. No inguinal granuloma or infection was observed in our group of patients despite the young age of the majority of the patients and the heavy suture material that had been used.

Learning curve

In this study, the surgeries performed by the senior trainee were evaluated to determine the learning curve of the FLAIR procedure. The senior trainee has basic laparoscopic skills with previous experience in performing laparoscopic procedures but is unacquainted with the FLAIR technique. It was observed that independence was achieved after performing 12 procedures of FLAIR. The number of procedures performed during the period of this study was inadequate to analyze the reduction in operative time.

Other advantages

It is known that the laparoscopic approach is superior to the open one in terms of cosmetic results. The same is applied in laparoscopic-assisted hernia repairs including FLAIR. No hypertrophic scars or any visible scars were noted during the follow-up period. The authors believe that the cosmetic advantage is just a bonus considering the aforementioned fundamental benefits [Fig. 11].

About one-fifth of patients in CAT-1 were having large umbilical hernias. Although the majority of umbilical hernias are close spontaneously [19], it is often a parental concern due to the fear of rare complications (strangulation and rupture) in addition to cosmetic reasons. After FLAIR is done and the umbilical port is removed, the umbilical hernia was repaired with fascial approximation and umbilicoplasty. All parents reported that they were pleased with the results [Fig. 12].

The clarity and magnification that laparoscopy provides, offers the surgeon almost the same scenery of the internal ring and its surrounding structures regardless of the status of the hernia (small, large, or incarcerated). The same is often not true for open hernia repair especially in young infants and in the presence of incarceration which usually leads to a longer time under general anesthesia and predisposes for recurrence [11].

Conclusions

The FLAIR technique is safe, has no recurrence on the mid-term follow-up, eliminates the possible risks of injury in some similar techniques, and has other practical advantages, particularly for high-risk for recurrence hernias.

Limitations

The study describes FLAIR and discusses the technique and its mid-term results in comparison to open and common laparoscopic-assisted percutaneous techniques described in the literature. Many aspects are discussed based on the theory of these techniques, thus a long-term multi-center study to compare these techniques is required to address the aforementioned controversial points and to define the best technique. In addition, the results of FLAIR need to be tested by other centers to confirm the reproductivity of the same results.

Declarations

Conflict of interest The authors have nothing to disclose and there is no conflict of interest.

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Consent to publish Consent to publish data and images was obtained.

Ethical issues None.

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