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Renorrhaphy techniques and effects on renal function with robotic partial nephrectomy

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Abstract

The management of small renal masses has evolved over the past several years. Partial nephrectomy is now thought of as the standard of care for the management of small renal masses. Bleeding and calyceal injuries can be challenging to manage and make the procedure technically challenging. The debate between renorrhaphy techniques during robot-assisted partial nephrectomy represents a subject of ongoing discourse. We aim to compare the perioperative and functional outcomes of different renorrhaphy during robot-assisted partial nephrectomy. Our study suggests that different renorrhaphy techniques demonstrated comparable perioperative and functional outcomes in terms of renal function.

Keywords: Robotic-assisted partial nephrectomy, renorraphy, renal function

INTRODUCTION

In 1870, Gustav Simon conducted the first partial nephrectomy[1]. Over the following century, this surgical procedure had limited application, mainly being designated for individuals with a single kidney, impaired renal function, and masses in both kidneys. This limitation stemmed from worries about the likelihood of local recurrence in multifocal tumors and the associated risks of bleeding, both during and after surgery[2]. The computed tomography (CT) dramatically transformed this scenario by enhancing the identification of asymptomatic small renal masses, simplifying preoperative preparations, and promoting the use of partial nephrectomy[3].

Between 1992 and 2003, only one randomized controlled trial was carried out to compare partial and radical nephrectomy. It concluded that partial nephrectomy yielded superior long-term renal function outcomes, reducing the chances of developing advanced-stage chronic kidney disease (3a and 3b). Nevertheless, in the case of renal cell carcinoma (RCC) patients, there were no notable distinctions in terms of local recurrence, cancer-specific survival, or overall survival[4,5]. Significantly, the partial nephrectomy group experienced higher rates of severe hemorrhages and reoperations[6]. Subsequently, there have been significant advancements in surgical techniques, integrating minimally invasive methods such as laparoscopy and robot-assisted surgery.

Nowadays, partial nephrectomy is the preferred surgical method for T1 renal tumors, especially for renal masses smaller than 4 cm (T1a); additionally, it is becoming the preferred option for managing complex tumors[7,8].

Likewise, the use of robotic-assisted partial nephrectomy (RPN) was proposed even for clinical T1 tumors, even when dealing with intricate renal structures[9]. While several surgical approaches can be employed in RPN, the "trifecta" concept often encapsulates the overarching objective. This concept entails attaining negative surgical margins, optimizing the retention of healthy renal tissue, and minimizing surgical complications[10].

With the progression of surgical expertise and technology, there has been a changing emphasis on safeguarding well-vascularized renal tissue by employing diverse methods such as enucleation, off-clamp procedures, selective clamping with near-infrared fluorescence, and early unclamping. This approach seeks to optimize renal function while reducing potential postoperative complications[11-13]. Presently, there are no existing guidelines advocating for reconstructive techniques. Consequently, no agreement exists on the best methods for performing renorrhaphy during robotic partial nephrectomy (RPN). Studies have indicated that partial nephrectomy can reduce renal function, which can vary but may be as high as 20% for treated kidneys[14-16]. It has been postulated that the primary factors contributing to this loss in renal function are the extent of healthy tissue removed, the duration of ischemia, and the damage caused by the reconstructive procedure during renorrhaphy[17-20].

Indeed, many studies have explored how ischemia time and the amount of healthy renal tissue removed affect renal function outcomes. Additionally, research has examined different reconstructive techniques and their impact on postoperative outcomes, including complications such as bleeding and urinary leaks. Nonetheless, limited data exists concerning the impact of renorrhaphy on renal function over an extended period [21,22]. Several renorrhaphy techniques have been documented in the literature, primarily influenced by a surgeon's expertise and the complexity of the tumor, taking into account factors such as size, location, or the presence of a solitary kidney. Furthermore, the choice of tumor removal technique, whether it involves resecting a healthy margin or performing enucleation, can significantly influence the type of reconstruction[22]. Generally, enucleation is commonly viewed as a less invasive method of reconstruction in comparison to resection with healthy margins. This is because enucleation typically involves fewer incisions into the renal sinus, and hemostasis is usually managed by addressing blood vessels encountered during the tumor removal process, rather than waiting until after the tumor has been excised[14]. The suturing technique should be tailored according to the tumor's depth. The key to a successful laparoscopic partial nephrectomy (LPN) primarily relies on effectively managing bleeding by coagulating smaller bleeding points and mechanically controlling larger ones. When it comes to the renal parenchyma, suturing proves to be the most efficient method for achieving hemostasis[23]. Although there is a significant connection between the suture technique and the functional results of partial nephrectomy, urological guidelines do not

offer recommendations regarding the best renorrhaphy technique due to inconclusive evidence supporting a preferred approach. In this context, our attention is directed toward studies that investigate the influence of various renorrhaphy techniques on renal function outcomes, subsequent to RPN.

CONVENTIONAL INTERRUPTED SUTURE REPAIR

Classical renorrhaphy technique has been described by Desai and Gill at the Cleveland Clinic[24]. Following the enucleation of the tumor mass, a diluted solution of indigo-carmine is retrogradely injected through the ureteric catheter. This injection verifies the entry into the renal collecting system, which is then specifically repaired using 2-0 polyglactin sutures on a CT-1 needle. A subsequent injection of indigo-carmine confirms the integrity of the closure. Any transected vessels in the resection area are also sutured to control bleeding. Hemostatic renorrhaphy is carried out by using simple 1/0 polyglactin sutures on a CT-X needle, with pre-fashioned Surgicel bolsters in place. Most suturing procedures are performed under warm ischemic conditions and streamlining the process by eliminating the need for knot tying can save valuable time and reduce warm ischemia. Utilizing the da Vinci robot (Intuitive Surgical, Inc., Sunnyvale, CA) in robotic-assisted LPNs enables the accurate positioning of sutures. Precise suturing seems to be superior to indiscriminate deep suturing[23].

RUNNING KNOTLESS SUTURING

Sliding clips

Many tools may be used to avoid suture application in the kidney, including Lapra-Ty (absorbable Polyglactin) clips, Suture-clips (Applied Medical, Rancho Santa Margarita, CA), Endoclips (US Surgical, Norwalk, CT) or Hem-o-lok clips (Weck, Research Triangle Park, NC. It is important to note that Lapra-Ty is designed for anchoring purposes, whereas the other options are specifically intended for vascular ligation[23].

The sliding clip renorrhaphy has been described by Benway *et al.* at Washington University[25]. If the collecting system is breached or significant blood vessels are still open, it is necessary to use absorbable sutures for repair before proceeding with renorrhaphy. Typically, the cortex is cauterized using monopolar cautery.

In the renorrhaphy process, sutures are initially prepared on the surgical table. A knot is formed at the end of a 15-centimeter-long polyglactin suture, which can be either size 0 or 1. Just above the knot, a LapraTy is positioned, followed by a 10-millimeter Weck Hem-o-Lock. These sutures are then inserted through the renal capsule at a 1-centimeter distance. When securing the end of each suture, the assistant attaches a second Hem-o-Lock to the loose end. Aiming for the center of the clip's jaws is important, ensuring smooth sliding. Before tightening any sutures, ensure all sutures are in place and clipped. To achieve tightening, the surgeon uses ProGrasp forceps to grip the loose end of each suture and applies tension perpendicular to the renal capsule to reduce the risk of tearing. With the robotic needle driver slightly open, the surgeon gently moves the clip toward the kidney. The correct tension is reached when the kidney's surface shows a slight dimpling effect. The assistant secures the closure using a LapraTy clip. It is possible to readjust the tension sliding the clip. However, be cautious not to apply excessive force when readjusting the LapraTy clip, as it can be challenging. After finishing the suture, remove the clamps and inspect the site to ensure no bleeding [Figure 1]. If needed, extra sutures or thrombogenic material can be employed.

Orvieto *et al.* introduced a suturing technique involving an absorbable clip known as Lapra-Ty in a cohort of 32 patients undergoing Laparoscopic Partial Nephrectomy (LPN) for cT1a tumors[26]. In this approach, they conducted freehand sutures on the collecting system and parenchyma with 2-0 and 1-0 polyglactin

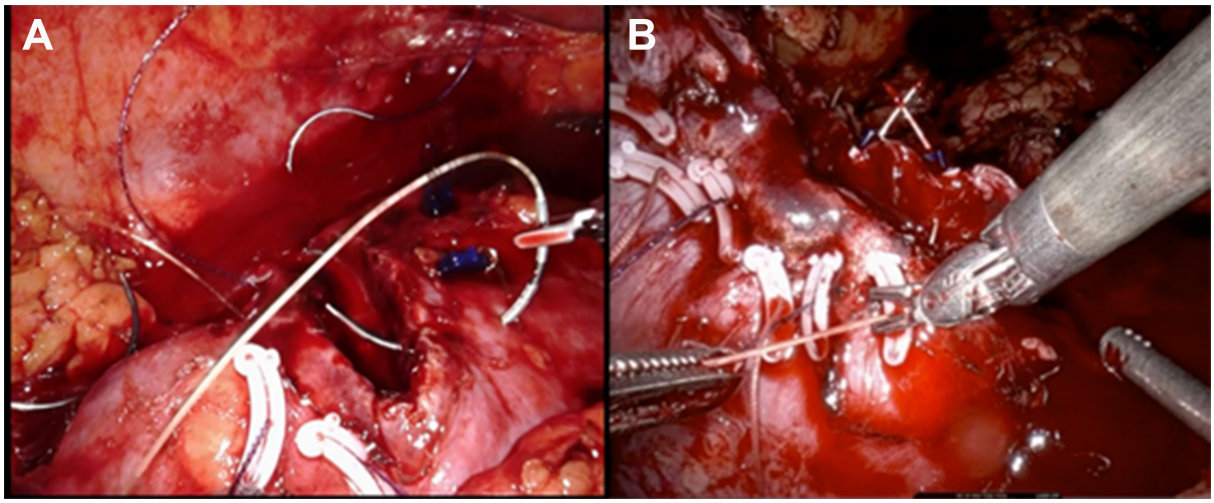

Figure 1. Step of sliding clip's renorrhaphy. (A) Step one of running knotless renorraphy technique with sliding clips: suturing the tumor bed; (B) Step two of running knotless renorraphy technique with sliding clips: to achieve tightening, forceps are used and gently move the clip toward the kidney. The correct tension is reached when the kidney's surface shows a slight dimpling effect.

sutures equipped with an absorbable clip (Lapra-Ty) at the end. After passing the suture, an additional clip was employed to secure it, eliminating the need for traditional knot tying. This technique was employed for both closing the collecting system and placing parenchymal compressive sutures over bolster materials.

When applying this procedure with an average tumor size of 2.1 cm (ranging from 0.3 to 4.2 cm), the mean operative duration was 224.2 min, the mean Warm Ischemia Time (WIT) was 33.1 min, and the mean estimated blood loss amounted to 222.7 mL. In 21 cases (65.6%), the procedure accidentally breached the collecting system, necessitating additional suturing. Notably, there were no postoperative bleeding or urinary leaks in this patient group. Following this, the authors presented a report on 41 patients who underwent LPN with several enhancements. These enhancements comprised the integration of a suture traction system to improve tumor visualization and suturing, the preloading of sutures and bolster materials on the abdominal wall to streamline the suturing procedure, and the substitution of knots with Lapra-Ty clips. As a result of these improvements, the mean warm ischemia time decreased to 29.7 min, and the median estimated blood loss was reduced to 150 mL. However, three cases necessitated conversion to open surgery[27]. In comparison to straightforward suture closure, sliding-clip renorrhaphy has been demonstrated to withstand nearly three times the applied force before causing renal parenchyma tearing[28]. This technique is now widely adopted by urologists who perform RAPN.

Barbed sutures

In 2011, Sammon *et al.* first described renorraphy technique through barbed sutures using the V-Loc 180 absorbable wound closure device (Covidien, Mansfield, MA)[29]. The V-Loc is a type of absorbable copolymer known as polyglyconate, featuring unidirectional barbs. It retains approximately 50% of its wound-closing strength after 30 days and is completely absorbed within 180 days. For the inner renorrhaphy layer, they employed 3-0 V-Loc sutures, each measuring six inches long, along with V-20 needles. To close the renal capsule, 2-0 V-Loc sutures, each measuring 12 inches in length, were used, along with GS-21 needles (36 mm tapered, similar to a CT-1), which were trimmed to seven to eight inches. A knot was placed at the trailing end of each suture and fastened with a sizable Weck Hem-o-lok clip to anchor the initial throw. To make the V-Loc suture bidirectional, the needle was threaded through the looped end of the opposing suture, enabling a single suture for both layers of renorrhaphy. The central knot

was secured using a Surgicel (Ethicon, Johnson & Johnson, Summerville, NJ) pledget to reduce the risk of the knot tearing through the renal capsule. Renorrhaphy was conducted in two layers, regardless of the type of suture used. The deep-layer closure was carried out in a continuous baseball stitch, which involved tying off blood vessels and mending the collecting system if it had been inadvertently breached. The spaces in the renorrhaphy were sealed by employing these identical sutures in a continuous mattress or baseball stitch pattern.

Sutureless technique

A selective suturing, as well as the no suturing of the tumor bed, was initially proposed by Farinha *et al.* in 2021[30]. Their study indicated that the introduction of this new technique did not lead to a higher incidence of complications, while concurrently reducing both the duration of operation and hospitalization. Brassetti *et al.*, in a recent study, conducted an evaluation of safety, oncologic outcomes, and functional results of complete sutureless, off-clamp RPN at a single, high-volume medical center[31]. The first step of this technique involves visualized bleeding vessels and the forced monopolar mode is used for high-precision coagulation. After the tumor excision, the entire tumor bed undergoes repeated monopolar coagulation to achieve a "caramelization" of the surgical field. The unintentional opening of the calyces is closed with a continuous running suture using a 4/0 absorbable monofilament thread. A hemostatic agent (Floseel) is applied to the tumor bed. A different range of hemostatic agents has been created to minimize bleeding during partial nephrectomy. These agents are typically classified into four kinds: mechanical, active or flowable agents and fibrin sealants. Mechanical agent categories include substances such as porcine gelatin, cellulose, bovine collagen, and polysaccharide spheres, which form a matrix at the site of bleeding and activate the extrinsic coagulation cascade. Active agents, which contain thrombin, directly influence the intrinsic coagulation pathway by converting fibrinogen into fibrin. Flowable hemostats, composed of gelatin or mixtures of gelatin and thrombin, have a fluid consistency that allows them to be delivered directly to the bleeding site via syringe. The gelatin granules expand by absorbing blood and serve as a tamponade. Fibrin sealants are formed from a combination of fibrinogen and thrombin, mimicking a fibrin clot in the final stage of the coagulation cascade[32]. The outcomes are quite remarkable concerning surgical duration, both intra- and postoperative complications, and the preservation of renal function. These findings signify notable progress in the surgical treatment of small kidney tumors. In relation to perioperative results, performing a sutureless, off-clamp partial nephrectomy significantly reduces both operative time and warm ischemia time. This reduction could be a key factor in preserving renal function. Additionally, the results suggest that sutureless partial nephrectomy is technically safe, providing promising perioperative results and preserving renal function. In a recent study by Franco *et al.*, the efficacy and safety of sutureless off-clamp robot-assisted partial nephrectomy (sl-oc RAPN) were assessed, focusing on its effects on renal function[33]. Researchers evaluated renal function preoperatively and at one- and three-month post-surgery through creatinine and blood urea nitrogen levels. They also conducted sequential renal scintigraphy before and at least one month after the operation to assess the renal function of both kidneys. It was observed that there was a statistically significant median decrease in renal function of 10 mL/min ($P < 0.01$). The scintigraphy results indicated an overall decline in renal function compared to preoperative values, with the operated kidney experiencing a range of changes from 0 to 15 mL/s and 0% to 40%, resulting in a median reduction of 4 mL/s and 12%. This finding underscores that sl-oc RAPN is a safe procedure with low impact on kidney function. In a separate study, De Nunzio *et al.* compared the perioperative outcomes of patients undergoing sl-oc RAPN performed by both novice and expert robotic surgeons, finding no statistically significant differences in trifecta outcomes (100% for experts *vs.* 87% for novices; $P = 0.07$)[34]. This highlights that the technique is not only feasible but also safe, even when conducted by less experienced surgeons. Furthermore, performing a totally sutureless technique could reduce the costs of robotic equipment, reducing the reliance on expensive robotic arms. However, only few studies demonstrated the possible impact of cost-effective measures, including the use of only one needle carrier or even none, and more efforts are needed to prove this hypothesis.

Comparison between interrupted and running renorrhaphy

A recently published systematic review[21] states that when it comes to minimally invasive partial nephrectomy, using an interrupted renorrhaphy technique led to increased operative time, ischemia time, and complications compared to the running suture technique. In another systematic review[35] on this topic, the same author underlined how these two different techniques affect renal function. There are no significant differences between pre- and postoperative estimated glomerular filtration rate (eGFR) in both patients who received an interrupted suture (WMD -4.88 mL/min, 95% confidence interval [CI] -11.38; 1.63, $P = 0.14$) or those who received a running suture (-3.42 mL/min, 95%CI -9.96; 3.12, $P = 0.31$). Despite the interrupted suture technique resulting in longer ischemia times, it does not produce a difference in renal functional outcome, affirming the existing literature's indication of a minimal effect on renal function due to prolonged ischemic periods.

Presenting similar baseline features, the analysis compared single- *vs.* double-layer renorrhaphy about pre- and postoperative GFR data (321 *vs.* 199 patients) and it showed a better functional outcome for the single-layer technique (-3.19 mL/min, 95%CI -8.09; 1.70, $P = 0.2$ *vs.* -6.07 mL/min, 95%CI -10.75; -1.39, $P = 0.01$).

In another study that compared 118 patients who underwent renorrhaphy with 38 patients who did not, the results demonstrated significant differences. The nonrenorrhaphy group exhibited a 3.8% volume loss compared to a 15.6% volume loss in the renorrhaphy group ($P < 0.001$). Moreover, a 2.4% GFR loss in the nonrenorrhaphy group versus an 8.9% GFR loss in the renorrhaphy group ($P = 0.03$). Volume changes were assessed using preoperative and postoperative CT scans, and multivariable analysis indicated that renorrhaphy was a predictor of renal volume loss ($P < 0.01$). Significantly, the two groups had no substantial differences in complications such as bleeding and urinary leaks. It is important to acknowledge a limitation of this study. All patients in the nonrenorrhaphy group were treated using an open approach, while the renorrhaphy group included both open and robotic approaches[36].

Comparison between single-layer and double-layer renorraphy

Porpiglia *et al.* conducted a study comparing patients who underwent a sliding loop single-layer renorrhaphy to the ones who received a double-layer closure[37].

They did not observe any significant disparities in serum creatinine levels and eGFR. Nevertheless, there was a discernible difference when assessing the renal function of the ipsilateral kidney at the three-month postoperative milestone. The group with double-layer closure exhibited a 16.3% decline, whereas the single-layer closure group displayed only a 7.3% decrease ($P < 0.05$)[36,38] [Table 1].

Comparison between barbed and no barbed renorrhaphy

Various studies have examined the comparison between barbed and non-barbed sutures. These studies ensured that the groups under investigation were well-matched considering age, body mass index (BMI), and tumor size. A favorable performance was observed in favor of running sutures, with notable reductions in operating time [mean difference of 8.80 min (95%CI 12.97, 4.64)], WIT [6.70 min (95%CI 7.82, 5.57)], and blood loss [46.31 mL (95%CI 55.23, 37.39)]. However, no discernible differences were detected regarding postoperative complications, transfusions, or urinary leakages[21].

RENORRHAPHY AND URINARY COLLECTING SYSTEM REPAIR

Numerous techniques for repairing urinary collecting system (UCS) injuries during RAPN have been

Table 1. Renal functional outcomes based on renorrhaphy technique

Authors Publication year	Renorrhaphy technique	Percentage of volume loss (%)	Percentage of GFR loss (%)	Percentage of ipsilateral split renal function decrease
Bahler *et al.*[36] (2015)	Single layer *vs.* double layer	3.8 *vs.* 15.6 $P < 0.001$	2.4 *vs.* 8.9 $P = 0.03$	n/a
Bahler *et al.*[38] (2015)	Single layer *vs.* double layer	9 *vs.* 17 $P = 0.003$	4.4 *vs.* 8.8 $P = 0.14$	n/a
Porpiglia *et al.*[37] (2016)	Single layer *vs.* double layer	n/a	n/a	7.3 *vs.* 16.3 $P < 0.05$

GFR: Glomerular filtration rate.

documented. In most of the studies considered in this analysis, injuries to the UCS, which tend to occur more frequently in cases involving larger and/or anatomically intricate renal masses, were managed using different thread types. Repair methods ranged from selective interrupted sutures (including figure-of-eight sutures) to incorporating repair within the running suture for inner-layer renorrhaphy. Desai *et al.* compared UCS repair and non-repair during partial nephrectomy, and discovered that repairing UCS injuries was linked to a significantly longer WIT[39]. However, no discernible differences in terms of functional outcomes or complication rates were found. Among the studies that compared running sutures to interrupted sutures, four of them documented the use of a specialized suture for the UCS[40-43]. The frequently utilized sutures were 2/0 or 3/0 polyglactin sutures. Williams *et al.* omitted the inner-layer suture in their study[44]. In particular, the authors performed a dedicated closure of the UCS and closed the outer layer by using sliding-clip renorrhaphy. Such kind of suture did not increase the risk of complications and did not reduce the renal function when compared to the double-layer renorrhaphy technique[21].

DISCUSSION AND CONCLUSION

Important data support the idea that preserving renal function after partial nephrectomy involves using complex techniques that avoid indiscriminate and compressive stitching of the renal parenchyma. Several studies have suggested some technical refinements in RPN to make intracorporeal suturing easier and reduce WIT.

The Cleveland Clinic Group introduced an early unclamping method that led to a notable reduction in WIT, enhanced visualization, and better management of residual bleeding during renorrhaphy. Another noteworthy modification entailed the substitution of conventional freehand knot-tying with either a sliding-clip technique or the use of self-retaining barbed sutures. Sliding-clip techniques were created to improve control and tension adjustment during suturing to reduce WIT and the potential for the "cheese-cutting effect" often associated with traditional sutures. Regardless of the specific type of suture employed, running sutures for both the inner and outer layers of renorrhaphy have been established to minimize WIT and simplify intracorporeal suturing during RPN. Selective suturing or a sutureless technique in RPN appears viable and secure[45]. Moreover, these methods represent less invasive surgical approaches. Several studies have reported positive results regarding the accomplishment of the trifecta and functional outcomes, confirming the safety and feasibility of this innovative and challenging technique. Additionally, when performing renorrhaphy, the focus should be on minimizing complications related to partial nephrectomy, such as bleeding and urinary fistulas [Table 2].

During medullary renorrhaphy, it is crucial to avoid overly deep needle passages to prevent the involvement of the UCS and minimize the risk of vascular fistulas. In the event of a UCS injury occurring during tumor excision, accurate superficial sutures or individual absorbable clips can be effectively employed to close the

Table 2. Postoperative complications rate based on renorrhaphy technique

Authors Publication year	Renorrhaphy technique	Events	Total	Odds ratio [95%CI]
Bahler *et al.*[38] (2015)	Single layer Double layer	1 5	15 30	0.36 [0.04-3.37]
Williams *et al.*[44] (2016)	Single layer Double layer	2 4	26 64	1.25 [0.21-7.28]

defect securely. Care should be taken to avoid excluding the calyx or including segmental arteries in the suturing process. In this chapter, we emphasized the substantial changes of suturing techniques on the kidney over the years in partial nephrectomy. The emphasis has been on emulating principles from open surgery, streamlining procedures, and safeguarding renal parenchyma. Running sutures, particularly those using barbed wires, have shown promise in reducing operating time and ischemia duration. Although no definitive evidence and recommendations are provided in this context, the surgeon's experience is still of utmost importance.

Future studies incorporating standardized reporting of resection and reconstruction techniques are essential to evaluate their influence on short-term and long-term functional outcomes. Techniques that shorten clamping time may benefit long-term renal function and should be explored further through additional research, although they may be harmful in non-high volume centers.

DECLARATIONS

Authors' contributions

Made substantial contributions to the conception and design of the study and performed data analysis and interpretation: De Nunzio C, Tema G, Ghezzo N, Cicione A

Performed data acquisition and provided administrative, technical, and material support: De Nunzio C, Tema G, Ghezzo N, Cicione A

Availability of data and materials

Not applicable.

Financial support and sponsorship

None.

Conflicts of interest

All authors declared that there are no conflicts of interest.

Ethical approval and consent to participate

Figure 1 and the graphic abstract are from a patient database, and the ethical review agency Azienda Ospedaliera Sant'Andrea has exempted ethical approval for this study due to the nature of the review.

Consent for publication

Not applicable.

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