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Reduced-Port Robotic Living Donor Nephrectomy Using the da Vinci Xi Platform: A Comparative Cohort Study of SP+1 RDN, Multi-port Robotic, and Laparoendoscopic Single-Site Techniques

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Running title: Xi SP+1 RDN Robotic Donor Nephrectomy

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'Clinical trial number: not applicable.'

Abstract

Background: Living donor nephrectomy is performed in healthy individuals and therefore demands a particularly high safety threshold. Robotic donor nephrectomy may improve visualization, dexterity, and ergonomics, while reduced-port approaches seek to decrease abdominal wall trauma. Dedicated da Vinci SP platforms enable true single-port robotic surgery but are not universally available. We evaluated a single-port-plus-one (SP+1 RDN) configuration performed with the conventional da Vinci Xi platform and compared it with laparoendoscopic single-site donor nephrectomy (LESS-DN) and conventional multi-port robotic donor nephrectomy (RDN).

Methods: This retrospective single-centre cohort included 808 living kidney donors in a prospectively maintained institutional database. Only 3 surgical techniques were included: 59 Xi SP+1 RDN, 706 LESS-DN, and 43 multi-port RDN. Continuous variables were compared by one-way analysis of variance, with Tukey-adjusted post-hoc comparisons where appropriate; categorical variables were compared using chi-square testing. The Xi SP+1 RDN technique used a 4–5 cm periumbilical GelPort containing the camera/working access and a 12-mm AirSeal assistant port, plus one upper quadrant 8-mm robotic port.

Results: Mean age was 36.5±9.6 years in SP+1 RDN, 33.4±8.1 years in LESS-DN, and 34.7±8.9 years in Multi-port RDN (P=.012). BMI was similar among groups (P=.378). Mean warm ischaemia time was 4.36±1.24, 3.53±1.02, and 4.05±1.08 minutes, respectively (P<.001). Mean operative time was 178.1±28.5 minutes for SP+1 RDN, 193.0±51.8 minutes for LESS-DN, and 254.8±45.5 minutes for Multi-port RDN (P<.001). Median length of stay was 2 days in all groups. All 59 SP+1 RDN procedures were completed robotically without transfusion or conversion; one intraoperative bleeding episode was controlled robotically.

Conclusions: Reduced-port SP+1 RDN donor nephrectomy using the da Vinci Xi platform is feasible and preserves short warm ischaemia time and a reasonably short operative time compared with the centre's earlier multi-port robotic experience. The approach should be regarded as an Xi-based reduced-port configuration—not as da Vinci SP surgery. Its principal practical advantage is the ability to pursue port reduction while retaining triangulation, assistant access, and existing Xi infrastructure.

Keywords: living donor nephrectomy; robotic surgery; da Vinci Xi; reduced-port surgery; SP+1 RDN; LESS; kidney transplantation

Abbreviations

ANOVA = Analysis of variance

BMI = Body mass index

ClassIntra = Classification of intraoperative adverse events

LESS-DN = Laparoendoscopic single-site donor nephrectomy

LOS = Length of stay

RDN = Robotic donor nephrectomy (used generically; Multiport RDN and SP+1 RDN denote the specific configurations compared in this study)

SD = Standard deviation

SP = Single Port (the purpose-built da Vinci SP surgical system)

SP+1 RDN = Single-port-plus-one robotic donor nephrectomy (the Xi-based reduced-port technique evaluated in this study)

WIT = Warm ischaemia time

Introduction

Living donor kidney transplantation provides superior patient and graft outcomes compared with dialysis and, in many settings, deceased-donor transplantation. Because the donor is a healthy individual who derives no medical benefit from nephrectomy, donor safety, rapid recovery, and preservation of long-term health are central ethical requirements of living donation [1–3]. The introduction of laparoscopic living donor nephrectomy transformed donor surgery by reducing pain, length of stay, and recovery time compared with open nephrectomy while maintaining acceptable graft outcomes [4–8].

Robotic donor nephrectomy developed as an extension of minimally invasive donor surgery. Three-dimensional vision, wristed instrumentation, stable camera control, and improved surgeon ergonomics can facilitate hilar dissection and complex vascular anatomy, although these

potential technical advantages must be balanced against cost, docking requirements, and the absence of consistent evidence for superior clinical outcomes over mature laparoscopic programs [9–15]. Contemporary comparative studies and meta-analyses generally support robotic donor nephrectomy as safe and effective, with low conversion and complication rates [10–14,16,17].

In parallel, donor surgery has moved toward reducing the number and size of abdominal access sites. Laparoendoscopic single-site donor nephrectomy (LESS-DN) has demonstrated feasibility and, in some studies, improved body-image or scar-satisfaction outcomes [18,19], although randomized and meta-analytic data have not shown consistent advantages in major perioperative endpoints [20–27]. True single-port robotic donor nephrectomy has more recently been reported using the purpose-built da Vinci SP system. Early series and comparative studies suggest that SP-platform donor nephrectomy is feasible, but the literature remains relatively small and dominated by highly specialized centres, and many series still used an extra port for suction and extra traction when needed [28–33]. Reduced-port configurations built on the earlier-generation da Vinci Si platform or the conventional multi-port Xi platform, rather than the purpose-built SP system, in fact predate these SP reports. Such a robotic single-site technique was reported prospectively by a Canadian group who compared it with standard laparoscopic donor nephrectomy; their design routed the camera, two working arms, and an accessory trocar through a single periumbilical GelPort, building on the same group's earlier robotic single-incision experience with pyeloplasty [25,34]. A small independent feasibility series using the same Si-generation platform was published the same year [35]. Single-site-plus-one-port configurations analogous in principle to the present technique have since been reported both in other urological and gynaecological procedures and, non-robotically, in large laparoscopic donor-nephrectomy series [36–38]. These earlier reports, however, are limited to small cohorts, non-donor indications, or non-robotic platforms, and none has directly compared a sizeable robotic Xi single-port-plus-one cohort with a mature single-centre LESS-DN and multi-port RDN experience.

The technique evaluated in this study is technically distinct from da Vinci SP surgery. We perform SP+1 RDN robotic donor nephrectomy using the conventional multi-port da Vinci Xi platform. A periumbilical GelPort platform accommodates the camera, Robotic working port and an assistant port, while one additional upper quadrant robotic port restores triangulation. This design aims to combine the cosmetic and abdominal-wall advantages of port reduction with the

familiar articulation, field exposure, assistant access, and vascular-stapling options of the Xi system. It may therefore be particularly relevant to centres that already own Xi systems but do not have access to a dedicated SP platform.

The present study compares perioperative outcomes of Xi SP+1 RDN robotic donor nephrectomy with our established LESS-DN and earlier conventional Multi-port RDN experience. We hypothesized that SP+1 RDN would maintain donor safety and acceptable warm ischaemia time while improving operative efficiency relative to the programme's multi-port RDN.

Materials and Methods

Study design and setting

This retrospective comparative cohort study was conducted at King Faisal Specialist Hospital and Research Centre, Jeddah, Saudi Arabia, a high-volume kidney-transplant centre performing approximately 220–230 kidney transplants annually, predominantly from living donors. Data were obtained from a prospectively maintained institutional transplant database and supplemented by review of perioperative records. The comparative dataset spans the centre's contemporary minimally invasive donor-nephrectomy programme; robotic donor nephrectomy was introduced in February 2022 and the Xi SP+1 RDN configuration in February 2024.

The study was approved by the Institutional review board (IRB) of King Faisal Specialist Hospital and Research Center, Jeddah, Saudi Arabia (approval number 2261301). Because this was a retrospective analysis of routinely collected clinical data, the IRB waived the requirement for individual informed consent. Data were analyzed in de-identified form.

Study population

The study period was from1st of Feb 2022 until 1st of July 2026 allowing for minimum follow up of 3 months and maximum of 53 months.

The final analysis cohort contained 808 living kidney donors: 706 LESS-DN, 43 conventional multi-port RDN, and 59 Xi SP+1 RDN. All 59 SP+1 RDN cases in the database were retained. Hand-assisted and open donor nephrectomies were excluded (total of 1 open and 5 hand assisted). One attempted SP+1 RDN case in which the robotic console developed a visual-system

malfunction before starting dissection was converted to LESS and was not counted as an SP+1 RDN procedure. The final eligibility count was confirmed as 808 donors: 59 Xi SP+1 RDN, 706 LESS-DN, and 43 multi-port RDN.

Robotic donor nephrectomies were performed by a single transplant surgeon with extensive prior experience in LESS-DN. Conventional multi-port RDN preceded the introduction of the Xi SP+1 technique, resulting in sequential rather than concurrent implementation of the robotic approaches.

Postoperative Follow-up

Donors were routinely followed at 1, 6, and 12 months postoperatively, with additional follow-up when clinically indicated. Follow-up duration was defined as the interval from donor nephrectomy to the last documented clinical assessment. Long-term follow-up beyond 12 months was not uniformly available across the cohort.

Operative techniques

Laparo-Endoscopic Single-Site Donor Nephrectomy (LESS-DN):

LESS-DN was performed transperitoneally using the centre's established single-site technique through a periumbilical incision using GelPoint Advanced Access platform (Applied Medical, Rancho Santa Margarita, CA, USA). Standard principles included complete ureteral and hilar dissection, preservation of maximal vessel length, secure vascular division, endoscopic-bag extraction, and immediate cold perfusion. The extraction incision was used as the principal access site, minimizing additional abdominal wall ports. For right-sided donor nephrectomy, a fixed, non-working 5-mm liver-retraction port was also used, as in the other two techniques described below.

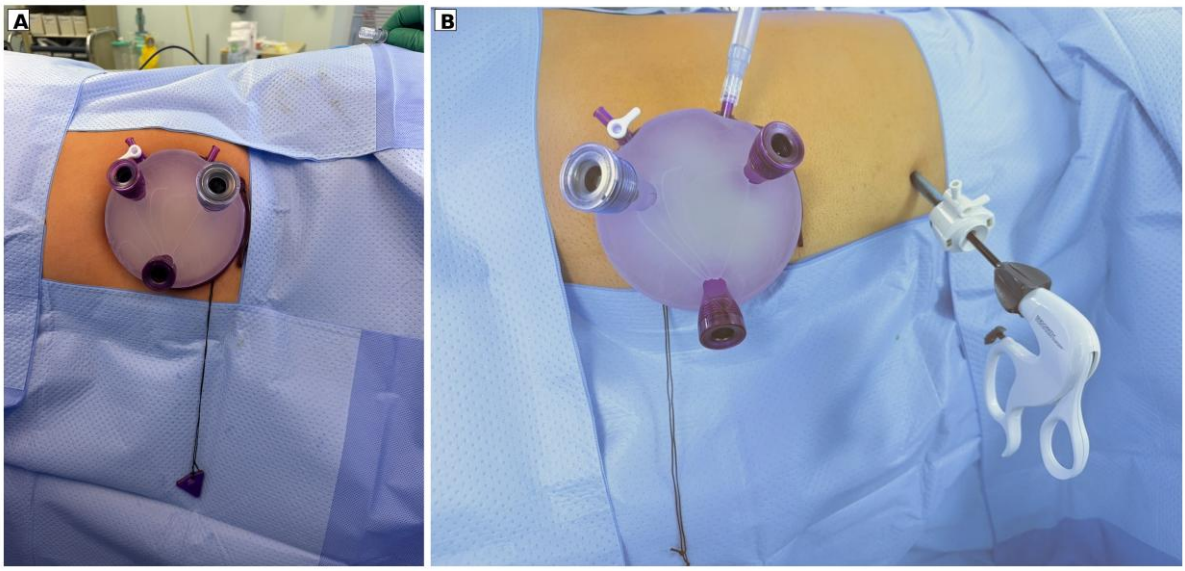


Figure 1. Intraoperative port configuration for laparoendoscopic single-site donor nephrectomy (LESS-DN). (A) Left-sided LESS-DN: a periumbilical GelPoint Advanced Access Platform accommodates the camera, working instruments, and the 12-mm AirSeal assistant port. (B) Right-sided LESS-DN: the same periumbilical platform is used together with a separate, fixed non-working port through which a laparoscopic grasper is passed beneath the liver and locked onto the diaphragm to provide static liver retraction, as described in the Methods.

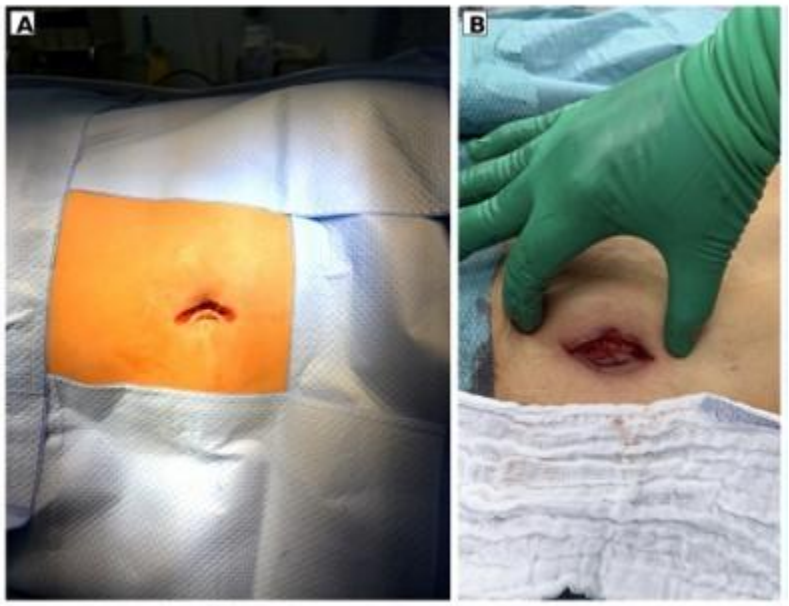


Figure 2. Periumbilical extraction-site incision (approximately 5 cm), shown in two different donors and sited adjacent to, rather than through, the umbilicus. (A) Closed incision at the end of the procedure. (B) The same incision type shown open, illustrating incision depth and access caliber.

Conventional multi-port robotic donor nephrectomy (Multiport RDN):

Conventional RDN was performed transperitoneally with the da Vinci Xi platform using standard multi-port robotic triangulation with 3 or 4 robotic ports in an oblique line from the upper midline towards the mid inguinal point of the side of the nephrectomy. One assistant port was placed through a Pfannenstiel incision using an Alexis wound protector with cap (Applied Medical, Rancho Santa Margarita, CA, USA). Robotic dissection was followed by stapled division of the renal vessels and extraction through the Pfannenstiel site. For right-sided donor nephrectomy, a fixed, non-working 5-mm liver-retraction port was also used, as in the other two techniques. Renal vessels were divided with either a laparoscopic or robotic stapler according to stapler availability, surgeon preference, and the availability of a second surgeon to receive and flush the graft.

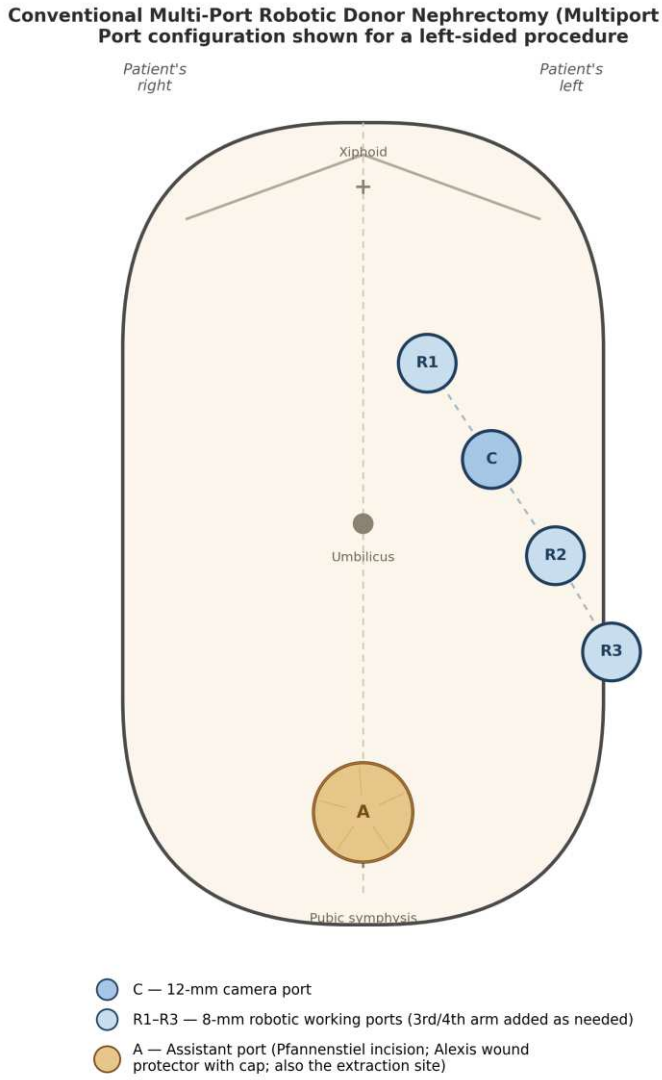


Figure 3. Schematic port placement for conventional multi-port robotic donor nephrectomy (Multiport RDN), shown for a left-sided procedure. C, 12-mm camera port; R1-R3, 8-mm robotic working ports positioned along an oblique line from the upper midline toward the ipsilateral mid-inguinal point (a fourth robotic port was added when required); A, assistant port sited through a Pfannenstiel incision, also used for specimen extraction. For right-sided procedures, an additional fixed 5-mm liver-retraction port (not shown) was placed in the right subcostal region, as described in the Methods.

Xi Single port +1 robotic donor nephrectomy (Xi SP+1 RDN):

All SP+1 RDN procedures were performed with the da Vinci Xi platform (Intuitive Surgical, Sunnyvale, CA, USA), not with the dedicated da Vinci SP system. A 4–5 cm periumbilical

incision was created for a GelPort Advanced Access Platform (Applied Medical, Rancho Santa Margarita, CA, USA). The GelPort accommodated robotic access and a 12-mm AirSeal assistant port (CONMED Corporation, Utica, NY, USA). Two robotic cannulas were positioned through the GelPort for the camera and primary working arm, and one additional 8-mm robotic port—the '+1' component—was placed under direct vision in the ipsilateral subcostal region to restore triangulation. For right-sided donor nephrectomy, a fixed, non-working 5-mm liver-retraction port was also used, as in the other two techniques; because this port was not an active working instrument, was common to all three approaches on the right side and the majority of donor nephrectomies are left-sided, it was not counted toward changing the '+1' port designation. This convention follows the broader single-port-plus-one literature, in which naming reflects active working ports rather than total incisions or passive access [39,40].

The assistant port was used for suction, limited dynamic retraction, specimen-bag manipulation, and laparoscopic vascular stapling when required. Renal vessels were divided with either a laparoscopic or robotic stapler according to intraoperative availability, surgeon preference, and the availability of a second surgeon to receive and flush the graft. When the robotic stapler was used through a GelPort robotic arm, instrument withdrawal and temporary undocking were required; with coordinated assistance this added approximately 30 seconds. The kidney was placed in an extraction bag and removed through the existing periumbilical incision without routine wound extension.



Figure 4. Intraoperative photograph of the Xi SP+1 RDN port configuration (left donor nephrectomy). The periumbilical GelPort accommodates the camera and primary working robotic cannula together with the 12-mm AirSeal assistant port; a separate 8-mm robotic cannula placed in the ipsilateral subcostal region (left of image) constitutes the additional '+1' port that restores triangulation.

Definitions and outcomes

Operative time was defined as the interval from skin incision to completion of skin closure; it therefore excludes anaesthesia induction, robot draping, preparation troubleshooting, and other pre-incision and post-closure room time, and should not be interpreted as total time in the operating room.

Warm ischaemia time (WIT) was defined as the interval from renal-artery division to the start of cold perfusion of the kidney.

Delayed graft function was defined as recipient dialysis within the first postoperative week.

The primary comparative endpoints were operative time, WIT, conversion, transfusion, and perioperative complications.

Secondary endpoints included length of stay (LOS), nephrectomy side, vascular anatomy, and selected recipient consequences attributable to donor operative events.

Complications were interpreted according to the Clavien-Dindo framework, with grade III or higher considered major [41].

Statistical analysis

Continuous variables are reported as mean ± standard deviation and median/range where informative. One-way analysis of variance (ANOVA) was used to compare continuous variables across the three groups, with Tukey-adjusted post-hoc comparisons performed to explore significant overall ANOVA results; homogeneity of variance across groups was considered when interpreting these results given the marked disparity in group size (n=59, 706, and 43). Categorical variables were compared using chi-square testing, or Fisher's exact test where expected cell counts were small (including comparisons of intraoperative and postoperative complication rates). A two-sided P value <0.05 was considered statistically significant. All analyses were performed using IBM SPSS Statistics for Windows (Version 30.0) IBM Corp. Because operative approach was implemented sequentially rather than randomized, statistical significance is interpreted as association rather than causation.

Results

Cohort characteristics

The final analysis cohort contained 808 donors: 59 SP+1 RDN, 706 LESS-DN, and 43 multi-port RDN. Baseline characteristics are summarized in Table 1. Mean age differed across groups (P=.012), driven by an older SP+1 RDN cohort compared with LESS-DN (36.5±9.6 vs 33.4±8.1 years; Tukey-adjusted P=.013). BMI was similar among groups (P=.378), as was sex distribution (P=.998).

Left nephrectomy predominated in all groups but was less frequent in SP+1 RDN (79.7%) than LESS-DN (95.5%) and Multi-port RDN (88.4%; P<.001). SP+1 RDN therefore included a greater proportion of right-sided procedures than the mature LESS cohort. The mean number of renal arteries did not differ significantly (P=.265). In SP+1 RDN, 48 donors (81.4%) had one

artery, eight (13.6%) had two arteries, and three (5.1%) had three arteries; thus, 11 of 59 donors (18.6%) had multiple arteries.

Operative outcomes

Mean **WIT** was 4.36±1.24 minutes for SP+1 RDN, 3.53±1.02 minutes for LESS-DN, and 4.05±1.08 minutes for Multi-port RDN (overall P<.001). Post-hoc testing showed longer WIT for SP+1 RDN than LESS-DN and for Multi-port RDN than LESS-DN, whereas SP+1 RDN and Multi-port RDN did not differ significantly. Importantly, the absolute WIT remained short across all approaches.

Mean **operative time** was 178.1±28.5 minutes for SP+1 RDN, 193.0±51.8 minutes for LESS-DN, and 254.8±45.5 minutes for Multi-port RDN (overall P<.001). SP+1 RDN was substantially faster than Multi-port RDN (Tukey-adjusted P<.001). The difference between SP+1 RDN and LESS-DN did not reach significance with Tukey adjustment despite a 14.9-minute lower mean in SP+1 RDN (adjusted P=.073).

Median **LOS** was 2 days in all three groups. Mean LOS was 2.09±0.29 days for SP+1 RDN, 1.73±0.78 days for LESS-DN, and 1.84±0.65 days for Multi-port RDN (P=.002). The SP+1 RDN cohort had no recorded 1-day discharges and had a narrowly distributed 2–3 day stay; this may reflect differences in discharge pathways rather than increased morbidity, though the study was not designed to determine the cause of this difference.

Safety and complications

Intraoperative and postoperative adverse events were graded separately, using the ClassIntra system [42] for intraoperative events and the Clavien-Dindo classification for postoperative complications, consistent with current recommendations that Clavien-Dindo not be applied to events occurring within the index operation.

Intraoperative adverse events occurred in 1/59 donors (1.7%) in the Xi SP+1 group, 0/43 (0.0%) in the multi-port RDN group, and 8/706 (1.1%) in the LESS-DN group. In the LESS-DN group, these comprised adrenal-vein bleeding (n=3), lumbar-vein bleeding (n=1), a partial main renal-artery injury (ClassIntra III), a stapler failure requiring open conversion (ClassIntra III), a bowel-entry injury managed with resection and anastomosis through a small extension of the extraction

incision (ClassIntra III), and a kidney fracture during specimen extraction (procurement-related graft injury) that required repair but with no adverse consequence (ClassIntra II). All bleeding events were controlled intraoperatively without conversion, transfusion, or reoperation.

Postoperative complications occurred in 0/59 donors (0.0%) after Xi SP+1, 1/43 (2.3%) after multi-port RDN, and 6/706 (0.8%) after LESS-DN. The multi-port RDN complication was a postoperative abdominal-wall haematoma (postoperative day 5) managed with angiographic embolization (Clavien-Dindo IIIa). In the LESS-DN group, postoperative complications comprised an internal hernia requiring reoperation on postoperative day 3 (Clavien-Dindo IIIb), incisional hernia in three donors requiring elective repair (Clavien-Dindo IIIb), and delayed chronic neuropathic pain in two donors, who improved with physiotherapy, analgesic medication, and eventually nerve block (Clavien-Dindo IIIa).

Rates of intraoperative and postoperative events did not differ significantly between the three approaches (Fisher's exact test, all pairwise P>.3), though the marked disparity in group size — particularly the small Xi SP+1 (n=59) and multi-port RDN (n=43) cohorts relative to LESS-DN (n=706) — limited statistical power to detect a true difference, and these comparisons should be interpreted as descriptive rather than confirmatory.

Discussion

The principal finding of this comparative experience is that a reduced-port SP+1 RDN can be performed with the da Vinci Xi platform while maintaining short WIT and a perioperative safety profile comparable to the centre's established techniques, within the descriptive limits of complication ascertainment in this cohort. The technique should not be conflated with da Vinci SP donor nephrectomy. The SP system is a purpose-built single-port robot with a multichannel cannula and articulating instruments specifically designed for intracorporeal triangulation [28–33]. In contrast, our approach adapts the widely deployed Xi platform by concentrating camera/working access at a periumbilical GelPort and adding one upper quadrant robotic port. The distinction is important technically, economically, and academically.

The contemporary literature supports the safety of robotic donor nephrectomy but has not established a single universally superior minimally invasive technique. Randomized and observational comparisons of robotic versus laparoscopic donor nephrectomy have generally

shown similar donor and graft safety, with some studies suggesting advantages in visualization, vascular handling, or learning curve and others emphasizing longer operative time and greater cost [10–15,43–45]. In our program, conventional Multi-port RDN had the longest operative time. This can be due to the surgeon's progressing robotic experience (Conventional Multi-port RDN was performed until end of January 2024 where it was replaced fully by SP+1 RDN), together with the additional time required to place and subsequently close the extra ports used in the conventional multi-port configuration. SP+1 RDN, introduced after substantial LESS and robotic experience, was approximately 77 minutes faster on average than the earlier multi-port robotic cohort. This is clinically notable but should not be attributed entirely to the access configuration because surgeon experience, team familiarity, case sequencing, and evolving perioperative workflows likely contributed. This may partly reflect greater fellow involvement and training opportunities during LESS-DN cases relative to SP+1 RDN, which could have lengthened operative time for LESS-DN. More broadly, because the multi-port cohort was drawn entirely from the surgeon's early robotic learning curve, it cannot be regarded as a like-for-like comparator to the more recent SP+1 RDN and LESS-DN cohorts; the statistically significant difference in operative time for Multi-port RDN should be interpreted as reflecting this early-experience effect rather than an inherent property of the multi-port configuration itself, and a fair comparison would require a head-to-head comparison between multi-port and SP+1 RDN within the same period.

The WIT findings deserve similar nuance. LESS-DN had the shortest mean WIT, whereas SP+1 RDN and Multi-port RDN were slightly longer. The absolute differences were less than one minute between SP+1 RDN and LESS and approximately 0.3 minute between SP+1 RDN and multi-port RDN. WIT in all groups remained within ranges commonly reported for minimally invasive donor nephrectomy, and the difference between SP+1 RDN and Multi-port RDN was not significant. Prolonged warm ischaemia has been associated with adverse early graft outcomes, but short differences within the low single-digit range are unlikely by themselves to outweigh donor-safety and technical considerations [46].

An important practical feature of SP+1 RDN is preserved assistant access. Pure single-site surgery can restrict triangulation, suction, exposure, and rescue maneuvers. These limitations have been described in the LESS literature and partly explain the development of robotic single-port technologies [20–33]. Our assistant AirSeal port permits independent suction, retraction, bag

manipulation, and laparoscopic stapling, while the lateral Xi arm restores triangulation. The value of that redundancy was demonstrated by the single SP+1 RDN bleeding event, which was controlled robotically without escalation. In donor surgery, where the tolerance for preventable risk is exceptionally low, maintaining a straightforward rescue pathway is a meaningful design principle.

The technique also proved applicable beyond straightforward left kidneys. Approximately one fifth of SP+1 RDN donors underwent right nephrectomy and 18.6% had multiple renal arteries. Neither anatomic feature prevented completion with the reduced-port configuration. This is relevant because port-reduction strategies can be criticized as suitable only for carefully selected anatomy. Our experience suggests that once the team is familiar with the configuration, right-sided cases and multiple arteries can be managed without abandoning reduced-port access.

The comparison with LESS-DN is particularly informative. LESS has been a highly mature technique in our centre, accounting for the majority of donor nephrectomies. The 2026 meta-analysis of randomized trials comparing LESS-DN with conventional laparoscopy found no significant differences in operative time, WIT, blood loss, LOS, or overall complications, reinforcing that the clinical value of port reduction may lie partly in patient-centered endpoints such as scar perception, pain, and recovery rather than dramatic differences in traditional perioperative metrics [27]. Earlier prospective studies similarly reported favourable body-image or pain outcomes with single-site approaches [23–26]. Our dataset did not systematically capture validated pain, cosmetic, or quality-of-life scores, so we cannot claim those benefits for Xi SP+1 RDN.

Dedicated SP donor nephrectomy is an important comparator but represents a different technological strategy. Garden and colleagues reported early feasibility of donor nephrectomy with the da Vinci SP system, and Palese and colleagues later compared SP robotic donor nephrectomy with laparoscopy [29,30]. More recent 2025 publications describe SP versus multi-port techniques and a standardized SP donor-nephrectomy workflow, while a 2026 case series continues to demonstrate early feasibility [31–33]. These studies establish a growing evidence base for purpose-built SP surgery. Notably, although these series are described as single-port procedures, several report routine use of a supplemental port in their methods rather than their titles: Garden and colleagues placed a 12-mm periumbilical assistant port used for suction,

specimen-bag introduction, and stapling alongside the SP incision, and the subsequent series from the same group similarly incorporated a 12-mm umbilical assistant port alongside the Pfannenstiel SP access [29,32]. This is not a criticism of these important early series, but it illustrates that even purpose-built SP platforms frequently require supplemental access for donor nephrectomy in practice, and that the practical distinction between "pure" single-port and reduced-port surgery is often narrower than title terminology alone suggests. The potential contribution of Xi SP+1 RDN is different: it offers a reduced-port pathway for centres that already possess an Xi platform and do not wish to acquire or cannot access a dedicated SP system.

Beyond platform availability, two further practical considerations favored the conventional Xi platform over the purpose-built SP system for a reduced-port strategy. First, the Xi platform offers direct compatibility with Intuitive's full vascular-stapler line and with dedicated advanced bipolar vessel-sealing instruments (Vessel Sealer Extend and, more recently, Vessel Sealer Curved), both of which facilitate rapid, secure control of the renal hilum, However, in our study we used only the Vessel Sealer Extend as the Vessel Sealer Curved was not available. Robotic vascular stapling and an equivalent dedicated vessel-sealing instrument have historically been unavailable on the SP platform, and comparative reports note that SP surgeons must instead rely on clips, standard bipolar energy, or a laparoscopic sealer introduced through an accessory port to accomplish tasks that the Xi instrument line performs natively [47]. Second, at least one report has described that the semi-rigid, double-jointed SP instruments transmit comparatively less mechanical force than standard 8-mm Xi instruments, resulting in weaker retraction of bulky or vascular structures and a narrower margin for firm traction during dissection [48]. For a procedure in which secure, high-force control of the renal vessels is paramount, these considerations reinforced our preference for a design that preserves full Xi instrumentation and stapling capability while still reducing the number and size of incisions.

The reduced-port concept underlying Xi SP+1 RDN is itself not new and has been reported previously using da Vinci platforms other than the purpose-built SP system. Luke and colleagues performed the first prospective comparative series of robotic single-site donor nephrectomy using the da Vinci Si platform, building on their own group's prior robotic single-incision pyeloplasty experience rather than any earlier robotic donor-nephrectomy precedent [25,34]. Their design routed all instrumentation through a single periumbilical GelPort, yet even this

"pure" single-site configuration required an additional 5-mm port placed through the same GelPort in 4 of 14 cases (28.6%) when splenic retraction proved difficult, echoing the pattern seen in the SP-platform series discussed above. Their R-LESS cohort was exclusively left-sided (0 of 14 right-sided procedures) and included multiple renal arteries in 3 of 14 donors (21.4%), a proportion similar to the 11 of 59 donors (18.6%) with multiple arteries in our SP+1 RDN cohort, though our series additionally included 12 right-sided procedures (20.3%) not represented in theirs. Mean operative time in the Luke series was 269±75 minutes, including robotic setup, compared with 178.1±28.5 minutes in our SP+1 RDN cohort; the two series differ in platform generation, era, and surgeon experience and cannot be compared statistically, but the difference illustrates how substantially reduced-port robotic donor nephrectomy has matured over the intervening decade. LaMattina and colleagues independently described robotic single-port donor nephrectomy using the same Si-generation platform in a three-case feasibility series published the same year [35]. Single-site-plus-one-port configurations analogous in principle to our design have also been reported with conventional Si or Xi platforms in other robotic urological procedures [36], and a large non-robotic laparoscopic single-site-plus-one-port living-donor-nephrectomy experience, including a randomized comparison with mini-laparoscopic donor nephrectomy, has been published by a high-volume Korean group [37,38]. These precedents differ from the present study in platform generation, operative modality, indication, or cohort size, and none provides a direct three-way comparison with a large contemporary LESS-DN cohort and an earlier multi-port RDN cohort within the same transplant programme. The contribution of the present study is therefore not the reduced-port concept itself, but its large-scale application to robotic Xi donor nephrectomy and its comparative evaluation against the centre's mature LESS-DN and multi-port RDN experience.

The "Single-port plus-one" naming has been used for reduced-port configurations in other robotic procedures in the literature[39,40]. Where a second genuinely active working port (Not static like in our study) has been required, other groups have instead adopted an explicit "plus-two" designation, reinforcing that the distinction turns on whether additional access is doing surgical work rather than simply on the total number of incisions.

Cost was not measured in this study and should not be inferred from port number alone. Robotic donor nephrectomy may carry higher direct procedural costs than laparoscopy, and acquisition of a second robotic platform introduces additional capital and maintenance considerations.

Nevertheless, an Xi-based technique can potentially leverage existing institutional infrastructure and training. A formal micro-costing analysis comparing disposables, operating-room time, robot utilization, and downstream recovery costs would be valuable before making economic claims.

The complication profile reinforces the central importance of surgical maturity and standardized rescue strategies. The very large LESS cohort accumulated several rare but meaningful adverse events over many years, whereas the much smaller SP+1 RDN cohort had only one intraoperative bleed controlled robotically. This should not be interpreted as proof that SP+1 RDN is intrinsically safer. Rare complications require very large denominators, and the groups were treated during different eras by teams at different stages. The appropriate interpretation is that introduction of SP+1 RDN did not reveal an obvious new safety signal in the first 59 cases.

This study has several limitations. It is retrospective, non-randomized, single-center, and strongly affected by temporal and learning-curve confounding. The groups are markedly unequal in size. All robotic procedures were performed by one surgeon who also contributed to the LESS cohort, improving technical consistency but limiting generalizability and potentially favoring later robotic cases through accumulated experience. Operative time was measured from skin incision to skin closure and therefore excludes robot draping, and other room time not attributable to the incision-to-closure interval; this narrower definition should be considered when comparing our operative-time figures with studies that report total time in the operating room. Patient-reported pain, cosmetic satisfaction, opioid use, cost, donor renal function, and long-term quality of life were not captured consistently.

Despite these limitations, the study has strengths: it compares three successive minimally invasive donor strategies within one high-volume transplant program; it includes a large, mature LESS-DN comparator; and it describes a technically reproducible reduced-port Xi configuration that is distinct from the increasingly published da Vinci SP approach. Prospective evaluation should focus on standardized complication reporting, pain and cosmetic outcomes, same-day or next-day discharge pathways, cost, and learning-curve analysis. A more convenient, dedicated fixed liver-retraction device would be a useful future refinement, as it could eliminate the additional right-sided retraction port used across all three techniques in this series. Multi-institutional validation would be particularly useful to determine whether Xi SP+1 RDN can be adopted safely outside a centre with extensive LESS-DN and robotic experience.

Conclusion

All three donor nephrectomy approaches proved reasonably safe within the benchmarks reported here: there were no conversions or transfusions in either robotic cohort (one LESS-DN procedure required conversion to open surgery after stapler failure), and complication rates were low across groups, though complications were not captured as a complete standardized row-level outcome and these rates should be interpreted descriptively. SP+1 RDN performed with the da Vinci Xi platform is a feasible reduced-port robotic technique that preserves assistant access and conventional Xi triangulation. In this 59-case experience, SP+1 RDN achieved short warm ischaemia time, no conversion or transfusion, and substantially shorter operative time than the centre's earlier Multi-port RDN cohort; however, because the Multi-port RDN cohort coincided with the surgeon's early robotic learning curve, this operative-time difference, despite reaching statistical significance, should not be interpreted as an inherent disadvantage of the multi-port configuration, and a comparison of Multi-port RDN performed past the learning curve is needed before firmer conclusions can be drawn. The approach should be presented as an Xi-based reduced-port configuration rather than true da Vinci SP surgery. Larger prospective studies incorporating standardized donor-reported outcomes, cost, and long-term follow-up are required before superiority over established LESS or multi-port techniques can be claimed.

Declarations

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Author contributions: All authors made substantial contributions to the conception or design of the work, or to the acquisition, analysis, or interpretation of data; drafted the manuscript or revised it critically for important intellectual content; approved the final version to be published; and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Ethics approval and consent to participate: This retrospective study was approved by the Institutional Review Board of King Faisal Specialist Hospital and Research Centre, Jeddah, Saudi Arabia (approval number 2261301), which waived the requirement for individual informed consent for this retrospective analysis of routinely collected, de-identified clinical data.

Declaration of Helsinki and Istanbul: This study was conducted in accordance with the Declaration of Helsinki and the Declaration of Istanbul on Organ Trafficking and Organ Donation.

STROBE adherence: This study was reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines for cohort studies.

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Tables

Table 1. Donor characteristics by operative approach

Variable	Xi SP+1 RDN (n=59)	LESS-DN (n=706)	Multi-port RDN (n=43)	*P* value
Age, y, mean ± SD	36.5 ± 9.6	33.4 ± 8.1	34.7 ± 8.9	.012
Male, n (%)	40 (67.8)	476 (67.4)	29 (67.4)	.998
BMI, kg/m², mean ± SD	27.1 ± 4.5	26.5 ± 4.6	25.9 ± 4.1	.378
Left nephrectomy, n (%)	47 (79.7)	674 (95.5)	38 (88.4)	<.001
Right nephrectomy, n (%)	12 (20.3)	32 (4.5)	5 (11.6)	
No. renal arteries, mean ± SD	1.24 ± 0.54	1.37 ± 0.63	1.30 ± 0.56	.265
Multiple arteries, n (%)	11 (18.6)	211 (29.9)	11 (25.6)	
Prior abdominal surgery, n/N (%)	11/59 (18.6)	114/605 (18.8)	9/37 (24.3)	.709

BMI, body mass index; LESS-DN, laparoendoscopic single-site donor nephrectomy; RDN, robotic donor nephrectomy. Smoking status is omitted because it was not reliably coded in the source database.

Table 2. Operative and postoperative outcomes

Outcome	Xi SP+1 RDN	LESS-DN	Multi-port RDN	*P* value
Warm ischaemia time, min, mean ± SD	4.36 ± 1.24 (n=59)	3.53 ± 1.02 (n=626)	4.05 ± 1.08 (n=37)	<.001
Operative time, min, mean ± SD*	178.1 ± 28.5	193.0 ± 51.8	254.8 ± 45.5	<.001
Operative time, median (range)	177 (140–271)	195 (80–390)	255 (155–390)	
LOS, d, mean ± SD	2.09 ± 0.29 (n=59)	1.73 ± 0.78 (n=706)	1.84 ± 0.65 (n=43)	.002
LOS, median	2	2	2	
Conversion, n (%)	0 (0)	1 recorded open conversion†	0 (0)	—
Transfusion, n (%)	0 (0)	1 case post operative, (mesenteric hematoma after bowel injury) †	0 (0)	—

† detailed events were reported descriptively in the text and in Table 3.

Table 3. Descriptive complications recorded during the study period

This table summarizes clinically significant intraoperative and postoperative events by operative approach. Because the source database did not encode a complete standardized row-level complication field.

Approach	Complication/event	N	Management or outcome	ClassIntra / Clavien–Dindo grade
Xi SP+1 RDN	Intraoperative bleeding	1	Controlled with robotic suturing; no conversion, transfusion, sequelae, reoperation, or ICU admission recorded.	ClassIntra II
Multi-port RDN	Postoperative abdominal-wall bleeding/haematoma (POD5)	1	Angiographic embolization; haematoma subsequently managed conservatively.	Clavien–Dindo IIIa
LESS-DN	Stapler failure	1	Open conversion.	ClassIntra III
LESS-DN	Partial main renal-artery injury	1	Prolonged WIT; recipient delayed graft function with subsequent recovery.	ClassIntra III
LESS-DN	Adrenal-vein bleeding	3	Recorded intraoperative bleeding events.	ClassIntra II
LESS-DN	Lumbar-vein bleeding	1	Recorded intraoperative bleeding event.	ClassIntra II
LESS-DN	Kidney fracture during bagging/extraction	1	Required Repair, No adverse recipient consequence recorded.	ClassIntra II
LESS-DN	Bowel-entry injury	1	Resection and anastomosis through a small extension of the extraction incision.	ClassIntra III
LESS-DN	Internal hernia	1	Reoperation on postoperative day 3.	Clavien–Dindo IIIb
LESS-DN	Incisional hernia	3	Repaired electively.	Clavien–Dindo IIIb
LESS-DN	Delayed chronic neuropathic pain	2	Recorded as delayed postoperative donor pain.	Clavien–Dindo IIIa

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