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*Original Article*

# Robotic Renal Autotransplantation: A Feasibility Study in a Porcine Model

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**We investigated the feasibility of robotic renal autotransplantation (RAT) in a porcine model to reduce invasiveness of RAT. Five pigs underwent robotic RAT using the da Vinci® robotic system. A robotic left nephrectomy was performed in all cases. Robotic RAT was performed on the left side in all but one case. Four ports were used. In 3 cases, the kidney was taken out through the GelPort® and irrigated on ice with Ringer's solution. In 2 cases, a complete intracorporeal robotic RAT was performed. An end-to-side anastomosis was performed between the renal vein and the external iliac vein and between the renal artery and the external iliac artery. Ureteroneocystostomy was also performed in 2 cases. All cases were performed robotically without open conversion. The median (IQR) console time was 3.1 (0.7) h, and the operative time was 3.8 (1.1) h. The estimated blood loss was 30 (0) ml. The warm ischemia time was 4.0 (0.2) min, and the cold ischemia time was 97 (17) min. Intracorporeal transarterial hypothermic renal perfusion was feasible in the 2 complete intracorporeal robotic RAT cases by using a perfusion catheter through a laparoscopic port. Robotic RAT has the potential to be a new minimally invasive substitute for conventional open surgery.**

**Key words:** renal autotransplantation, robotic, porcine model, transplantation

There are many indications for renal autotransplantation (RAT), including renal vascular trauma, thrombosis, stenosis, and aneurysm, as well as complex ureteral injuries, renal cell carcinoma, urolithiasis, retroperitoneal fibrosis, and loin pain-hematuria syndrome [1,2]. However, RAT is underutilized because of its invasiveness. The conventional open approach requires a large midline xiphoid-to-pubis or flank incision for the donor nephrectomy with a second pelvic incision for renal transplantation into the iliac fossa [2,3]. The current gold standard approach to RAT is a laparoscopic nephrectomy followed by an open autotransplantation [4], but this approach still requires a large pelvic incision. It is also a lengthy surgery; the average reported operative time was 8-12 h [1,5-7].

Robotic technology enables a surgeon to operate with enhanced vision, precision, and control. We can perform more complex minimally invasive surgery with the da Vinci® surgical system (Intuitive Surgical,

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Sunnyvale, CA, USA). The da Vinci system is a master-slave robot that incorporates three-dimensional visualization, movement scaling, and fully articulated wristed instrumentation. These factors allow surgeons to perform complex dissections and suturing in a minimally invasive fashion. Herein, we report the results of a feasibility study of the performance of robotic RAT in a porcine model.

## Methods

All animal experiments were performed in accord with the approved protocols and guidelines of the Animal Research Committee at Okayama University (Authorization no. OKU-2018315). Five farm pigs (2-3 months old, females, weighing 30-40 kg) underwent general anesthesia for robotic surgery. The type of swine was Sangenton, which was a crossbreed of Landrace, Large White and Duroc, provided from Okayama JA Livestock Co., Ltd. Each pig was placed in the supine position and the GelPort® (Applied Medical, Santa Ranchero, CA, USA) was placed 15 cm below the xiphoid process. Following the creation of pneumoperitoneum with $CO_2$ (12 mmHg), two 12-mm ports and two 8-mm ports were inserted below the left costal margin in the configuration demonstrated in Fig. 1.

Following the trocar placement, the animal was placed in the right decubitus position, and then the da Vinci® S system was docked. A robotic left nephrectomy was performed in all 5 cases. The robotic RAT was performed on the left side in all cases except case #4, in which it was performed on the right side. A change in the pig's surgical position and re-docking was not required in any case except case. The position was changed to the left decubitus position in case #4. At the time point of the nephrectomy and vascular anastomosis, the same port configuration was used. Following the left nephrectomy, the kidney was taken out through the GelPort® and irrigated on ice with Ringer's solution in 3 cases (cases #1, #4, and #5). In 2 cases (cases #2 and #3), the kidney was intracorporeally irrigated with heparinized ice-cold Ringer's solution and a complete intracorporeal robotic RAT was performed. The procedure involves the 5 technical steps listed below in detail.

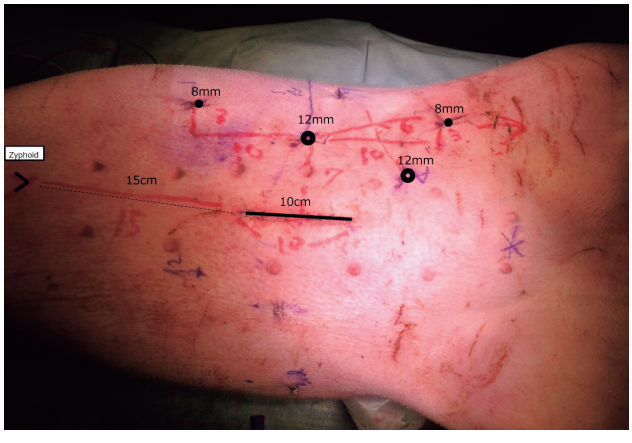


Fig. 1 Port configuration. The animal was placed in the right decubitus position, and a 4-port transperitoneal laparoscopic technique was used. A GelPort® was also placed. A 10-mm 30° laparoscope was used.

*Step 1: Preparation of the left kidney.* The descending colon was mobilized and the left kidney was exposed. The left renal artery was dissected up to its aortic origin, and the renal vein was dissected to the medial border of the aorta. The kidney was circumferentially mobilized. In case #3, the ureter was widely mobilized into the pelvis and prepared for a ureteroneocystostomy.

*Step 2: Preparation of the iliac vessels.* The left (cases #1, #2, #3, and #5) or right (case #4) external iliac artery (EIA) and vein (EIV) were completely dissected. Any branch was controlled, and the iliac lymph nodes were excised. The EIA and EIV were taped with red and blue vessel loops, respectively.

*Step 3: Left live-donor nephrectomy and intra/extra-corporeal irrigation.* Attention was then directed to the left kidney. The renal artery was secured with a Hem-o-lok® (Teleflex, Wayne, PA, USA) clip at its origin from the aorta and partially transected distally. The renal vein was similarly secured and transected. The vessels were not clipped on the side of the autograft. The kidney was taken out through the GelPort® and irrigated on ice with Ringer's solution in 3 cases (cases #1, #4, and #5). In cases #2 and #3, intracorporeal irrigation with heparinized ice-cold Ringer's solution through a 3-mm vessel cannula (Medtronic, Minneapolis, MN, USA) was performed at a pressure of 120mmHg (Fig. 2).

*Step 4: Vascular anastomoses (renal autotransplantation).* Ten min prior to clamp placement, 10,000 U of heparin was administered intravenously. The EIV was clamped proximally and distally with laparoscopic bulldog clamps. The kidney was carefully positioned in the pelvis (on the right in cases #1, #2, #3, and #5, on the left in case #4) close to the clamped iliac vessels. An

external iliac venotomy (1-1.5 cm) was precisely created with scissors, and the venous lumen was thoroughly irrigated. A running end-to-side anastomosis was created between the renal vein and the EIV using CV-5 Gore-Tex® suture (W.L. Gore, Flagstaff, AZ, USA) (Fig. 3).

Upon the completion of the venous anastomosis, a bulldog clamp was placed on the renal vein, and the clamps were released from the EIV. Likewise, a running end-to-side arterial anastomosis was created using CV-6 Gore-Tex® suture (Fig. 4). Upon the completion of that anastomosis, a bulldog clamp was placed on the renal artery, and the clamps were removed from the EIA. The color of the kidney was checked (Fig. 5). The kidney was attached to the peritoneum with 3-0 Vicryl suture and Hem-o-lok® clips (Fig. 6). Hemostasis was confirmed.

*Step 5: Ureteroneocystostomy.* A ureteroneocystostomy was performed in cases #3 and #5, by the Lich-Gregoir extravesical technique over a 6-Fr stent in the

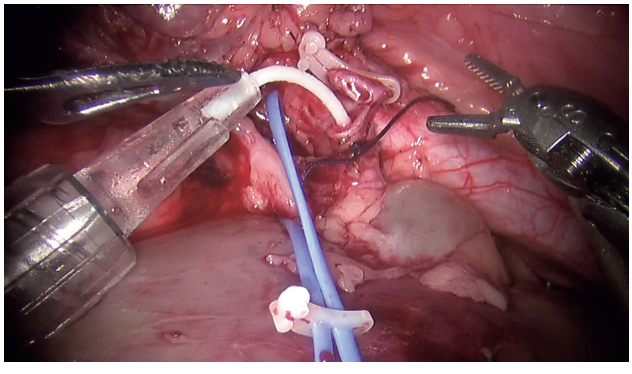

**Fig. 2** Irrigation of the kidney. The kidney was perfused with heparinized ice-cold lactated Ringer's solution through a 3-mm vessel cannula placed in the lumen of the transected renal artery.

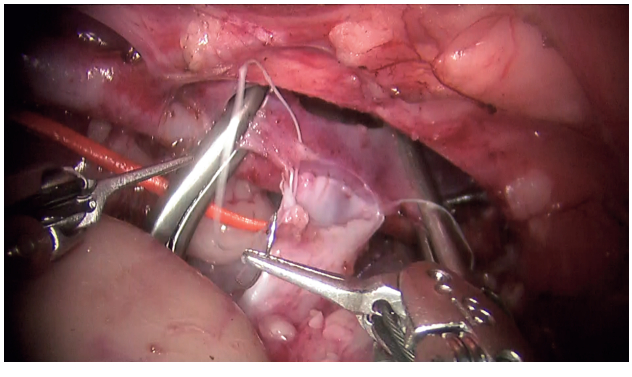

**Fig. 3** Venous anastomosis. A running end-to-side anastomosis was created between the renal vein and the external ileac vein using CV-5 Gore-Tex® suture.

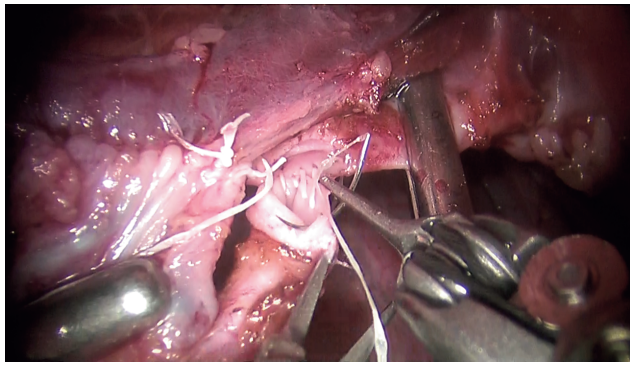

**Fig. 4** Arterial anastomosis. A running end-to-side arterial anastomosis was created using CV-6 Gore-Tex® suture. Hemostasis was confirmed.

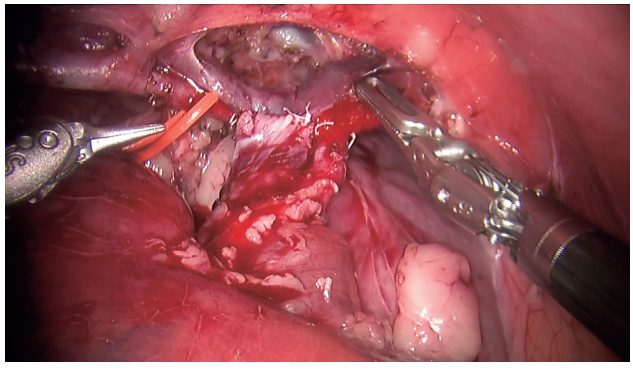

**Fig. 5** Reperfusion of the autograft. Upon completion of the vessel anastomosis, the clamps were removed. The color of the kidney was checked.

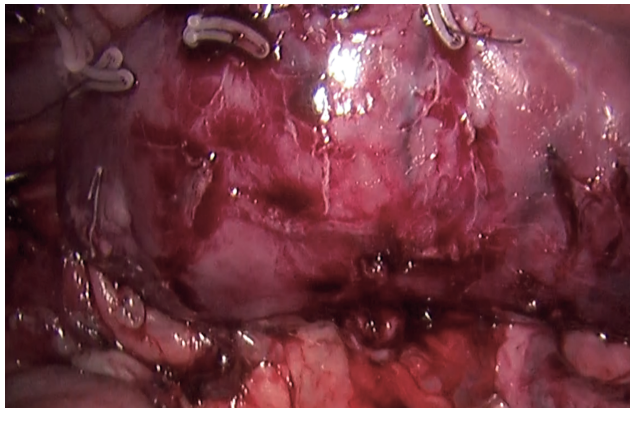

**Fig. 6** Fixation of the kidney to the peritoneum. The kidney was attached to the peritoneum with 3-0 Vicryl suture and a Hem-o-lok® clip.

running fashion with 4-0 Vicryl suture (Fig. 7).

***Confirmation of vessel anastomotic integrity.*** The integrity of the arterial and venous anastomoses was confirmed with a 18G vessel cannula in all 5 animals.

***Euthanasia of experimental animals.*** The animals were euthanized by rapid intravenous injection of potassium chloride immediately after the robotic RAT.

## Results

All cases were performed robotically without the need for open conversion. The median (interquartile range [IQR]) console time was 3.1 (0.7) h, and the median total operative time was 3.8 (1.1) h (Table 1). The median warm ischemia time, *i.e.*, the time from the left renal artery clipping to the intra-arterial hypothermic irrigation, was 4.0 (0.2) min. The median (IQR) cold ischemia time, *i.e.*, the time from the hypothermic perfusion to the reperfusion at the completion of the arterial anastomosis, was 97 (17) min. The median venous anastomosis time was 13 (12) min. The median (IQR) arterial anastomosis time was 20 (4) min. The median (IQR) estimated blood loss was 30 (0) ml.

Upon the release of the bulldog clamps, the autotransplanted kidney immediately turned pink and perfused well in all animals. Ureteroneocystostomy was performed only in cases #3 and #5. Ureteroneocystostomy took an additional 29 min in average. Urine was seen from the ureter at 25 min post-reperfusion.

The heart rate and rectal temperature remained within normal limits in each case. No intraoperative complications occurred. The integrity of the arterial and venous anastomoses was confirmed with a cannula, and good patency was demonstrated in all animals (Fig. 8).

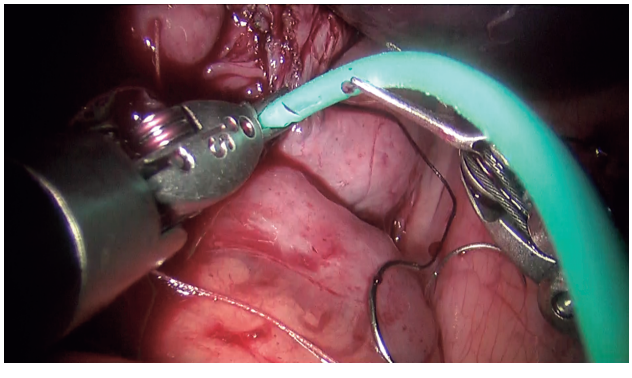

**Fig. 7** The ureteroneocystostomy. Each ureteroneocystostomy was performed by the Lich-Gregoir extravesical technique over a 6-Fr stent in the running fashion with 4-0 Vicryl.

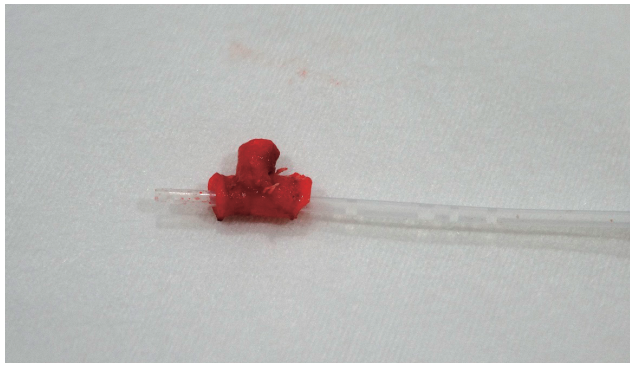

**Fig. 8** Confirmation of the patency of the anastomoses. The integrity of the arterial and venous anastomoses was confirmed with a cannula.

**Table 1** Operative outcomes of the robotic renal autotransplantations (RATs)

| Case | Irrigation | Ureteroneo-cystostomy | WIT (min) | CIT (min) | TIT (min) | Venous anast. (min) | Arterial anast. (min) | Console time (h) | Operative time (h) | EBL (ml) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | E | − | 3.8 | 90 | 93.8 | 13 | 16 | 3.7 | 4.5 | 30 |
| 2 | I | − | 7.6 | 160 | 167.6 | 9 | 21 | 4.2 | 4.9 | 30 |
| 3 | I | + | 3.0 | 75 | 78 | 10 | 17 | 3.1 | 3.8 | 50 |
| 4 | E | − | 4.0 | 107 | 111 | 27 | 20 | 3.0 | 3.4 | 20 |
| 5 | E | + | 4.0 | 97 | 101 | 22 | 24 | 2.6 | 3.2 | 30 |
| Median (IQR) | | | 4.0 (0.2) | 97 (17) | 101 (17.2) | 13 (12) | 20 (4) | 3.1 (0.7) | 3.8 (1.1) | 30 (0) |

E, extracorporeal irrigation; I, intracorporeal irrigation; WIT, warm ischemia time; CIT, cold ischemia time; TIT, total ischemia time; anast, anastomosis time; EBL, estimated blood loss.

## Discussion

Robotic RAT is a new, minimally invasive approach to renal preservation. It is a new hope for patients and healthcare providers who have qualms about the invasiveness of the open approach. Feasibility studies of new surgical techniques are conducted by using animal models before human surgery. In the present investigation, the robotic RAT (including completely intracorporeal robotic RAT) was successful in all cases. Our first successful robotic RAT in a human was based on our present findings [8]. The prior findings will lead to our first completely intracorporeal robotic RAT in the future as well.

In 1963, J.D. Hardy performed the first RAT in order to repair a high ureteric injury [9]. The indications of RAT have expanded in the > 50 years since then [1,2]. Although RAT has an excellent outcome, the disadvantage of the conventional open approach is a large incision [2,3]. Currently, the gold standard approach is a laparoscopic nephrectomy followed by open autotransplantation, which requires a large pelvic incision [4]. We aimed to minimize the invasiveness of RAT with robot in a porcine model.

In 2001, Meraney reported their study of laparoscopic RAT in a porcine model [10]. Prior to starting the survival arm of that study, the researchers used inanimate dry suturing models and seven farm pigs to practice laparoscopic vascular suturing techniques and to work out various intraoperative logistical details. They then performed laparoscopic RAT in 6 pigs. The mean operating time was 6.2 h (range 5.3-7.9 h) without a ureteroneocystostomy, which is 1.5 times longer than the times we achieved in the present study. In the Meraney study, the venous anastomosis time was 33 min (range 22-46 min), and the arterial anastomosis time was 31 min (range 27-35 min), which is 2 times longer than the times obtained herein. The da Vinci® system allows surgeons to perform complex suturing in a minimally invasive fashion. This comparison demonstrates the superiority of robotic RAT over the laparoscopic approach, especially in suturing.

The first robotic-assisted kidney transplantation (RAKT) was reported by Hoznek *et al.* in 2002 [11]. Deceased donor renal transplantation was performed on a 26-year-old man using an incision in the left lower quadrant with the aid of a self-retaining retractor. The first true robotic-assisted laparoscopic kidney transplant was reported by a group from the University of Illinois in 2010 [12], and this technique has been used and reported by several groups since then. The early clinical experiences with robotic-assisted laparoscopic kidney transplants suggest that it is associated with comparable graft function and lower rates of complications [13-16].

In 2014, the first completely intracorporeal robotic RAT was reported by Gordon *et al.* for the repair of a ureteral injury [2]. Although a few similar cases have been performed since then [4], robotic RAT is such a complex surgery that we felt the need for an animal study before we performed this technique on a patient, and after conducting that animal study [8], we performed the first robotic RAT in Asia. The patient was a 38-year-old woman with an iatrogenic 2.7-cm left ureteral stenosis that had required a chronic ureteral stent exchange for the prior 8 years. Balloon dilation and laser incision had been attempted but were unsuccessful. The patient was also thought to have a left ureteropelvic junction (UPJ) obstruction. She refused to undergo a conventional open RAT because of its large incision. Robotic RAT was not available at that time. Four years later, she visited us again, and she elected to undergo a robotic RAT. She became stent-free after the surgery. We believe that our experience with this feasibility study led to the first successful case of robotic RAT outside of North America. It was the fourth case in the world.

Regarding the irrigation modality, we performed both intra- and extra-corporeal irrigation of the autograft in the present study. The advantage of intracorporeal irrigation is the minimization of the number of incisions. However, ice-cold lactated Ringer's solution irrigation intracorporeally does not achieve the degree of hypothermia that can be reached with irrigation of the autograft placed on ice. Although laparoscopic techniques for renal cooling have been attempted, primarily in partial nephrectomy, they are not routinely used [17-22].

Inadequate hypothermia during cold ischemia is a concern. In contrast, the advantage of extracorporeal irrigation is that adequate hypothermia is achieved, to a degree as cold as that achieved with renal allo-transplantation; however, extracorporeal irrigation requires an incision for the removal of the autograft. Menon *et al.* reported robotic renal transplantation with regional hypothermia [22]. Their technique is reproducible but still cumbersome, especially for those who have never

attempted it. We placed a GelPort® in all 5 of the present cases, regardless of the modality of irrigation. We used the GelPort® as a safety net. Since this is a new surgical technique, safety is the first priority. We can omit the use of a GelPort® once we have more experience with this new approach.

There are some limitations in the present study. First, only 5 cases were included. However, five subjects are enough for a technical investigation of robotic RAT. Second, renal functions such as serum creatinine or proteinuria after RAT were not evaluated because of the animals' euthanization on the day of the surgery. Third, histopathological evaluations regarding ischemia-reperfusion injury were not performed. However, despite these limitations, technical issues were resolved and minimally invasiveness was confirmed.

In conclusion, robotic RAT has the potential to be a new minimally invasive substitute for conventional open RAT.

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