

Holding Strength of Suture: An Experimental Study Using Porcine Kidney

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ABSTRACT

Background and Objectives: The search for the perfect suture is going on and has resulted in the introduction of many different suture types into the market. The purpose of this study is to investigate the holding strength (HS) of different sutures in the renal parenchyma in an experimental study on pig kidneys.

Methods: The HS that caused sliding of the suture was investigated in 5 adult porcine kidneys with 7 suture variants. HS-caused tearing of the kidney was investigated with 3 suture types on 5 kidneys. The third investigation, performed on 5 porcine kidneys, was a comparison between 2-0 Vicryl sutures with a Hem-o-lok clip and 2-0 V-Loc sutures with 1 knot. The Friedman test was used to compare the groups. Post hoc analysis was performed with the Wilcoxon signed ranks test (Bonferroni corrected).

Results: For HS causing sliding of the suture, the mean HSs of the tested sutures were as follows: 2-0 Vicryl with 1 Hem-o-lok clip, 3.26 ± 0.55 N; 2-0 Vicryl with 2 Hem-o-lok clips, 4.1 ± 0.46 N; 2-0 V-Loc, 2.52 ± 0.63 N; 4-0 V-Loc, 1.62 ± 0.17 N; 0 Quill, 0.48 ± 0.16 N; 2-0 Vicryl with 1 Hem-o-lok clip (halfway), 3.62 ± 0.66 N; and 2-0 V-Loc (halfway), 1.02 ± 0.40 N. For HS causing tearing of the kidney, the mean value of 2-way 2-0 Vicryl (Hem-o-lok in the middle) was 13.28 ± 1.38 N, 2-0 2-way Vicryl (Hem-o-lok at the end) was 5.86 ± 0.75 N, and 2-way 2-0 V-Loc was 3.98 ± 1.60 N. For the third group, the difference between the 2 suture variants was not statistically significant.

Conclusion: Our study revealed that 2-0 Vicryl (polyglactin 910) sutures with 2 Hem-o-lok clips had the maximum HS in renal parenchyma when compared with other sutures.

Key Words: Animal model, Holding strength, Polyglactin 910, Suture materials, Tensile strength.

INTRODUCTION

The suture is a natural or synthetic biomaterial that is used for ligating blood vessels and approximating the edges of tissues. The search for the perfect suture has been ongoing for many years. As a result, there is a wide spectrum of sutures on the market consisting of absorbable and non-absorbable materials, ranging from synthetic polymers to animal derivatives. An appropriate suture should have tissue biocompatibility, sufficient resorption rates, and tensile strength.¹

Tensile strength can be defined as the maximum power that a suture can resist before breaking. Numerous studies to date have evaluated the tensile strength of different sutures throughout modern surgical history, giving information on different suture types and suturing techniques, both in vivo and in vitro.^{2,3} In addition to the aforementioned issues, there is another factor involved in suturing of parenchymal organs—that is, the amount of power that results in violation of the tissue or slipping of the suture, the holding strength (HS).

With the advancements in minimally invasive surgery, robot-assisted and laparoscopic nephron-sparing surgeries are gaining popularity among urologists around the world. One of the difficult and key challenges in renal surgery is the closure of the parenchyma, problems of which may cause serious complications, such as bleeding and increased warm ischemia time. Although several suture types and techniques can be used for this goal, there have been limited studies to date investigating the HSs of different suture types and techniques.^{4,5} In this study, our intent was to conduct an experiment on pig kidneys to find the most appropriate suture type in renal parenchyma closure.

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MATERIALS AND METHODS

Resistance of sutures to applied pressure and HS that caused sliding of the sutures and tearing of the kidney were investigated in 15 adult porcine kidneys (**Figure 1A**). All of the kidneys were obtained from a meat packing company and stored in physiologic saline solution at a maximum temperature of 7°C for conservation until the investigations were performed. All tests were performed within 6 h after harvesting. This porcine kidney preservation method is similar to that used in a recent study dealing with tissue damage while suturing intra-abdominal organs.⁶

HS that caused sliding of the suture was investigated in 5 adult porcine kidneys with 7 suture variants. These variants were 2-0 Vicryl suture with 1 Hem-o-lok clip, 2-0 Vicryl with 2 Hem-o-lok clips, 2-0 V-Loc suture, 4-0 V-Loc suture, 0 Quill suture, 2-0 Vicryl suture with 1 Hem-o-lok clip, which was cinched at the middle point of the suture, and 2-0 V-Loc suture that was locked at the middle point of the suture.

Initially, a longitudinal incision on the kidneys with a width of 0.5 cm from the top of the kidney to the bottom (**Figure 2A, B**) was performed. In each kidney, 5 suture types were investigated. The length of the sutures in the renal parenchyma from the insertion of the needle to the exit point was 1.5 cm (**Figure 2C**). When the investigation of one suture was finished, this suture was pulled out of the kidney and another suture was prepared for a new measurement (**Figure 3**). The suture points were placed 2 cm away from each other in the kidney to avoid the influence of prior measurement on the current measurement. HS was measured in Newtons (N) with a Universal UltraTest machine (Mecmesin, Slinfold, UK) (**Figure 1B**). The sutures were each held by 2 nurses who were blinded to the study and the HS that caused sliding of the suture was noted by 2 investigators. Each suture type was investigated 5 times on 5 porcine kidneys.

HS that caused tearing of the kidney was investigated with 3 suture types on 5 kidneys. The suture types were a 2-way 2-0 Vicryl suture (Hem-o-lok in the middle),

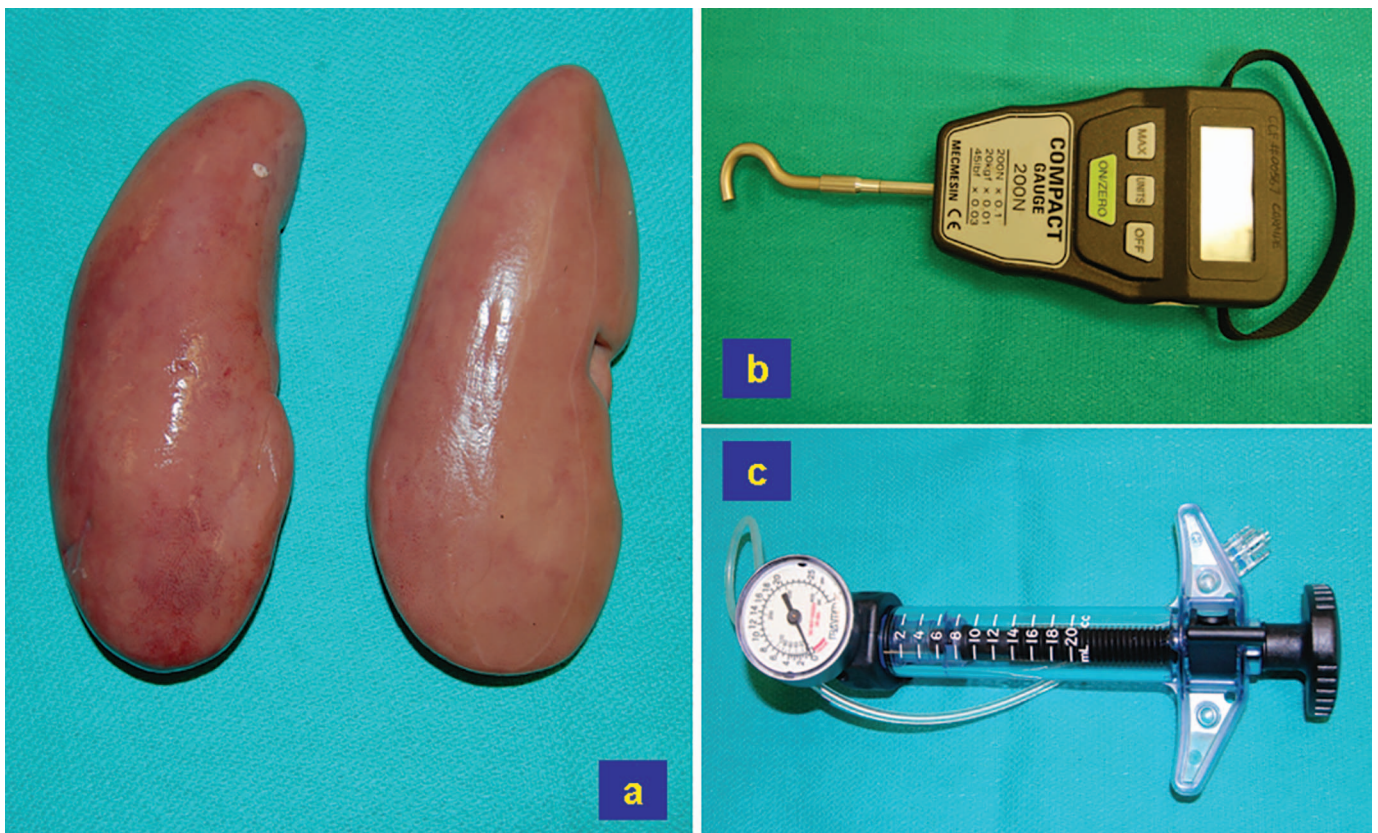


Figure 1. Materials and devices used in the experiment. **A**, Gross view of the porcine kidney. **B**, UltraTest machine. **C** High-pressure insulator.

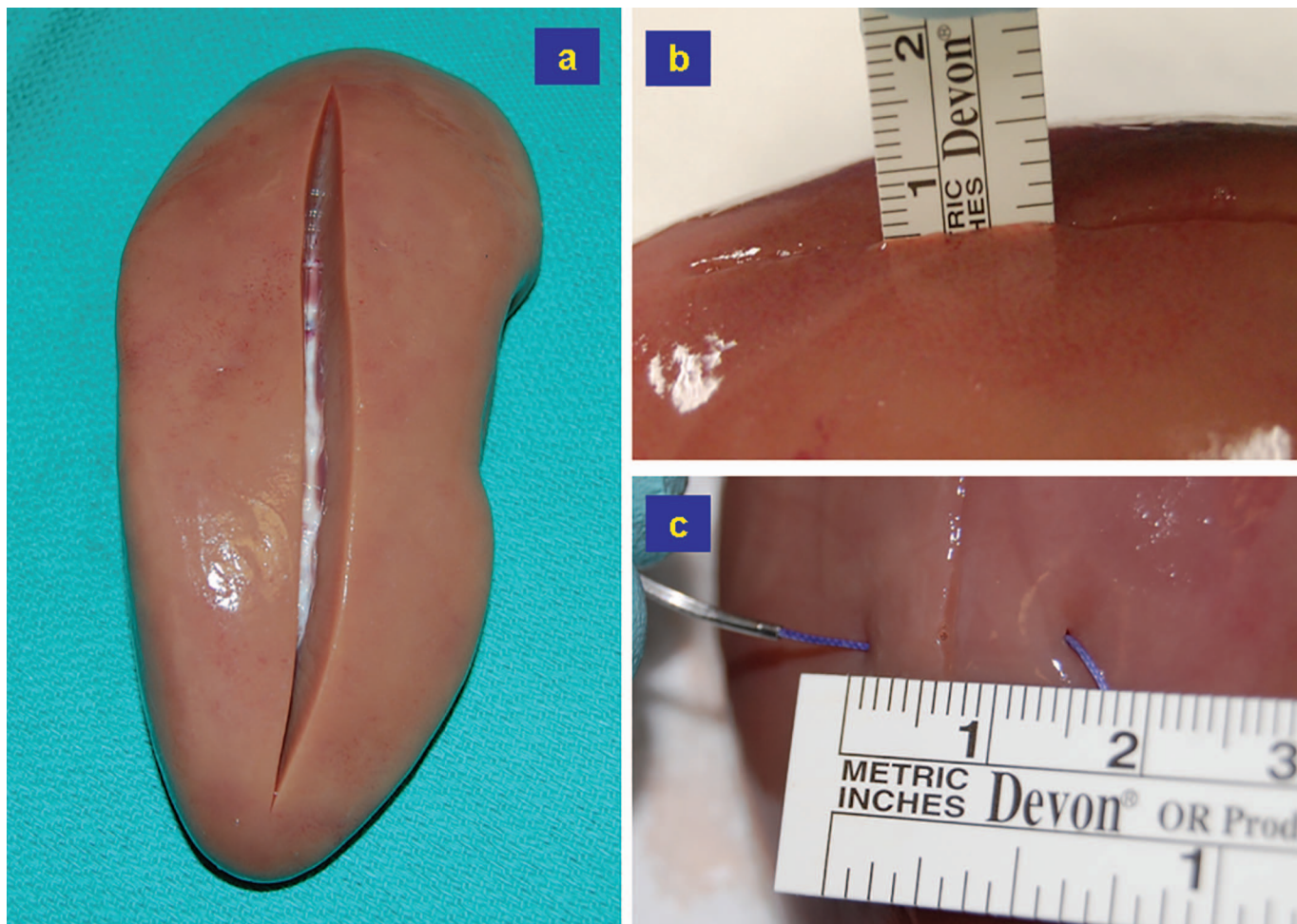


Figure 2. Longitudinal incisions of kidney. **A**, Longitudinal incision of the kidney. **B**, Incisions from the top of the kidney to the bottom. **C**, The length measurement of the sutures in the renal parenchyma from the insertion of the needle to the exit point.

a 2-way 2-0 Vicryl suture (Hem-o-lok at the end), and a 2-way 2-0 V-Loc suture (**Figures 4, 5, 6**). As in the former scenario, each suture type was investigated 5 times on 5 adult porcine kidneys. Two-way sutures are those that are inserted from one side, exiting from the opposite side, and again inserted from the top of the prior exit point, reaching the top of the initial position. The sutures were each held by 2 nurses who were blinded to the study and the HS that caused tearing of the kidney was recorded by 2 investigators.

The third investigation was the comparison of 2-0 Vicryl with Hem-o-lok clip and 2-0 V-Loc suture with 1 knot on 5 porcine kidneys. In this scenario, we inserted a Nephromax balloon dilation catheter (Boston Scientific, Natick, Massachusetts, USA) (**Figure 1C**) longitudinally inside the incised kidneys. After insertion of the balloon

catheter, the edges of the renal parenchyma were approximated by using continuous sutures. Then, the balloon catheter was insufflated to >30 atm, with a LeVein High-Pressure Insufflator (Boston Scientific), and the separation between the edges of the parenchyma was observed. The separations were noted by 2 investigators (**Figure 7**). Each suture type was investigated 5 times.

Statistical Analysis

Continuous variables are expressed as means \pm SD. The Friedman test was used to compare groups of more than 2. Post hoc analyses were performed with the Wilcoxon signed-ranks test (Bonferroni corrected). Two-tailed $P < .05$ was accepted as statistically significant. Data were analyzed with the Statistical Package

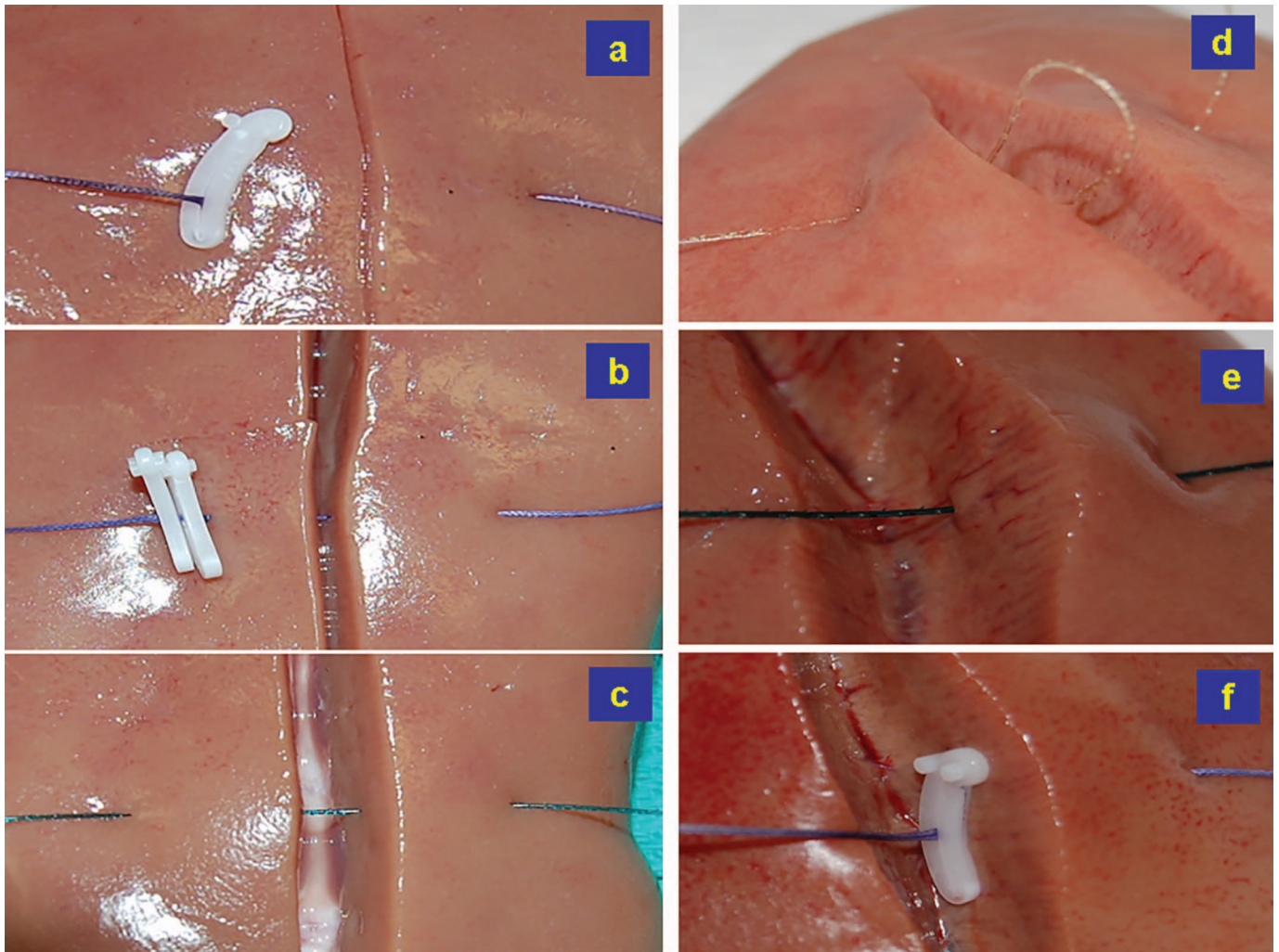


Figure 3. Measurements of different sutures. **A**, 2-0 Vicryl with 1 Hem-o-lok clip. **B**, 2-0 Vicryl with two Hem-o-lok clips. **C**, 2-0 V-Loc suture. **D**, 0 Quill. **E**, 4-0 V-Loc suture. **F**, 2-0 Vicryl with 1 Hem-o-lok cinched in the middle.

for Social Sciences, Ver. 15.0 (SPSS Inc., Chicago, Illinois, USA).

RESULTS

For the first comparison of the 7 suture variants' HS causing sliding of the suture, the mean HSs were as follows: 2-0 Vicryl with 1 Hem-o-lok clip, 3.26 ± 0.55 N; 2-0 Vicryl with 2 Hem-o-lok clips, 4.1 ± 0.46 N; 2-0 V-Loc, 2.52 ± 0.63 N; 4-0V-Loc 1.62 ± 0.17 N; 0 Quill, was 0.48 ± 0.16 N; 2-0 Vicryl with 1 Hem-o-lok clip (halfway), 3.62 ± 0.66 N; and 2-0 V-Loc (halfway), 1.02 ± 0.40 N (**Figure 3**). When these 7 suture variants were evaluated together using the Friedman test, a significant difference between the sutures was found ($P < .05$; **Table 1**).

The mean value of 2-0 2-way Vicryl (Hem-o-lok in the middle) was 13.28 ± 1.38 N, 2-way 2-0 Vicryl (Hem-o-lok at the end) was 5.86 ± 0.75 N, and 2-way 2-0 V-Loc was 3.98 ± 1.60 N. The Friedman test was used to evaluate the HS that caused tearing of the kidney in the 3 suture variants. When these sutures were compared in terms of kidney tearing, we found a significant difference between the variants. Two-way 2-0 Vicryl (Hem-o-lok in the middle) was significantly superior to 2-way 2-0 Vicryl (Hem-o-lok at the end) ($P = .043$). Two-way 2-0 Vicryl (Hem-o-lok in the middle) was also superior to 2-way 2-0 V-Loc ($P = .042$). The comparison of 2-way 2-0 Vicryl (Hem-o-lok at the end) and 2-way 2-0 V-Loc revealed no significant difference ($P = .138$) (**Figures 4, 5, and 6; Table 2**).

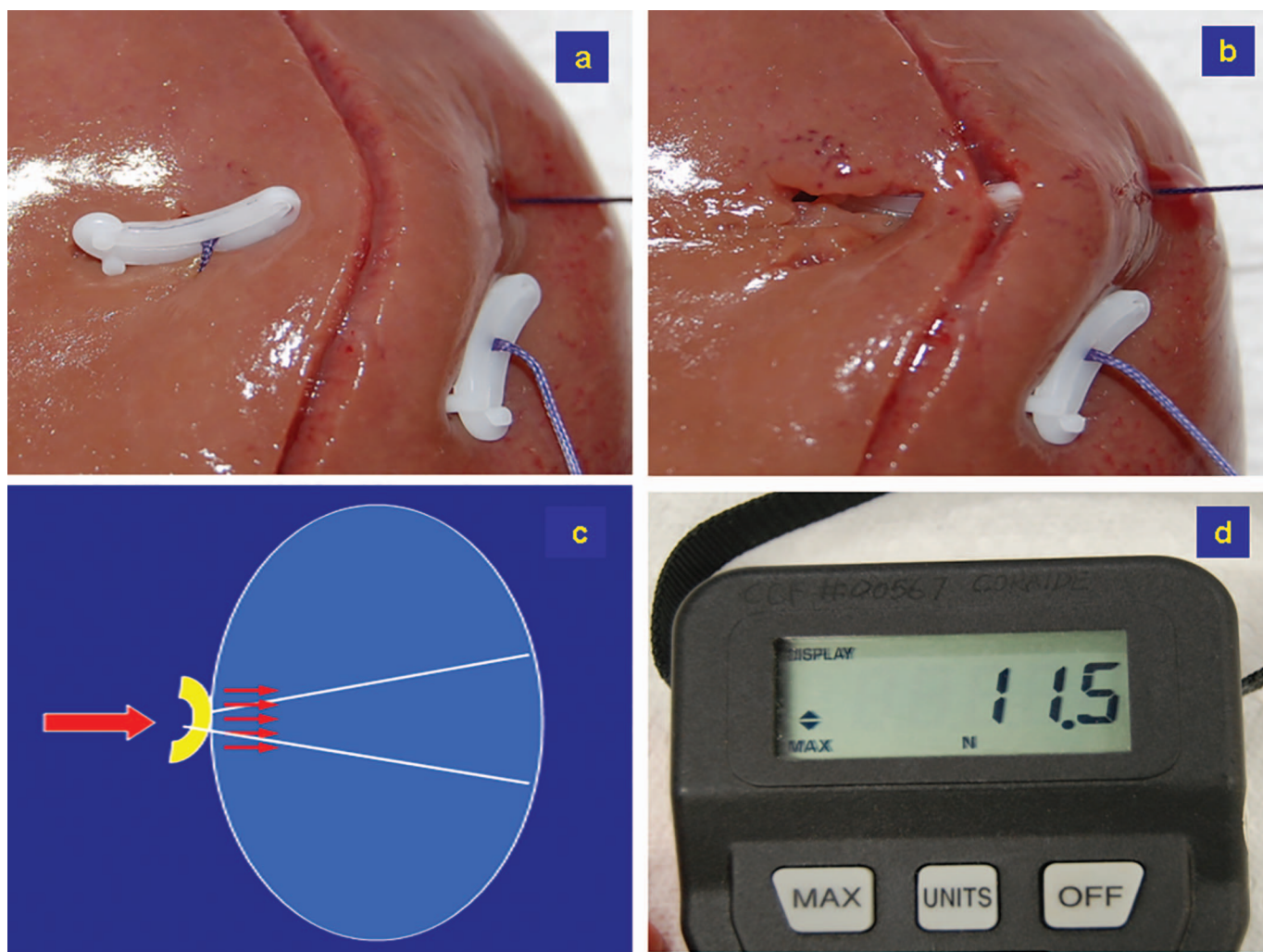


Figure 4. Holding strength measurement of different suture materials. **A**, 2-way 2-0 Vicryl Hem-o-lok in the middle. **B**, Schematic view of pressure forces. **C**, Tearing of the kidney. **D**, Measurement via UltraTest machine.

In the third investigation, before attaching Hem-o-lok clips to the Vicryl, the separation between the edges of the suture was observed when the pressure reached >30 atm (**Figure 7**). After attaching Hem-o-lok clips to the Vicryl, we observed no separation of the edges of the sutured parenchyma after reaching >30 atm. The 2-0 Vicryl with a Hem-o-lok clip and 2-0 V-Loc with 1 knot were resistant to the applied pressure and strongly held the 2 edges of the parenchyma. The difference between the 2 suture variants was not statistically significant (**Figure 7**).

DISCUSSION

Although sutures change according to the various surgical applications and tissues, a surgeon should know the ideal

suture types and their HS. In our study, we focused on standardizing the HS of various sutures in renal parenchyma that caused the suture to slide, thereby tearing the kidney. In our opinion, these specifications and manipulations of the sutures should be known by urologists and practiced in a nonclinical setting to improve their sense of HS during minimally invasive renal surgery.

Force sensing in surgical sutures is very important. Too low or too high suture tension can have a negative impact on wound healing. Low tension may cause wound dehiscence, and high tension may lead to edema, ischemia, and necrosis of the tissue.⁷⁻⁹ In a very recent study, the design and evaluation of the Stitch Force sensor and the Hook-In Force sensor were described. These sensors were devel-

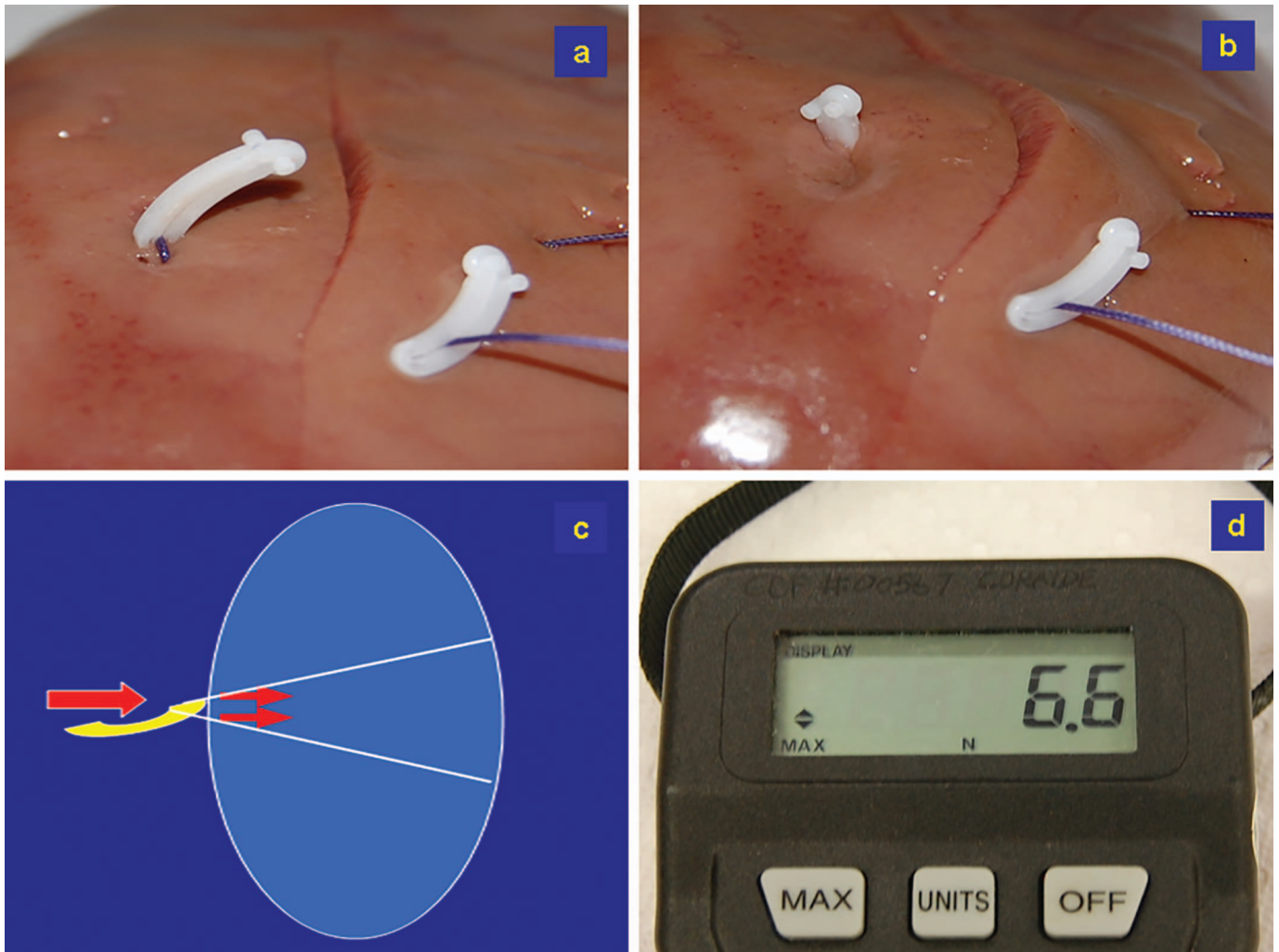


Figure 5. A, 2-way 2-0 Vicryl Hem-o-lok at the end. **B,** Schematic view of pressure forces. **C,** Tearing of the kidney. **D,** Measurement via UltraTest machine.

oped to measure the force on a tensioned suture inside the closed incision and the pulling force required for closure of the incision. The accuracy of both sensors was found high for determining the relationship between the pulling force applied on a suture and the force tolerated in the thread of a stitch.¹⁰ The investigators concluded that these tools could warn surgeons about excessive force on sutures, which could reduce postoperative complications such as burst abdominal wall and incisional hernia.

The acceptable maximum force that a tissue can resist may vary from tissue to tissue. Every tissue has its own individual range of acceptable maximum force before damage occurs. This question was investigated in another study,⁶ in which tractive forces were applied by adding increasing loads on sutures in 8 different tissue types: fascia, aorta,

vena cava, peritoneum, fallopian tube, uterus, and small and large bowels of 10 different pigs. The load that caused visual tissue damage was noted by investigators. The suture type was 3-0 Vicryl. The maximum resistance was noted in the fascia with an accepted force of 11.43 N, although the fallopian tube had a maximum accepted force of 1.25 N. The authors also revealed that small bowel may be handled with a tractive force almost 1.5-fold higher than large bowel. They concluded that trainers educated in surgical and laparoscopic skills should be aware of maximum handling forces of various tissues. In addition, there have been 2 similar studies evaluating specifically suture anchors for renal and hepatic parenchyma. In the first study, Ames et al¹¹ laid the grounds for lower ischemia time during laparoscopic partial nephrec-

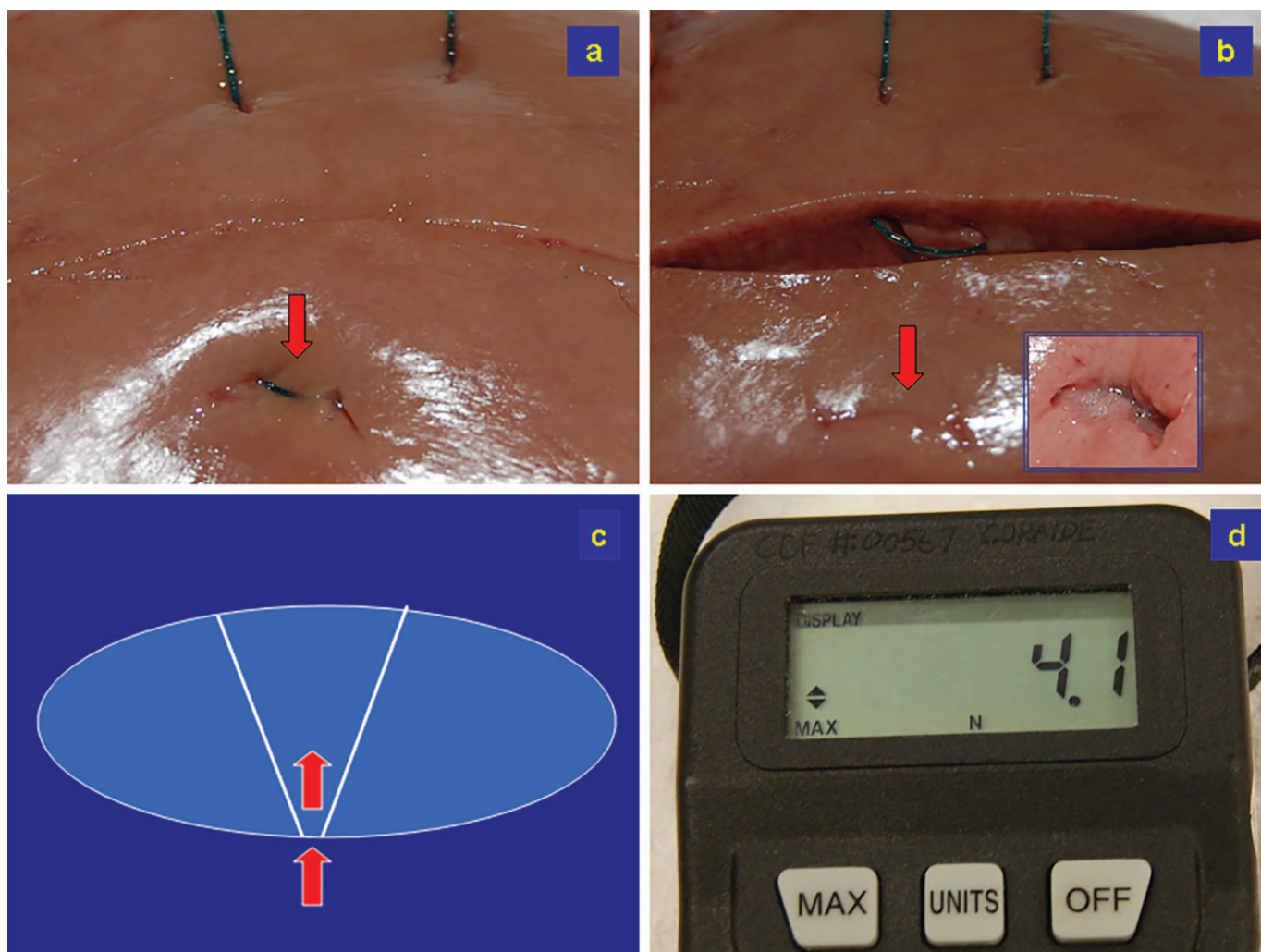


Figure 6. A, 2-way 2-0 V-Loc. **B,** Schematic views of pressure forces. **C,** Tearing of the kidney. **D,** Measurement via UltraTest machine.

tomy using anchored sutures instead of the classic intracorporeal suturing. Furthermore, Tarin et al¹² concluded that using Hem-o-lok suture anchors results in a more secure and cost-effective closure. In our study, we focused on HS of different sutures in terms of suture sliding and tissue tearing of the renal parenchymal tissue.

Synthetic monofilament absorbable sutures, such as polyglyconate, polydioxanone, and polyglecaprone, were introduced to the market with the advantages of less tissue drag when compared with multifilament sutures.¹³ In a study of Wistar rats, the tensile strength of 3 types of surgical sutures was evaluated in the abdominal wall after laparotomy.¹⁴ Catgut, 3-0 polyglactin 910, and polyglecaprone were compared. Three-centimeter laparotomy incisions were performed in rats and closed with the aforementioned sutures. After 63 days, the rats

were euthanized, and a 6 × 2-cm strip was obtained from the rats. The tissue sample was fixed in a mechanical test machine, and the maximum force of the tissue was recorded until full rupture occurred. The measurement was in Newtons. The researchers revealed that polyglactin 910 had the maximum tensile strength when compared with the other 2 suture types, and this value was statistically significant. Although we did not investigate the tensile strength of the sutures, the HS of polyglactin 910 (Vicryl) with 1 or 2 Hem-o-lok clips was significantly superior to that of polyglyconate (V-Loc) and Quill (polyglycolic acid-polycaprolactone) sutures in adult porcine kidneys. Attachment of 1 more Hem-o-lok clip onto the polyglactin 910 statistically increased the HS of the suture when compared with polyglactin 910 suture with 1 Hem-o-lok clip.

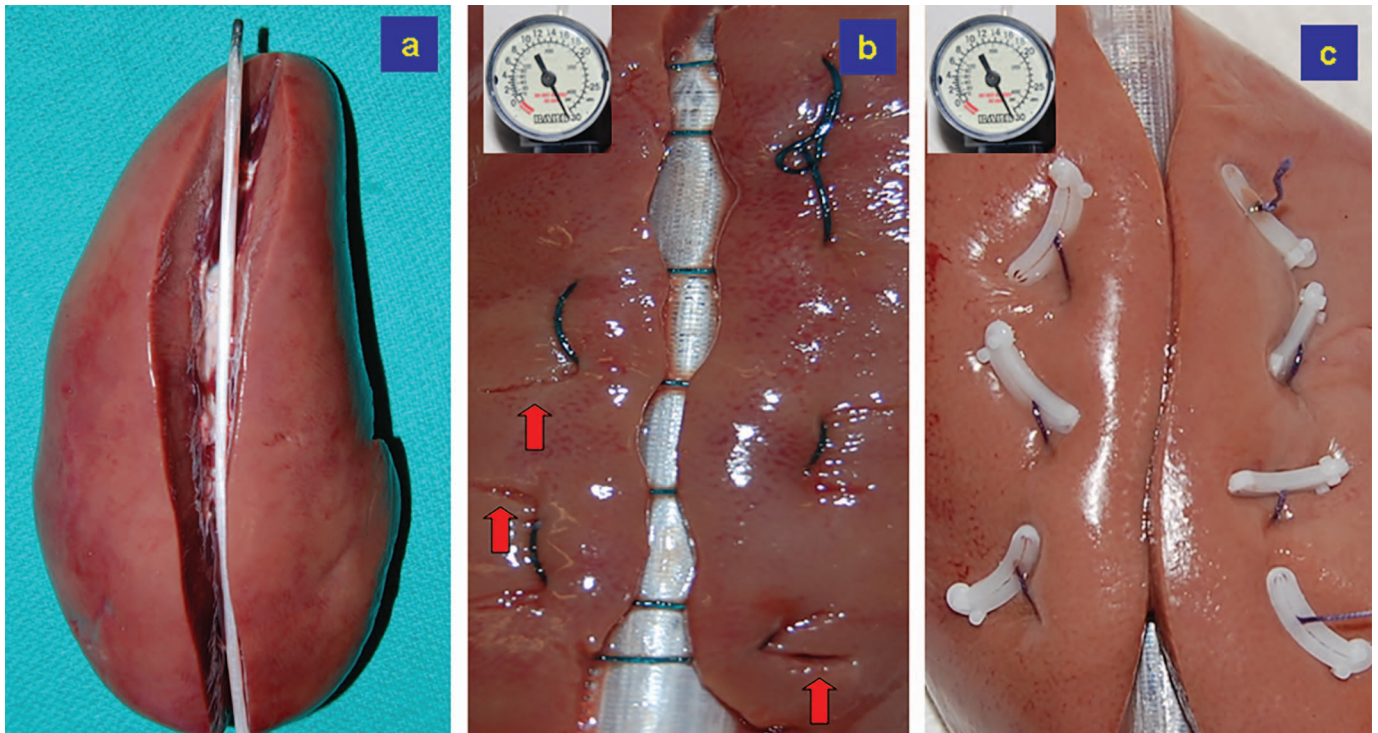


Figure 7. Comparison of 2-0 Vicryl with Hem-o-lok clip with 2-0 V-Loc suture with 1 knot. **A,** Placement of balloon dilatation catheter. **B,** Measurement of separation with 2-0 V-Loc suture with 1 knot. **C,** Measurement of separation with 2-0 Vicryl with Hem-o-lok clip.

Table 1.

Mean Holding Strength Causing Sliding of the Suture Variants	
Suture Variants	Mean HS Causing Sliding of the Suture (N)
2-0 Vicryl with 1 Hem-o-Lok	3.26 ± 0.55
2-0 Vicryl with 2 Hem-o-Lok	4.1 ± 0.46
2-0 V-Loc	2.52 ± 0.63
4-0 V-Loc	1.62 ± 0.17
0 Quill suture	0.48 ± 0.16
2-0 Vicryl with 1 Hem-o-Lok cinched in the middle	3.62 ± 0.66
2-0 V-Loc suture locked in the middle	1.02 ± 0.40

An experimental study in rats dealt with the tensile strength and durability of 7 suture materials in various pHs and different conditions.¹ The size of all suture materials was 5-0, and the suture types were Maxon (Medtronic, Minneapolis, Minnesota, USA), Vicryl (Ethicon), plain catgut, surgical silk, polypropylene, Caprosyn, and Biosyn (both from Medtronic). The suture experiments were conducted on the intestine, bile duct (after obstruction), stom-

ach, and bladder in vivo. For in vitro assessment, bile (pH 1.0) and urine (pH 10.0) of rats were preferred. Vicryl significantly lost its tensile strength in all except for the intravesical condition. Polypropylene was the only suture material that conserved its stability in all in vivo and in vitro conditions ($P > .05$). The investigators revealed that Biosyn and Caprosyn lost maximum tensile strength in intravesical and urine conditions ($P < .05$). Statistically significant tensile strength losses were observed in catgut in all conditions, in Biosyn and silk in all except in intraintestinal and intragastric conditions, and in Maxon in all except the intravesical condition. All absorbable sutures and silk disintegrated in acid and alkaline conditions. After the procedures, the highest tensile strength loss was noted in silk, Maxon, Caprosyn, Biosyn, and catgut; the least tensile strength loss was observed in polypropylene. The conclusion was that Caprosyn and Biosyn are preferable in urologic interventions. Even though we did not compare the sutures in different pH conditions, polyglactin 910 seemed to have the maximum HS for renal parenchymal repair in our study.

To date, there is little knowledge about the maximum tolerance of a knotted suture to an applied force in the body. These forces may vary among individuals and local

Table 2.
Comparison of Suture Variants in Terms of Mean Holding Strength and Tearing of the Kidney

Suture Variants	2-0 Vicryl Suture With 2-Way (Hem-o-Lok in the Middle)	2-0 Vicryl Suture With 2-Way (Hem-o-Lock in the Middle)	2-0 V-Loc Suture With 2-Way
2-0 V-Loc suture with 2-way	$P = .042$	—	—
2-0 Vicryl suture with 2-way (Hem-o-Lok in the Middle)	—	$P = .043$	—
2-0 Vicryl suture with 2-way (Hem-o-Lok in the Middle)	—	—	$P = .138$

The probabilities show mean holding strength/tearing of the kidney.

factors, such as the tissue to which it is applied. Until further knowledge is acquired from prospective, randomized trials involving large samples, it is better and advisable to ensure that knotted sutures should be as strong as the surrounding tissue.¹⁵ The surgeon can increase the strength of a knotted suture in different ways, by adding more throws, changing the suture gauge, or choosing a different suture with better knot profile and security.¹⁶ Knot security is especially important today because of the frequent use of rapidly absorbable suture materials. It is a known fact that sutures lose their strength during the resorption process. Similar to the aforementioned studies, we found that adding an extra Hem-o-lok clip to polyglactin 910 significantly increased its HS in the tissue. In our opinion, every surgeon should be aware of differences in knot security when considering various suture types in different tissues.

There are several limitations of our study such as the use of fresh post mortem porcine kidneys. The reason for our using porcine kidneys was the worldwide acceptance of this model in laparoscopic training. However, the tissue properties may be different in humans. Therefore, the outcome of our study should be interpreted accordingly. In our study, the kidneys were freshly obtained and kept in cold saline. As a result, post mortem degradation could have occurred and may have affected our results.¹⁷ We tried to keep the degradation of the kidneys to a minimal level, similar to a recent study, by storing the tissue in physiologic saline solution at a maximum temperature of 7°C and quickly investigating the kidneys within 6 h after death.⁶ No bleeding in the tissues is another limitation of using post mortem tissues. Although bleeding is accepted as among the first signs of tissue damage, we could observe the parenchyma of the kidneys only in terms of macroscopic damage or tearing. Microscopic tissue damage could have been evaluated before macroscopic damage occurrence, but we did not evaluate the samples

microscopically. We could have used the initial 7 suture materials in the other scenarios, but we preferred to use other types of sutures. We should also mention that if we used the Wilcoxon signed ranks test for the first comparison of 7 suture materials dealing with HS causing the suture to slide, a new P -value was calculated, and the significant difference between the variants disappeared. Instead of the Wilcoxon test, we preferred to use the Friedman test for comparing the suture materials.

CONCLUSIONS

Our study revealed that 2-0 Vicryl (Polyglactin 910) with 2 Hem-o-lok clips in renal parenchyma had the maximum HS when compared with the other sutures studied. Adding 1 Hem-o-lok clip to the suture significantly increased the HS. In terms of tearing, 2-way 2-0 Vicryl had the maximum HS when the Hem-o-lok clip was in the middle. It should be kept in mind that the decision on appropriate suture material depends on the surgeon's and hospital's tradition; however, surgeons should be aware of differences in knot and holding security when various suture types are used in different tissues. Urologists should know these differences and train themselves in a nonclinical setting to improve their sense of HS.

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