Pyeloureteral magnetic anastomosis (PUMA) device to simplify laparoscopic pyeloplasty: a proof of concept study

Tamas Cserni [a,b], Daniel Urban[b], Daniel Hajnal[b], Daniel Erces[b], Gabriella Varga[b], Andras Nagy[c], Marton Cserni[d], Mahmoud Marei[e], Supul Hennayake[a], Rainer Kubiak[f]

[a]Royal Manchester Children's Hospital, Manchester University NHS Foundation Trust, UK

[b]Institute of Surgical Research, University of Szeged, Hungary

[c]Department of Radiology, University of Szeged, Hungary

[d]Faculty of Mechanical Engineering, University of Technology and Economics Budapest, Hungary

[e]Cairo University, Faculty of Medicine (Kasr Alainy), Egypt

[f]Department of Pediatric Surgery, Faculty of Medicine (UMM) Mannheim, University of Heidelberg, Germany

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record. Please cite this article as doi: 10.1111/BJU.15301

Corresponding author:
Tamas Cserni MD, PhD, FEBPS, FEAPU
Department of Paediatric Urology
Royal Manchester Children's Hospital, Manchester University NHS Foundation Trust, UK
Manchester M13 9WL
Tel. +4471612761234
E-mail address: Tamas.Cserni@mft.nhs.uk

Keywords: Laparoscopy; Magnamosis; Pyeloplasty; Pyeloureteral magnetic anastomosis device (PUMA); Surgical innovation

DR. TAMAS CSERNI (Orcid ID : 0000-0003-4316-1448)

Article type : Research Communication

Laparoscopic pyeloplasty (LP) is a standard, but demanding operation. According to the European Association of Urology guidelines this procedure scores 13 out of 18 on the difficulty scale [1]. Articulating instruments, 3D video systems and robots may facilitate complex suturing of the ureteropelvic anastomosis at higher costs [2,3]. Magnetic compression anastomosis (magnamosis) has been used safely and effectively in the gastrointestinal tract [4,5], however not been applied in the urinary tract.

Our aim was to prove the concept of magnamosis in the urinary system and to develop a pyeloureteral magnetic anastomosis (PUMA) device in order to simplify LP.

The study was conducted by a stepwise approach [6] in six female Vietnamese minipigs in accordance with the National Institutes of Health guidelines and EU directive 2010/63 for the protection of animals used for scientific purposes and was approved by the National Scientific Ethical Committee (V.2480/2017). In order to perform the procedure laparoscopically throughout, a hydronephrosis model [7] was finally applied in animal no. 5 and 6 (Table).

In all cases N35 neodymium nickel coated magnetic cylinders with 4 mm outer diameter, 2 mm inner diameter and 8 mm length were applied to a 4.8 Fr, 22 cm long JJ stent or a 4.7 Fr, 12-18 cm pyeloureteral stent (Salle stent). The “ureteric” magnet was fixed to the stent. The “pelvic” magnets were left unattached in animal 1 and 2, but inserted/fixed into a 10 Fr “nephrostomy” tube (animal 3 and 4) or into a Malecot catheter tip (animal 5 and 6), respectively. A surgical needle (31 mm ½ c tapered) was integrated into the proximal end of the stents using cyanoacrylate glue.

The stents with the "ureteral" magnet were threaded into the ureter and/or the bladder. The proximal part of the stents with the integrated needle was stitched inside-out from the ureter 10 mm below the free end, which was closed with a 5 mm titanium clip (Video).
The stents were stitched into the "pelvis" in an outside-inside fashion. The "pelvic" magnet was threaded onto the stents. In animal 1, 5 and 6 JJ stents, in animals 2-4 Salle stents were applied with the proximal tip being brought out as a "nephrostomy" via a 10 Fr suction catheter in the latter. The "pelvis" was closed with a 4/0 barbed suture (Fiblock) without the need of knot tying (Video).

Because each intervention required another anesthesia, postoperative imaging was kept to a minimum. The animals were sacrificed between 2 (animal 1) and 10 (animal 6) weeks after the procedure, and the anastomoses were assessed macroscopically and/or microscopically, using hematoxylin and eosin staining. The magnets were removed via the UVJ in animals 1 and 5 at autopsy. In animal 6 the PUMA was removed via cystoscopy in vivo four weeks prior to termination (Table).

A PUJO model made from a spherical birthday balloon (40 mm, representing the dilated pelvis) and a sausage balloon (5 mm, representing the proximal ureter) was placed on a laparoscopic simulator (Eosurgical ltd., Edinburgh, U.K). Eleven surgeons experienced in laparoscopy were asked to perform a standard laparoscopic ureteropelvic anastomosis followed by using the PUMA device. The time required for the procedures was recorded. The quality of the performance was assessed by the instructor (TC) as well as the candidates and rated ranging from 1 (poor) to 5 (excellent). Subsequently, a time-quality score (TQ) was calculated using the formula TQ = Time X 5/quality score.

After initial failure in animal 1-2, a widely patent anastomosis was achieved in animals 3-6. After having switched to the hydronephrotic animal model the procedure was carried out laparoscopically throughout. The need for laparoscopic suturing and knot tying was eliminated. Removal of the magnetic JJ stent was possible via the UVJ (Table). The anastomosis remained widely patent after removal of the device.
In the simulation the mean time required for the anastomosis dropped from 39.91±14.08 to 8.18±2.75 minutes ($p<0.0001$) and the quality increased from a median of 3 (range, 2-5) to 5 (range, 3-5) with the PUMA device ($p=0.0156$). The mean time-quality score (TQ) was significantly higher (i.e. less favorable) with the standard technique (67.79±34.42) compared

with the PUMA method (9.45±5.14) (p=0.0003). Of note, in each case the time taken for the procedure was less and the estimated quality either better or equivalent with the PUMA device.

The ideal magnetic compression force to create a ureteric anastomosis is unknown. A most recent experimental study estimated the optimal pressure between 79.8 kPa - 169 kPa for an intestinal anastomosis in dogs [8]. The maximal magnetic compression force of the magnets that were applied in this study lies between 3-4 N as stated by the manufacturer (Euromagnet KFT, 1172 Budapest, Hungary). It is well known that the magnetic force is inversely proportional to the square of the distance between the magnets. In order to calculate the magnetic pressure we considered a 2 mm separation (i.e. two times the ureteral wall thickness) of the magnets since the normal ureteral wall thickness has been estimated about 1 mm. Subsequently, the area of the magnets was calculated by using the equitation: $Area_{(surface)} = Area_{outside} - Area_{inside} = \left(\frac{diameter_{outside}}{2}\right)^2 * \pi - \left(\frac{diameter_{inside}}{2}\right)^2 * \pi$. Therefore, the magnetic pressure in our study ranged between 79.6 - 106.1 kPa calculated by: $Pressure = 0.25 * \frac{Force}{Area\ (surface)}$. These numbers were in accordance with the above-mentioned study [8].

In this series, postoperative X-rays revealed that the magnets did not cut trough very rapidly providing a reasonable time (i.e. 7 days) for the ureteric wall to remodel and heal. Moreover, no extravasation of contrast was seen on intravenous urography. We observed a narrowing of the anastomosis only in animals 1-2, in which the magnets passed below and only a small caliber stent was present at the PUJ 14 days after the procedure. However good-sized anastomosis was achieved in those animals in which the magnets or large caliber stent remained at the level of the PUJ for at least 14 days. This may indicate that the anastomosis has to be kept open at a full caliber for a few weeks to prevent stricture. Of note, in animal 6 no narrowing was observed four weeks after stent removal.

The simulation revealed a significant shorter operating time with the PUMA device compared with the standard method. The quality of the new operation (i.e. position and adherence of the magnets) was rated as being equivalent or superior in each case. Moreover, all participants found the new technique less demanding. In addition, although not in accordance with our original study protocol, we asked five pediatric nurses, who had never received training in laparoscopic instrumentation, to perform an anastomosis with the PUMA device in the simulator after watching a short tutorial video. Interestingly, their average time to complete the task was only slightly longer compared with that of the surgeons (10.60±1.67 vs. 8.18±2.75 minutes).

Our study is a proof of concept study and has its limitations. A limited number of animals has been used and only short-term follow up was applied to prove a patent anastomosis.

In summary, magnamosis has a great potential in creating a purpose-built anastomosis device in order to simplify laparoscopic pyeloplasty.

Conflicts of Interest

Tamas Cserni reports a UK patent application filed pending. Daniel Urban, Daniel Hajnal, Daniel Erces, Gabriella Varga, Andras Nagy, Marton Cserni, Mahmoud Marei, Supul Hennayake, and Rainer Kubiak have nothing to disclose.

References

1. Doublet JD, Janetschek G, Joyce A, Mandressi A, Rassweiller J, Tolley D. The difficulty scoring system of laparoscopic procedures. In: European Association of Urology GUIDELINES ON LAPAROSCOPY; pp.14-16. https://uroweb.org/wp-content/uploads/laparoscopy.pdf
2. Tuncel A, Lucas S, Bensalah K, et al. A randomized comparison of conventional vs. articulating laparoscopic needle-drivers for performing standardized suturing tasks by laparoscopy-naive subjects. BJU Int 2008;101:727-30.
3. Trevisani LF, Nguyen HT. Current controversies in pediatric urologic robotic surgery. Curr Opin Urol 2013; 23:72-7.
4. Jamshidi R, Stephenson JT, Clay JG, Pichakron KO, Harrison MR. Magnamosis: magnetic compression anastomosis with comparison to suture and staple techniques. J Pediatr Surg 2009; 44:222-8.
5. Graves CE, Co C, Hsi RS, et al. Magnetic Compression Anastomosis (Magnamosis): First-In-Human Trial. J Am Coll Surg 2017; 225:676-81.
6. MacArthur CL. The 3Rs in research: a contemporary approach to replacement, reduction and refinement. Br J Nutr 2018; 120:S1-S7.
7. Bowen J, Cranley J, Gough D. The flank approach to the porcine upper urinary tract: safe and reliable. Lab Anim 1995; 29:204-6.
8. Zhao G, Ma J, Yan X, Li J, Ma F, Wang H, Liu Y, Lv Y. Optimized force range of magnetic compression anastomosis in dog intestinal tissue. J Pediatr Surg. 2019; 54:2166-71.

Table Summary of the animal series.

Video https://www.dropbox.com/s/wf70aknoh561v9u/Video-Puma2.mp4?dl=0

Animal no.	Kidney anatomy	Surgery	PUMA prototype	Post-OP X-ray (day)	Position of magnets on day 14	Stent diameter at level of anastomosis▼	Removal of stent (day)	Observation/ complications	Appearance of anastomosis
1	Normal	Open	JJ stent with "pelvic" magnet unattached	0/7/14§	Below anastomosis	4.7 Fr	At autopsy (14) (via UVJ)	Hydronephrosis	Narrow
2	Normal	Laparoscopy/ open#	Salle stent with "pelvic" magnet unattached	0/7/14*/28‡	Below anastomosis	4.7 Fr	At autopsy (28)	Hydronephrosis	Narrow
3	Normal	Laparoscopy/ open#	**Salle stent with "pelvic" magnet fixed in a 10 Fr nephrostomy**	0/7/14	**At level of anastomosis**	**10 Fr**	At autopsy (42)	Normal anatomy	**Good caliber**
4	Normal	Laparoscopy/ open#	**Salle stent with "pelvic" magnet fixed in a 10 Fr nephrostomy**	14	**At level of anastomosis**	**10 Fr**	At autopsy (42)	Normal anatomy; infection	**Good caliber**
5	Induced hydronephrosis▲	Laparoscopy	**JJ stent with "pelvic" magnet fixed in Malecot tip**	-	n.a.	**12 Fr**	At autopsy (42)	Normal anatomy; infection	**Good caliber**
6	Induced hydronephrosis▲	Laparoscopy	**JJ stent with "pelvic" magnet fixed in Malecot tip**	-	n.a.	n.a.†	Cystoscopy (42) (via UVJ)†	Normal anatomy	**Good caliber**

Abbreviations: PUMA, pyeloureteral magnetic anastomosis; Fr, French; n.a., not assessed; UVJ, ureterovesical junction.

▼ At autopsy.

§ Retrograde contrast study performed on day 14 prior to termination.

Conversion to open surgery required in order to bring Salle stent out as nephrostomy and to insert the (second) "pelvic" magnet into the non-hydronephrotic (normal) proximal ureter.

* Intravenous pyelogram (IVP) performed on day 14.

‡ Nephrostogram performed on day 28 prior to termination.

▲ Loose ligation of the ureter (laparoscopic approach) was performed with a 15 cm long rubber vascular loop [7] 4 weeks prior to pyeloplasty in animal no. 5 and 6.

† No stent in situ at autopsy; the stent was removed via cystoscopy on day 42, 4 weeks prior to termination.