INSTRUMENTAL PALPATION IN ENDOSCOPIC RENAL SURGERY: CASE REPORTS AND ANALYSIS

Solodova RF[1] ✉, Tolstykh MP[2], Isaev TK[3], Trushkin RN[3], Vtorenko VI[3], Staroverov VM[1], Sokolov ME[1]

[1] Faculty of Mechanics and Mathematics, Lomonosov Moscow State University, Moscow

[2] Yevdokimov Moscow State University of Medicine and Dentistry, Moscow

[3] City Clinical Hospital №52, Moscow Health Department, Moscow

Palpation is one of the classic examination methods in open surgeries. In minimally invasive surgery, intra-operational manual palpation is impossible to use for assessing tactile characteristics of tissues. In Russia, the only available instrument for intra-operational assessment and objective registration of tissue visco-elastic properties is the Medical Tactile Endosurgical Complex (MTEC). The aim of this work was to study the performance of MTEC in renal surgery. The study was performed during nine elective laparoscopic surgeries for clear cell renal carcinoma and simple renal cysts. We have found several differences in the use of MTEC in renal surgery, as compared to its use in gastrointestinal or lung surgeries. The key factor determining these differences was the inverse relations between tissue visco-elastic properties: the studied tumors were softer than the surrounding tissue. Detection of intraparenchymal tumors by tactile methods was impossible. For surface tumors, in one case out of nine it was possible to strictly locate the border of the tumor by tactile examination. We were able to quantitatively assess and determine the difference in hardness of tumors and intact tissue using MTEC. This allows studying the prognostic value of objectively registered tactile characteristics of renal tumors.

Keywords: renal surgery, instrumental mechanoreceptoric palpation, objective registration of tactile images, Medical Tactile Endosurgical Complex (MTEC), clear cell renal carcinoma, renal cyst

Funding: the work was done with the financial support of the Russian Science Foundation (project No. 16-11-00058 “Development of methods and algorithms for automated medical tactile information analysis and tactile image classification”).

Acknowledgments: the authors thank Galatenko A.V. and Galatenko V.V. (Lomonosov Moscow State University) for valuable comments, criticism, and help with preparing the manuscript.

✉ **Correspondence should be addressed:** Rozaliya F. Solodova
Leninskie gory 1, bl. 46, Moscow, 119991; rozaliya@solodov.org

Received: 26.07.2018 **Accepted:** 23.11.2018

DOI: 10.24075/brsmu.2018.069

ИНСТРУМЕНТАЛЬНАЯ ПАЛЬПАЦИЯ В ЭНДОСКОПИЧЕСКОЙ ХИРУРГИИ ПОЧЕК: ОПЫТ ПРИМЕНЕНИЯ

Р. Ф. Солодова[1] ✉, М. П. Толстых[2], Т. К. Исаев[3], Р. Н. Трушкин[3], В. И. Вторенко[3], В. М. Староверов[1], М. Э. Соколов[1]

[1] Механико-математический факультет, Московский государственный университет имени М. В. Ломоносова, Москва

[2] Московский государственный медико-стоматологический университет имени А. И. Евдокимова, Москва

[3] Урологическое отделение, Городская клиническая больница № 52, Москва

Пальпаторная оценка — один из классических методов исследования при открытых хирургических вмешательствах. В малоинвазивной хирургии интраоперационная мануальная пальпация невозможна при оценке тактильных характеристик тканей. В России единственным доступным прибором для интраоперационной оценки и объективной регистрации вязко-упругих характеристик тканей является медицинский тактильный эндохирургический комплекс (МТЭК). Целью работы было изучить возможности применения МТЭК в хирургии почек. Исследование проводили в ходе девяти плановых лапароскопических вмешательств: по поводу светлоклеточного рака почки и простых кист почки. Выявлены особенности, отличающие использование МТЭК в хирургии почек от его применения на органах гастроинтестинального тракта и легких. Ключевым фактором, определяющим наличие этих особенностей, является обратное соотношение вязко-упругих характеристик: исследованные опухоли оказались мягче окружающей ткани. Сделан вывод о невозможности выявления тактильными методами новообразований, расположенных в паренхиме. Для поверхностных новообразований в одном из девяти случаев механорецепторная пальпация позволила выявить четкое расположение границы опухоли. Применение МТЭК позволило количественно оценить и зафиксировать разницу в жесткостных характеристиках опухоли и неизмененной ткани, что открывает возможность исследования прогностической значимости объективно регистрируемых тактильных характеристик новообразований почки на основании полученных цифровых данных.

Ключевые слова: хирургия почек, инструментальная механорецепторная пальпация, объективная регистрация тактильного образа, медицинский тактильный эндохирургический комплекс (МТЭК), светлоклеточный рак почки, киста почки

Финансирование: работа выполнена при поддержке Российского научного фонда: проект № 16-11-00058 «Разработка методов и алгоритмов автоматизированного анализа медицинской тактильной информации и классификации тактильных образов».

Благодарности: авторы выражают благодарность А. В. Галатенко и В. В. Галатенко (МГУ имени М. В. Ломоносова) за замечания, ценные комментарии и помощь в подготовке текста.

✉ **Для корреспонденции:** Розалия Фаилевна Солодова
Ленинские горы, д. 1, к. 46, г. Москва, 119991; rozaliya@solodov.org

Статья получена: 26.07.2018 **Статья принята к печати:** 23.11.2018

DOI: 10.24075/vrgmu.2018.069

Palpation, based on the sense of touch, is one of the basic parts of physical examination and is routinely used in open surgeries. During manual palpation, the visco-elastic properties of tissues and organs are assessed. This method is based on the evaluation of tactile characteristics, which change due to various pathologic processes. In particular, when malignant tumors form, the hardness of the tissue usually increases [1].

With the advent of minimally invasive surgery, intra-operational assessment of tissue tactile characteristics has changed. It is mediated by instruments and has taken the form of kinesthetic feedback in endoscopic surgery [2], and has practically disappeared in robot-assisted surgery [3, 4]. Information value of the feedback during manipulation strongly depends on the qualification and experience of the surgeon. It needs to be noted that even traditional palpation, despite its prolonged use in medical practice, is not a thoroughly standardized procedure, and the interpretation of its results depends significantly on the skill of the doctor [5, 6].

Development of instrumental tactile methods will help increase the awareness of the operator about tactile properties of the tissues during minimally invasive surgery and, in particular, will allow such assessment during robot-assisted surgery [7]. It will also help make palpation more objective, due to the possibility to save and reproduce the acquired information, among other features.

In medical practice, instruments for objective assessment of tissue tactile characteristics and tumor detection with tactile mechanoreceptor diagnostics are used in mammary glands and the prostate [8, 9]. An instrumental tactile vaginal examination method has been described for diagnosing pelvic organ prolapse [10]. Another instrumental palpation method has been described for detecting kidney stones during their laparoscopic extraction [11].

In Russia, the only commercially available instrument for intra-operational assessment of tissue tactile characteristics is the Medical Tactile Endosurgical Complex, MTEC-01 (“SPLAV”; Russia). MTEC is used, in particular, to detect and locate tumors in patients with peripheral lung cancers and gastrointestinal malignant tumors [12, 13].

Active implementation of minimally invasive treatment methods in renal surgery leads to an increased need for instrumental tactile examination. It is crucial for precise localization of the zone of pathological changes and additional assessment of the spread of the pathological process during surgery. The aim of this work was to study the performance of MTEC in renal surgery.

METHODS

Patients

From March to May 2017, nine surgeries were performed using MTEC-01 in the City Clinical Hospital №52. The study was approved by the ethics committee of the hospital (protocol No. 0101/0117, January 25, 2017). Inclusion criteria were: indications for an elective, potentially organ-preserving laparoscopic surgery (cyst fenestration, kidney resection) or the diagnostic stage of a laparoscopic surgery on kidney parenchyma (in the course of nephrectomy). Exclusion criteria were: lack of the possibility and indications for a laparoscopic surgery. Nine patients took part in the study, four men and five women, aged 48–78 (average age 63.7 years). After the patients were informed about the possibility of using additional intra-operational diagnostic methods during surgery, all of them signed a voluntary informed consent form for the surgical procedure.

The surgeries included seven kidney resections, one nephrectomy and one elective nephradrenalectomy (see Table).

MTEC description

To perform an instrumental tactile examination during surgeries, we used MTEC-01 (“SPLAV”, Russia). It comprises tactile mechanoreceptors (probes), a computer with special software, and an optional tactile display from which the surgeon can feel tactile images by hand. The instrument exists in two versions with different diameters of working part — 20 and 10 mm. On the working surface of the probe, depending on its diameter, 19 or 7 pressure sensors are located. They transfer data to the computer through a wireless connection, up to 100 times per second. Fig. 1 shows a probe with diameter 10 mm and seven sensors at the working surface. The results are shown on the tactile display in real-time, and also on a screen with the use of an adaptive color scale. With an average press force, softer tissues are shown green, harder tissues — red, and blue indicates intermediate results.

Table. Clinical characteristic of patients, type of surgery and results of histological analysis

Patient	Sex	Age	Diagnosis	Laparoscopic procedure	Histological description	Tumor size, mm
1	M	52	Renal cancer in left kidney, T3aN0M0. Chronic renal failure st. 1. Chronic kidney disease st. 3.	Left nephrectomy	Clear cell renal carcinoma, G2 according to Fuhrman	68
2	M	66	Renal cancer in left kidney, T1bN0M0	Left nephradrenalectomy	Clear cell renal carcinoma, G3 according to Fuhrman	54
3	F	78	Renal cancer in sole remaining right kidney, T1aN0M0	Resection of sole right kidney with tumor	Clear cell renal carcinoma, G1 according to Fuhrman	34
4	F	77	Cyst in the upper segment of right kidney Bosniak IIF	Resection of upper pole of right kidney with cyst wall	Simple tense renal cyst	62
5	F	48	Cyst in upper segment of right kidney Bosniak III	Resection of right kidney with cyst wall	Simple renal cyst	86
6	F	53	Cyst in lower segment of left kidney Bosniak IIF	Resection of left kidney with cyst wall	Simple renal cyst	79
7	M	63	Cyst in lower pole of left kidney Bosniak IIF	Resection of left kidney with cyst wall	Simple renal cyst	64
8	M	68	Cyst in middle segment of left kidney Bosniak III	Resection of left kidney with cyst wall	Simple renal cyst	57
9	F	68	Cyst in upper segment of left kidney Bosniak IIF	Resection of left kidney with cyst wall	Simple renal cyst	41

Surgical team training

When a new type of instrument is being introduced into clinical practice, theoretical and practical personnel training is necessary. Training with a simulator helps ensure reproducibility of results. All members of the surgical team (not only the operating surgeon) developed instrumental palpation skills with a box trainer. The aims of training were: to form a realistic vision of the method's capabilities, without unreasonably high expectations; to develop skills for understanding the adaptive color scale and assessing the amount of mistakes made when locating a hard object in soft tissues. Experienced practicing surgeons took part in the training. The length of the training was no more than 45 minutes. Later, during the study, one surgeon did all assessments, while assisting surgeons could also use the method if necessary. The training began with a brief explanation of the basics of the method and use of the instrument. Then the surgeons performed instrumental palpation on objects of different hardness, not hidden inside tissue. After that, they practiced palpating a metal ball placed inside soft spongy material. All surgeons mastered the method in 5 minutes, except one surgeon who needed a personal training session. Even taking this into account, six sessions with a laparoscopic box trainer were enough to achieve the goals of training.

The results of training have confirmed that information acquired by the surgeon with instrumental tactile examination is not analogue of information received during traditional palpation. While using MTEC, the surgeon combines kinesthetic sensations from contact with tissues, a visual image of the palpated organ, visualization of the tactile image based on the adaptive color scale and, optionally, a tactile image on the tactile display. The surgeon analyzes this information to find answers to the questions set by the aim of examination (for example, locating the border of the tumor to determine the necessary and sufficient resection margins).

Course of the study

MTEC was used for patients who, according to medical urological indications, had elective laparoscopic kidney resection, cyst fenestration, or nephrectomy. Tactile examination was performed by one surgeon in a stable laparoscopic surgical team. When planning the surgery, we took into account that the increase in surgery and anesthesia time cannot be more than 10–15 min. The palpation zone was controlled visually at all times. The paranephrium over the examination zone was removed according to the standard surgical protocol. Instrumental mechanoreceptor palpation and is results did not affect the initial surgery plan. To verify intra-operationally the location of the tumor and to verify the results of instrumental tactile examination, an intra-operational ultrasound examination was performed with an ultrasound apparatus Flex Focus (BK Medical; Denmark). There was no need to extend the stages of the surgery that require temporary cessation of blood flow (during resection). Thus, in the course of instrumental tactile examination the surgeon was not subjected to temporal stress due to the use of a new instrument. Additional laparoscopic ports, apart from the ones installed as a part of the standard laparoscopy protocol, were not used.

Conditions of instrumental palpation differed depending on tumor characteristics. Examination of visible tumors was performed starting from an arbitrary point closest to the renal hilum, clockwise until the tumor was fully localized. Two types of examination were used: static and dynamic. For static examination, the tactile probe was applied to different parts of the tissue step by step. For dynamic examination, the probe was moved along the tissue under light pressure, while constantly preserving the contact between sensors and the tissue. When the border of the tumor was not visible, instrumental tactile examination was started from the upper pole of the assumed tumor location zone and continued clockwise. In the course of examination, (1) the possibility to locate the tumor border based on tactile mechanoreceptor data was analyzed; (2) a tactile characteristic of the tumor was given; (3) the kinesthetic sensation was recorded (soft-hard, softer or harder than healthy kidney tissue).

When visualizing the tactile image based on the adaptive color scale, the following templates were described:

– soft: the center is outside the palpation zone due to pressure on the outside perimeter of the mechanoreceptor working part (center is light green) (Fig. 2A);

– firm: the center is under pressure, the outside perimeter is partially outside the palpation zone (center is blue or red, perimeter color indicates lower pressure) (Fig. 2B);

– border: a border line without acute angles is visible, and on both sides of it the registered pressure values are close to uniform (but the pressure on different sides of the line is visualized with different colors) (Fig. 2C).

Due to the standard position of laparoscopic ports, the optimal contact angle (when the tactile probe is almost perpendicular to the examined tissue) could be reached when examining mainly the front, medial and, partly, other side surfaces of the kidney. Instrumental palpation of the back surface of the kidney required mobilizing the organ and rotating the renal pedicle. Because of this, in order to avoid ischemic injury, instrumental palpation of the back surface was performed only in the cases when kidney removal was planned.

RESULTS

During the study, the following points were considered most important:

– the possibility of "palpatory visualization" of the renal tumor for surface tumors and tumors located inside the parenchyma;

– how visco-elastic properties of the surrounding tissue (characteristics of the parenchyma) influence the information value of instrumental tactile examination;

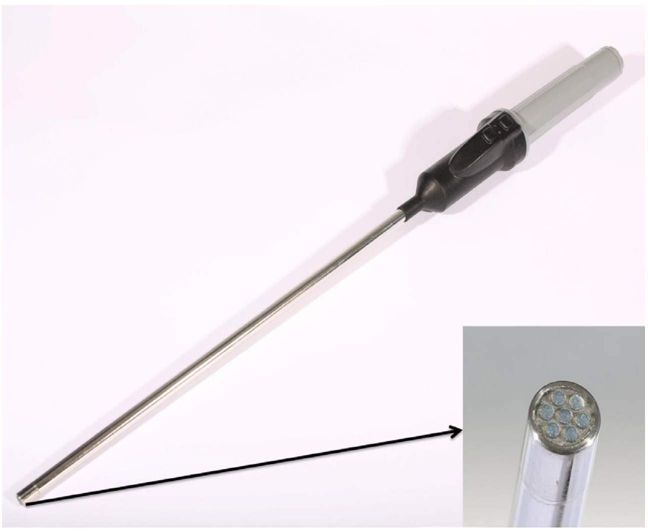

Fig. 1. A tactile probe with diameter 10 mm and seven pressure sensors on the working surface

– comparability of the results of instrumental tactile examination to information acquired from kinesthetic feedback.

The following results were obtained.

Patient Po., 52 years old. Macroscopically solid nodular tumor, up to 68 mm in size, located on the surface and visualized during laparoscopy (Fig. 3). Kinesthetically hard. According to kinesthetic sensation, the tumor was softer than intact tissue, which was consistent with the visualization of the registered tactile image based on the adaptive color scale (Fig. 3C). The border was convincingly detected by the instrumental tactile method. It needs to be noted that, due to the size of the tumor, the working angle of the tactile probe on the tumor was substantially different than on intact kidney tissue.

Patient Pe., 66 years old. Macroscopically cystic tumor, 54 mm in size, located on the surface and visualized during laparoscopy. Kinesthetically soft. According to kinesthetic sensation, kidney parenchyma is harder than the tumor. Instrumental palpation also showed that the tumor was softer than the parenchyma. Precise determination of the tumor border with instrumental tactile examination was deemed impossible.

Patient S., 78 years old. Tumor in the upper pole of the kidney, 34 mm in size (T1aN0M0). An organ-preserving resection of the sole remaining kidney was performed. The tumor was located under the renal capsule, was not visible and could not be located with instrumental tactile examination (Fig. 4). Resection became technically possible only after tumor visualization with an ultrasound 3D-reconstrucion, which confirmed resectability and allowed determining the necessary operative procedure. At the same time, the tumor was found to be only 2 mm below the surface of the organ (Fig. 4A). The surgery lasted 140 mins. Temporary hemostasis control was obtained by endoscopically applying a bulldog clip on the whole renal pedicle. Warm ischemia time was 17 mins. Final hemostasis was reached by stitching the kidney wound.

Patient Sh., 77 years old. Macroscopically tense renal cyst, located on the surface, 62 mm in size, easily visible. Kinesthetically soft. According to kinesthetic sensation, the cyst was softer than kidney parenchyma. According to tactile characteristics visualized with the adaptive color scale, it did not differ significantly from healthy tissue and was difficult to localize. Under moderate pressure all fields were green.

The remaining five cases were presented with macro- and microscopically non-tense simple renal cysts and were analyzed together. In all five cases, strict localization of cyst borders based on the data from instrumental mechanoreceptoric examination was deemed impossible.

Cyst visualization yielded a template with an evenly colored perimeter. With this template, an analysis of cyst tension was possible by comparing the colors of the central and peripheral fields. A tense cyst yielded the firm template, and non-tense cysts yielded intermediate patterns between distinctly soft and distinctly firm templates.

DISCUSSION

When the first laparoscopic nephrectomy was described [14], the era of minimally invasive operations in renal surgery has started. Advantages of endoscopy, including less trauma, shorter postoperative period, and better visualization during surgery with instruments, come together with a shortage of available examination methods because palpating organs and tissues is rendered impossible. In endoscopic surgery, the only available feedback is kinesthetic, determined by the pressure applied to muscles and ligaments [2]. Standard robot-assisted surgery lacks both tactile and kinesthetic feedback [3]. Studies with additional instruments creating tissue response have shown that these instruments allow reducing grasping power and, consequently, decreasing tissue damage [15].

In literature, several types of instruments have been described that help obtain kinesthetic and tactile information during laparoscopic surgeries, including robot-assisted surgeries [12, 13, 16–19]. The majority of these instruments performs specific tasks, such as controlling the grasping power, and does not allow an instrumental tactile examination. MTEC, on the contrary, is designed specifically for mechanoreceptoric palpation.

Apart from obtaining additional information during endoscopic surgery, with instrumental palpation it is possible to make the results of tactile examination more objective. This, in turn, increases the efficiency of examination for less experienced surgeons.

Implementing an objective method of tissue tactile characteristic assessment during surgery seems to be a promising but understudied aspect of renal surgery. In this work, we studied the performance of MTEC for instrumental mechanoreceptoric palpation in renal surgery. We found several features that differentiate the use of MTEC for instrumental mechanoreceptoric palpation in renal surgery from its use on gastrointestinal organs and lungs [12, 13]. The key factor determining these differences is the inverse relations between tissue visco-elastic properties of renal tumors and surrounding tissues. While most malignant tumors are harder than healthy tissue [1, 20–22], the studied renal tumors (according to histological examination, all studied tumors were clear cell renal carcinoma) were softer than the surrounding healthy tissue. These results consistent with observations showing that Young's modulus of healthy kidney tissue is significantly higher than Young's modulus of renal cell carcinoma [23]. The difference between direct and inverse relations of hardness in tumors and surrounding tissue is essential because, even with manual palpation, tissue softness is assessed not separately but together with other tissues and parameters. Because of this, intraparenchymal tumors, even at a small depth (2 mm), cannot be located with tactile methods

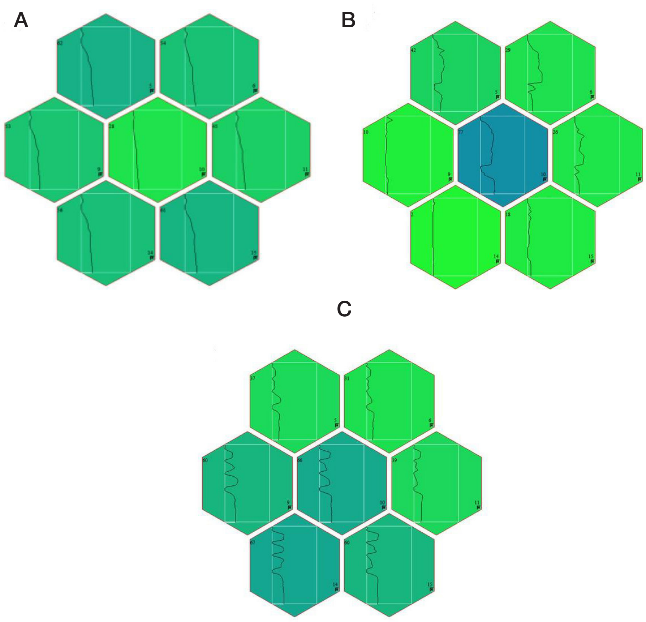

Fig. 2. Visualization of characteristic tactile frames in the adaptive color scale: soft template (**A**), firm template (**B**), border template (**C**)

due to their softness: the harder surrounding tissue conceals softer structures. We can propose an appropriate cooking analogy. When baking, the readiness of dough cannot be assessed with tactile characteristics, because the upper crust springs in the same way regardless of the state of inner parts. Other methods are used to determine if the product is ready. At the same time, surface tumors were identified with tactile examination. In one case, tactile examination made it possible to precisely localize the tumor border.

Cysts, according to their instrumentally registered tactile characteristics, did not differ significantly from healthy kidney tissue, which conformed well to results of instrument-mediated palpation and further manual palpation of removed specimens. Hardness of the tense cyst was slightly higher than in surrounding tissue, but it was impossible to locate its border with tactile methods.

Another important observation is that instrumental tactile examination with MTEC becomes more informative with dynamic rather than static palpation. The key feature of dynamic palpation is the “roll-over” of the instrument’s working surface from the initial point over the study area. Because the probe was fixed inside a trocar, freedom of movement for dynamic palpation was limited but still sufficient for the manipulation. Static palpation, with pressure applied along the axis of the probe, was notably less informative.

During training with a metal ball inside spongy material, we discovered that with MTEC, localizing hard inclusions smaller that the working surface of the probe is easier than localizing larger inclusions. We propose that MTEC efficiency can be enhanced if the working surface area is increased without increasing the diameter of the probe itself.

For renal surgery, it is necessary to modify MTEC software to include a regime for localizing tumors softer that the surrounding tissue. Current software is aimed at searching for harder structures [24, 25]. A simple change in the adaptive color scale that would highlight softer zones during visualization will already help the surgeon read the image more naturally.

In most cases it was impossible to localize tumor borders based solely on the results of instrumental tactile palpation with MTEC. However, the study has shown differences in registered tactile templates for cases when tumors were harder or softer than the surrounding tissue. Standardization of instrumentally registered tactile information (for example, allocation of tactile frames which correspond to the pressure exactly determined by the probe’s weight) raise a question of studying the prognostic value of instrumentally registered tactile characteristics for tumor staging. Standardization will also help specify surgical tactics. For several types of malignant tumors this connection was already described [22, 26, 27].

CONCLUSIONS

Malignant renal tumors show an inverse relations of tumor and healthy tissue hardness: tumors are softer than the surrounding kidney tissue. This feature is highly significiant for instrumental tactile examination. Because of this, it is impossible to locate tumors situated inside the parenchyma, even at a small depth, with tactile methods. For surface tumors, in one of the cases, information from mechanoreceptoric palpation was sufficient to precisely locate the tumor border. In other cases, it was impossible to locate the tumor based on the information from instrumental tactile examination. However, in these cases use of MTEC allowed a quantitative evaluation of the difference in hardness between the tumor and intact tissue. The advent of a technology that can perform such an evaluation opens the possibility to study the prognostic value of objectively registered tactile characteristics of renal tumors for intra-operational express diagnosis. In the course of this study, the methodology of tactile examination was improved and templates for use in diagnosing renal tumors were developed.

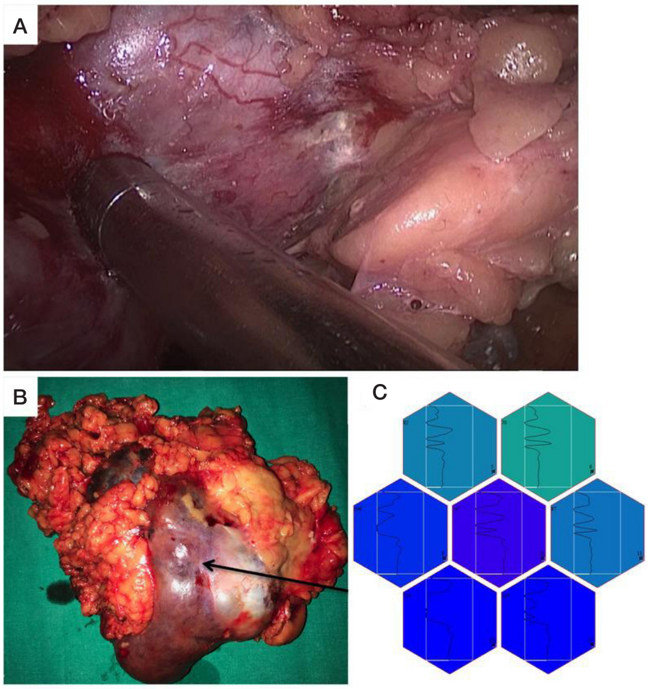

Fig. 3. Examining a tumor with a visible border. **A**. Image from a laparoscopic camera, examination with a tactile probe. **B**. Removed specimen; the visual border of the tumor is shown. **C**. Visualization of a tactile frame with the adaptive color scale

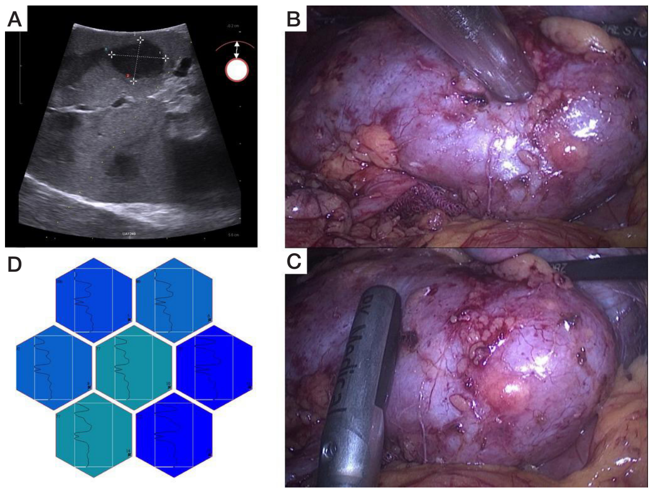

Fig. 4. Examining a non-visible tumor inside the parenchyma. **A**. Ultrasound visualization of the tumor; distance from the surface is shown. **B**. Examination with a tactile probe: image from a laparoscopic camera. **C**. Scanning with an ultrasound sensor; image from a laparoscopic camera. **D**. Visualization of a tactile frame with the adaptive color scale

References

1. Paszek MJ, Zahir N, Johnson KR, Lakins JN, Rozenberg GI, Gefen A, et al. Tensional homeostasis and the malignant phenotype. Cancer Cell. 2005; 8 (3): 241–54.
2. Abdul-Muhsin HM, Humphreys MR. Advances in laparoscopic urologic surgery techniques. F1000Res. 2016; 5(F1000 Faculty Rev): 716.
3. Okamura AM. Haptic feedback in robot-assisted minimally invasive surgery. Curr Opin Urol. 2009; 19 (1): 102–7.
4. Lim SC, Lee HK, Park J. Role of combined tactile and kinesthetic feedback in minimally invasive surgery. Int J Med Robot. 2015; 11 (3): 360–374.
5. Fletcher SW, O'Malley MS, Pilgrim CA, Gonzalez JJ. How do women compare with internal medicine residents in breast lump detection? A study with silicone models. J Gen Intern Med. 1989; 4 (4): 277-83.
6. McDonald S, Saslow D, Alciati MH. Performance and reporting of clinical breast examination: A review of the literature. CA: A Cancer J Clin. 2004; 54 (6): 345–361.
7. Lim SC, Lee HK, Park J. Role of combined tactile and kinesthetic feedback in minimally invasive surgery. Int J Med Robot. 2015; 11 (3): 360–374.
8. Egorov V, Sarvazyan AP. Mechanical imaging of the breast. IEEE Trans Med Imaging. 2008; 27 (9): 1275–87.
9. Weiss RE, Egorov V, Ayrapetyan S, Sarvazyan N, Sarvazyan A. Prostate mechanical imaging: a new method for prostate assessment. Urology. 2008; 71 (3): 425A.9.
10. Egorov V, van Raalte H, Lucente V. Quantifying vaginal tissue elasticity under normal and prolapse conditions by tactile imaging. Int Urogynecol J. 2012; 23 (4): 459–66.
11. Afshari E, Najarian S, Simforoosh N. Application of artificial tactile sensing approach in kidney-stone-removal laparoscopy. Biomed Mater Eng. 2010; 20 (5): 261–7.
12. Barmin V, Sadovnichy V, Sokolov M, Pikin O, Amiraliev A. An original device for intraoperative detection of small indeterminate nodules. Eur J Cardiothorac Surg. 2014; 46: 1027–1031.
13. Solodova RF, Galatenko VV, Nakashidze ER, Shapovalyants SG, Andreytsev IL, Sokolov ME. et al. Instrumental mechanoreceptoric palpation in gastrointestinal surgery. Minimally invasive surgery. 2017; 2017.
14. Clayman RV, Kavoussi LR, Soper NJ, Dierks SM, Merety K,S, Darcy MD, et al. Laparoscopic nephrectomy: initial case report. J Urol. 1991; 146 (2): 278–282.
15. Wottawa CR, Genovese B, Nowroozi BN, Hart SD, Bisley JW, Grundfest WS, et al. Evaluating tactile feedback in robotic surgery for potential clinical application using an animal model. Surg Endosc. 2016; 30 (8): 3198–209.
16. Puangmali P, Althoefer K, Seneviratne LD, Murphy D, Dasgupta P. State-of-the-art in force and tactile sensing for minimally invasive surgery. IEEE Sensors J. 2008; 8 (4): 371–381.
17. Dahiya RS, Metta G, Valle M, Sandini G. Tactile sensing — From humans to humanoids. IEEE Trans Robot. 2010; 26 (1): 1–20.
18. Schostek S, Schurr MO, Buess GF. Review on aspects of artificial tactile feedback in laparoscopic surgery. Med Eng Phys. 2009; 31 (8): 887–898.
19. Schostek S, Zimmermann M, Schurr MO, Prosst RL. Design and Performance of a Low-Cost Telemetric Laparoscopic Tactile Grasper. Surg Innov. 2016; 23 (3): 291–7.
20. Samani A, Zubovits J, Plewes D. Elastic moduli of normal and pathological human breast tissues: an inversion-technique-based investigation of 169 samples. Phys Med Biol. 2007; 52 (6): 1565–76.
21. Hoyt K, Castaneda B, Zhang M, Nigwekar P, di Sant'agnese PA, Joseph JV, et al. Tissue elasticity properties as biomarkers for prostate cancer. Cancer Biomark. 2008; 4 (4-5): 213–25.
22. Kawano S, Kojima M, Higuchi Y, Sugimoto M, Ikeda K, Sakuyama N, et al. Assessment of elasticity of colorectal cancer tissue, clinical utility, pathological and phenotypical relevance. Cancer Sci. 2015; 106 (9): 1232–9.
23. Lee JW, Lorenzo EI, Ahn B, Oh CK, Kim HJ, Han WK, et al. Palpation device for the identification of kidney and bladder cancer: a pilot study. Yonsei Med J. 2011; 52 (5): 768–72.
24. Solodova R, Staroverov V, Galatenko V, Galatenko A, Solodov E, Antonov A., et al. Automated detection of heterogeneity in medical tactile images. In: Westwood JD, Westwood SW, Fellander-Tsai L, Fidopiastis CM, Liu A, Senger S, et al, editors. Medicine Meets Virtual Reality 22. Vol. 220 of Studies in Health Technology and Informatics. Amsterdam: IOS Press, 2016; 383–389.
25. Solodova RF, Galatenko VV, Nakashidze ER, Andreytsev IL, Galatenko AV, Senchik DK, et al. Instrumental tactile diagnostics in robot-assisted surgery. Med Devices (Auckl). 2016; 9: 377–382.
26. Evans A, Armstrong S, Whelehan P, Thomson K, Rauchhaus P, Purdie C, et al. Can shear-wave elastography predict response to neoadjuvant chemotherapy in women with invasive breast cancer? Br J Cancer. 2013; 109 (11): 2798–802.
27. Fenner J, Stacer AC, Winterroth F, Johnson TD, Luker KE, Luker GD. Macroscopic stiffness of breast tumors predicts metastasis. Sci Rep. 2014; 4: 5512.

Литература

1. Paszek MJ, Zahir N, Johnson KR, Lakins JN, Rozenberg GI, Gefen A, et al. Tensional homeostasis and the malignant phenotype. Cancer Cell. 2005; 8 (3): 241–54.
2. Abdul-Muhsin HM, Humphreys MR. Advances in laparoscopic urologic surgery techniques. F1000Res. 2016; 5(F1000 Faculty Rev): 716.
3. Okamura AM. Haptic feedback in robot-assisted minimally invasive surgery. Curr Opin Urol. 2009; 19 (1): 102–7.
4. Lim SC, Lee HK, Park J. Role of combined tactile and kinesthetic feedback in minimally invasive surgery. Int J Med Robot. 2015; 11 (3): 360–374.
5. Fletcher SW, O'Malley MS, Pilgrim CA, Gonzalez JJ. How do women compare with internal medicine residents in breast lump detection? A study with silicone models. J Gen Intern Med. 1989; 4 (4): 277-83.
6. McDonald S, Saslow D, Alciati MH. Performance and reporting of clinical breast examination: A review of the literature. CA: A Cancer J Clin. 2004; 54 (6): 345–361.
7. Lim SC, Lee HK, Park J. Role of combined tactile and kinesthetic feedback in minimally invasive surgery. Int J Med Robot. 2015; 11 (3): 360–374.
8. Egorov V, Sarvazyan AP. Mechanical imaging of the breast. IEEE Trans Med Imaging. 2008; 27 (9): 1275–87.
9. Weiss RE, Egorov V, Ayrapetyan S, Sarvazyan N, Sarvazyan A. Prostate mechanical imaging: a new method for prostate assessment. Urology. 2008; 71 (3): 425A.9.
10. Egorov V, van Raalte H, Lucente V. Quantifying vaginal tissue elasticity under normal and prolapse conditions by tactile imaging. Int Urogynecol J. 2012; 23 (4): 459–66.
11. Afshari E, Najarian S, Simforoosh N. Application of artificial tactile sensing approach in kidney-stone-removal laparoscopy. Biomed Mater Eng. 2010; 20 (5): 261–7.
12. Barmin V, Sadovnichy V, Sokolov M, Pikin O, Amiraliev A. An original device for intraoperative detection of small indeterminate nodules. Eur J Cardiothorac Surg. 2014; 46: 1027–1031.
13. Solodova RF, Galatenko VV, Nakashidze ER, Shapovalyants SG, Andreytsev IL, Sokolov ME. et al. Instrumental mechanoreceptoric palpation in gastrointestinal surgery. Minimally invasive surgery. 2017; 2017.
14. Clayman RV, Kavoussi LR, Soper NJ, Dierks SM, Merety K,S, Darcy MD, et al. Laparoscopic nephrectomy: initial case report. J Urol. 1991; 146 (2): 278–282.
15. Wottawa CR, Genovese B, Nowroozi BN, Hart SD, Bisley JW, Grundfest WS, et al. Evaluating tactile feedback in robotic surgery

for potential clinical application using an animal model. Surg Endosc. 2016; 30 (8): 3198–209.

16. Puangmali P, Althoefer K, Seneviratne LD, Murphy D, Dasgupta P. State-of-the-art in force and tactile sensing for minimally invasive surgery. IEEE Sensors J. 2008; 8 (4): 371–381.
17. Dahiya RS, Metta G, Valle M, Sandini G. Tactile sensing — From humans to humanoids. IEEE Trans Robot. 2010; 26 (1): 1–20.
18. Schostek S, Schurr MO, Buess GF. Review on aspects of artificial tactile feedback in laparoscopic surgery. Med Eng Phys. 2009; 31 (8): 887–898.
19. Schostek S, Zimmermann M, Schurr MO, Prosst RL. Design and Performance of a Low-Cost Telemetric Laparoscopic Tactile Grasper. Surg Innov. 2016; 23 (3): 291–7.
20. Samani A, Zubovits J, Plewes D. Elastic moduli of normal and pathological human breast tissues: an inversion-technique-based investigation of 169 samples. Phys Med Biol. 2007; 52 (6): 1565–76.
21. Hoyt K, Castaneda B, Zhang M, Nigwekar P, di Sant'agnese PA, Joseph JV, et al. Tissue elasticity properties as biomarkers for prostate cancer. Cancer Biomark. 2008; 4 (4-5): 213–25.
22. Kawano S, Kojima M, Higuchi Y, Sugimoto M, Ikeda K, Sakuyama N, et al. Assessment of elasticity of colorectal cancer tissue, clinical utility, pathological and phenotypical relevance. Cancer Sci. 2015; 106 (9): 1232–9.
23. Lee JW, Lorenzo EI, Ahn B, Oh CK, Kim HJ, Han WK, et al. Palpation device for the identification of kidney and bladder cancer: a pilot study. Yonsei Med J. 2011; 52 (5): 768–72.
24. Solodova R, Staroverov V, Galatenko V, Galatenko A, Solodov E, Antonov A., et al. Automated detection of heterogeneity in medical tactile images. In: Westwood JD, Westwood SW, Fellander-Tsai L, Fidopiastis CM, Liu A, Senger S, et al, editors. Medicine Meets Virtual Reality 22. Vol. 220 of Studies in Health Technology and Informatics. Amsterdam: IOS Press. 2016; 383–389.
25. Solodova RF, Galatenko VV, Nakashidze ER, Andreytsev IL, Galatenko AV, Senchik DK, et al. Instrumental tactile diagnostics in robot-assisted surgery. Med Devices (Auckl). 2016; 9: 377–382.
26. Evans A, Armstrong S, Whelehan P, Thomson K, Rauchhaus P, Purdie C, et al. Can shear-wave elastography predict response to neoadjuvant chemotherapy in women with invasive breast cancer? Br J Cancer. 2013; 109 (11): 2798–802.
27. Fenner J, Stacer AC, Winterroth F, Johnson TD, Luker KE, Luker GD. Macroscopic stiffness of breast tumors predicts metastasis. Sci Rep. 2014; 4: 5512.