



## A comparison of transcutaneous, transrectal, and hand-assisted laparoscopic abdominal ultrasonography in standing horses

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### Abstract

**Objective:** The study was designed to compare three imaging modalities transcutaneous (TC), transrectal (TR), and hand-assisted laparoscopic ultrasonography (HALU) for evaluation of the abdominal viscera in the horse, and compared against the gold standard of actual measurements from each organ at post-mortem (PM) examination after 30 days of surgery

**Methods:** Six non-pregnant mares were examined with TC, TR, and HALU. The TC and HALU were performed with the same probe so that a more accurate resolution comparison could be made. Measurements were taken from each of the different ultrasound images.

**Results:** The measurements obtained with HALU were much closer to that obtained with the PM examination and more accurate than those obtained with TC and TR ultrasonography. The measurements obtained with TR are more accurate than those obtained with the TC. This illustrates the accuracy of HALU ultrasound compared to TC and TR ultrasonography.

**Conclusions and Clinical Relevance:** It was obvious via subjective and objective results of image analysis that HALU was far more accurate and had better resolution than TC and TR. TC and TR ultrasonography would be recommended to be used as an initial screening method to evaluate the abdominal viscera, but if more details regarding organ structure are needed, HALU should be performed without reservation.

**Keywords:** Transcutaneous, Transrectal, Hand-assisted, Laparoscopy, Ultrasonography.

### 1. Introduction

Transcutaneous abdominal ultrasonography (TC) is a minimally invasive method to evaluate the abdominal viscera. Limitations of TC include incomplete examination of the abdominal viscera and poor image resolution (Desmaizieres et al., 2003). To improve the diagnostic accuracy of multiple abdominal abnormalities, laparoscopy has been used to provide direct visualization of the equine abdomen. Laparoscopy has been used most commonly for equine urogenital surgery but others have used laparoscopy for the examination of the equine gastrointestinal tract (Dili et al., 2017; Ferguson et al., 2007; Freeman 2002; Freeman 2003; Gerlach and Ferguson, 2001; Gerlach et al., 2001). Laparoscopy provides direct visualization of the abdominal organs but can be limited by portal size and surgeon experience (Dili et al., 2017; Gerlach and Ferguson, 2001; Gottschalk and van den Berg 1997). Some of the limitations of laparoscopy can be overcome with the use of hand-assisted laparoscopic techniques. Hand-assisted laparoscopic surgery (HALS) combines laparoscopic imaging with the insertion of the hand via a small laparotomy incision to allow direct palpation of the organ of interest.

HALS has been used for nephrectomy, ovariectomy, and ovariohysterectomy in the horse (Hanson and Galuppo 1999; Janicek et al., 2004; Keoughan et al., 2003). HALS is preferred by some equine surgeons because it overcomes the limitations of laparoscopy

alone and combines it with traditional methods of abdominal exploration familiar to the surgeon (Klotter and Ruckert 1983; Liu et al., 2018; Matthews and Toal 1996). HALS can be combined with intra-abdominal ultrasonography to allow a complete examination of the abdominal viscera via manual palpation and direct placement of the ultrasound probe on the organ of interest. With direct positioning of the probe on the organ, image quality is improved and allows for complete ultrasonographic imaging of the entire organ. This cannot be accomplished with transcutaneous ultrasonography. The laparoscopic ultrasound would appear to be the most suitable as it provides the greatest number of advantages and can be used during many types of operation. Also, probably, the most cost-effective, this is an essential quality in an area of financial constraints (McGinnis et al., 2001; Palmer 1993). Intraoperative ultrasound overcomes the two-dimensional capability of laparoscopy and provides a third arm and so frequently alters the course of the operation by identifying deep parenchymatous additional hepatic tumors not seen on laparoscopic inspection. It also provides a more precise delineation of the relationship between tumors and major vascular and biliary structures (Ragle and Schneider 1995).

The study described here was designed to compare three imaging modalities for evaluation of the abdominal viscera in the horse. The three imaging modalities compared were transcutaneous (TC), transrectal

(TR), and hand-assisted laparoscopic ultrasonography (HALU). The objectives were to describe a technique for intraoperative ultrasound not previously described and emphasize the importance of HALU in equine abdominal examination and evaluate the diagnostic utility via subjective and objective data of HALU compared to TC and TR abdominal ultrasound in the examination of the equine abdominal viscera.

## 2. Materials and methods

### 2.1. Animals

Six adult non-pregnant mares ranging in age from 12-16 years old with a normal physical and rectal examination were used. Prior to abdominal ultrasonography and standing laparoscopy, horses were withheld from food, to allow for emptying of the gastrointestinal tract and to aid in the laparoscopic examination, but not water for 48 hours. Horses were restrained in metal stocks for all procedures. Horses were sedated with detomidine hydrochloride (10-20 µg/kg, IV) and butorphanol tartrate (0.01-0.03 mg/kg, IV). These dosages were repeated as needed during the surgical procedure to maintain patient comfort and cooperation. To supplement intravenous sedation and provide analgesia, epidural anesthesia was performed with a combination of morphine sulfate (60 mg), mepivacaine hydrochloride (400 mg), and sterile saline (added to bring the total volume to 25 ml). Horses were administered potassium penicillin G (22,000 IU/kg, IV), and phenylbutazone (3mg/kg, IV) immediately prior to and following the surgical procedure). All procedures were approved by the Purdue University Animal Care and use Committee. Ultrasonography of the abdominal cavity was performed in the following order: TC, TR, and HALU.

### 2.2. Transcutaneous ultrasound

Using a 4 MHz convex transducer on all aspects of the external abdominal wall (along both flanks from the lung margins cranially to the caudal extent of the paralumbar fossa, and on the ventral abdomen from the xiphoid process of the sternum to the pubis (Desmaizieres et al., 2003). Systemic ultrasonographic evaluation was performed, and the following organs and/or structures were examined and measured: stomach, duodenum, jejunum, ileum, cecum, large colon, liver, spleen, left and right kidney, and proximal ureter. All measurements were performed in centimeters and recorded on a standardized form created de novo by the authors.

### 2.3. Transrectal ultrasonography

TR was facilitated by epidural anesthesia and intravenous sedation, as previously described. Using a 7 MHz linear rectal probe was used for the examination. The following organs/structures were examined with transrectal ultrasonography: jejunum, cecum, large colon, spleen, left kidney, bladder, uterus, ovaries, and aorta. Color Flow Doppler images were performed when possible. Measurements and still images were acquired in millimeters and recorded as previously described.

### 2.4. Hand-assisted laparoscopic ultrasonography

The right and left paralumbar fossae were aseptically prepared. A grid incision was made only large enough to accommodate the surgeon's arm so that abdominal insufflation could be maintained. Once a hand was inserted into the abdomen a 1 cm skin incision was made 2-3 cm proximal to the initial incision for insertion of the laparoscopic cannula into the abdominal cavity. A 30-degree 57-cm length laparoscope was inserted into the cannula for direct visualization of the abdominal viscera. The laparoscope was connected to a xenon 6000 W light source. The cannula was then attached to a CO<sub>2</sub>

insufflator. A video camera was attached to the laparoscope and connected to a video monitor. The same probe used for transcutaneous ultrasonography was used to perform an IA ultrasound. A sterile plastic sleeve was positioned over the ultrasound probe and secured with a sterile adhesive strip to maintain close contact of the probe with the sterile acoustic coupling gel positioned between the probe and the plastic sleeve. The covered probe was then inserted into the abdominal cavity via the abdominal incision (Fig. 1). The abdomen was insufflated as needed with CO<sub>2</sub> to maintain an intra-abdominal pressure of 10-20 mm of Hg. Abdominal insufflation could be maintained despite the insertion of the arm into the abdominal cavity. Following the completion of bilateral intra-abdominal ultrasonography, the flank incisions and laparoscopic portals were surgically closed.

### 2.5. Postoperative monitoring

Following the procedures, horses were returned to their stalls and allowed to eat when they no longer appeared sedated. Horses were monitored twice daily for signs of abdominal pain. Heart and respiratory rates were monitored for the first 7 days after the surgical procedure. Flunixin meglumine was administered as 1.1 mg/kg, IV, q 12 h for 48 hours after surgery. The incision sites were monitored for signs of excessive swelling or abnormal surgical wound drainage. Skin sutures were removed in 12 days after surgery. Horses were euthanized with an overdose of barbiturates 30 days following surgery and a necropsy was performed (Keoughan et al., 2003).

### 2.6. Necropsy

At necropsy, the left and right abdominal incisions were evaluated for healing and intra-abdominal adhesion formation. The abdominal viscera were also evaluated for evidence of intra-abdominal adhesion formation. The same measurements obtained during the TC, TR, and HALU ultrasound examinations were conducted postmortem (PM) and recorded. The necropsy measurements were considered to be the "gold standard" method of accurately determining the absolute measurement for each organ/viscus evaluated.

### 2.7. Ultrasonographic analysis

All ultrasound pictures obtained from the three methods of examination (TC, TR, and HALU) were blindly evaluated by three board-certified radiologists. These radiologists were not involved in the examination (e.g., did not obtain any of the images) and were blinded to the method of examination depicted in each picture. Images were grouped according to organ/viscus and randomly organized onto a compact disc. The individual ultrasonographic images were evaluated by each radiologist and a resolution score was generated for each image and recorded on a standardized form. The resolution scoring system was developed de novo for this study by the authors. Images were scored on a 3 point scale, ranging from 1 to 3. The scoring system was developed for each organ/viscus imaged. A score of 1 was representative of good image quality, a score 2 was representative of fair image quality, and a score of 3 was representative of poor image quality.

### 2.8. Statistical analysis

Analysis of Variance (ANOVA) and Tukey's multiple comparison tests were used to compare image scores between ultrasonographic views (e.g., TC, TR, and HALU), organs, and examiners. The agreement between examiners was evaluated by calculating the Kappa coefficient. Bland-Altman plot was used to compare measurements, obtained from TC, TR, and HALU ultrasonography, to the actual post-mortem measurements. Statistical analysis was performed with a commercially available statistical program (SAS 9.2, SAS Institute Inc., Cary, NC).

### 3. Results and discussion

#### 3.1. Transcutaneous abdominal ultrasound

Gastrointestinal tract (GIT), Liver, spleen, and kidneys were examined, while urinary bladder, ureters, urethra, and reproductive tract were not visible and were not examined.

#### 3.2. Transrectal abdominal ultrasound

Transrectal evaluation of the right caudal abdomen allowed visualization of the base of the cecum, right dorsal colon, small intestine, the caudal edge of the spleen, left kidney, bladder, aorta, ovaries and uterus, and caudal vena cava. The right kidney was not accessible and could not be imaged.

#### 3.3. Hand-assisted laparoscopic ultrasound

The image quality was not adversely affected by covering the probe with a sterile plastic sleeve. It was possible to easily position the ultrasound probe against the desired abdominal organ and obtain diagnostic images. In contrast to transcutaneous ultrasonography, HALU ultrasound did not require constant repositioning of the probe to obtain diagnostic images. HALU ultrasonography was particularly useful in those organs which must be visualized between the ribs using the larger transcutaneous probes which often provide limited visual fields. The entire surface of the organ/viscus could be imaged with the intra-abdominal probe. In addition, the relatively large image field obtained through intra-abdominal imaging provided improved tissue detail and better orientation relative to the complete organ thus facilitating a complete examination (Fig. 2). Direct visualization of the ultrasound probe with the laparoscope allowed us to precisely position the probe against the organ of interest and allowed us to definitely identify viscera, such as the descending colon, which can be almost impossible to confirm with transcutaneous ultrasonography. A further advantage of HALU was the reduced effect of movement which can interfere with constant, prolonged imaging of a specific organ or tissue using TC. Using direct application of the probe head to the selected surface under direct laparoscopic vision established controlled imaging. The ability to examine organs in multiple planes under visualization increased the amount of information collected and allowed for a complete examination of the organ of interest.

#### 3.4. Surgical outcomes

No problems were encountered with the surgical procedure including epidural anesthesia and patient cooperation. The following postoperative complications were observed: edema, and incisional infection. Three horses developed mild ventral flank edema between day 2 and 4 after surgery. The edema resolved between postoperative days 5 to 8 and did not affect incisional healing. One horse developed signs of incisional infection starting on day 2 after surgery. The incisional infection was resolved with the establishment of ventral drainage, wound lavage, and antimicrobial (trimethoprim sulfamethoxazole 30 mg/kg, PO, q 12 h), and anti-inflammatory therapy (phenylbutazone 2.2 mg/kg, IV, q 12 h). The incision was healed via the second intention by day 15 postoperatively .

#### 3.5. Postmortem examination

All 12 incisions were healed with no evidence of intra-abdominal adhesion formation between the abdominal viscera and abdominal

incision. The horse with the incisional infection still had a small ventral skin defect but the peritoneal side of the incision had healed without complications. Each organ of interest was removed and measurements previously described were obtained and recorded for further analysis.

#### 3.6. Ultrasonographic evaluations

A total of 1818 readings were obtained of ten organs (kidney, liver, spleen, stomach, small intestine, large intestine, uterus, ovaries, urinary bladder, and aorta) using TC, TR, and HALU. These images were reviewed and scored by three diplomates of the American College of Veterinary Radiology (Examiner 1, Examiner 2, and Examiner 3). The overall score for all methods ranged from 1-3 (1= good, 2= fair, and 3= poor), with mean + standard deviation of 1.94 + 0.66 and median score of 2.00. Kappa agreement between examiners: Moderate agreement between examiners was determined. This indicated that there was more than the expected amount of agreement between examiners was observed. Agreement ranged from 43.89% to 51.82% between the three different radiologists. Results indicate that HALU images had a significantly improved resolution score when compared to TR and TC abdominal ultrasonography

#### 3.7. Measurements

For the 6 horses a total of 725 measurements were obtained using four techniques (138 TC, 150 TR, 215 HALU, and 222 PM). In summary, statistical analysis of the measurements obtained with the four different methods (TC, TR, HALU, and PM) revealed that the measurements obtained with HALU were much closer to that obtained with the PM examination and more accurate than those obtained with TC and TR ultrasonography. The measurements obtained with TR are much closer to that obtained with the PM examination and more accurate than those obtained with the TC. This illustrates the accuracy of HALU ultrasound compared to TC and TR ultrasonography.

### 4. Discussion

Transcutaneous ultrasonography (TC) is considered to be the best method to provide a minimally invasive image of the equine abdomen. However, the limitations of TC include poor image quality and incomplete evaluation of the organ of interest (Ragle et al., 1996). An improved method of equine abdominal imaging could improve the diagnosis of many disorders within the equine abdomen. The primary objective of this project was to determine whether or not hand-assisted laparoscopy ultrasonography (HALU) could overcome the limitations associated with TC., via subjective and objective image analysis.

To ensure an accurate evaluation of the ultrasound images, we would recommend that a team approach be used between the surgeon and radiologist. HALU allowed for a relatively large image field and provided improved tissue details and better orientation. It also reduced the effect of movement which normally interferes with constant and prolonged imaging of a specific organ or tissue using the transcutaneous method. Direct application of the probe head to the selected surface under direct visualization with laparoscopy established controlled imaging and improved the ability to examine organs in multiple planes under visualization. Similar findings have been reported in the horse (McGinnis et al., 2001; Palmer 2003). Moreover, the

positive attributes of HALU increase the amount of information collected during an intra-abdominal ultrasound, which is not feasible with transcutaneous or transrectal technique alone. The same result was obtained in dogs, particularly advantageous is the simultaneous comparison between surface information provided by laparoscopy and the

sonographic structural examination of the parenchyma. Intra-abdominal ultrasonography generally provides useful information for intra-surgical maneuvers where more than surface examination and manual palpation can provide (Rahusen et al., 1999; Rantanen 1986).

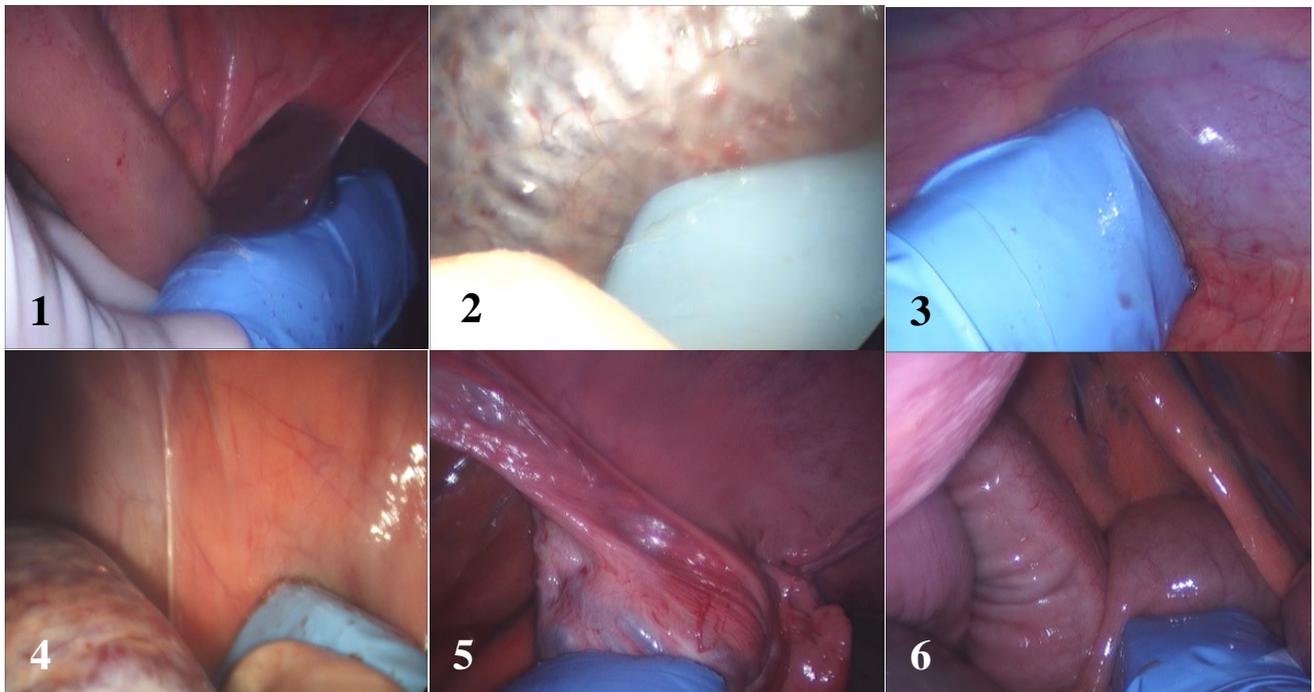


Figure 1. Intra-abdominal 4 MHz convex transducer covered with a sterile plastic sleeve, scanning 1: liver, 2: spleen, 3: kidney, 4: stomach, 5: ovary & 6: Jejunum.

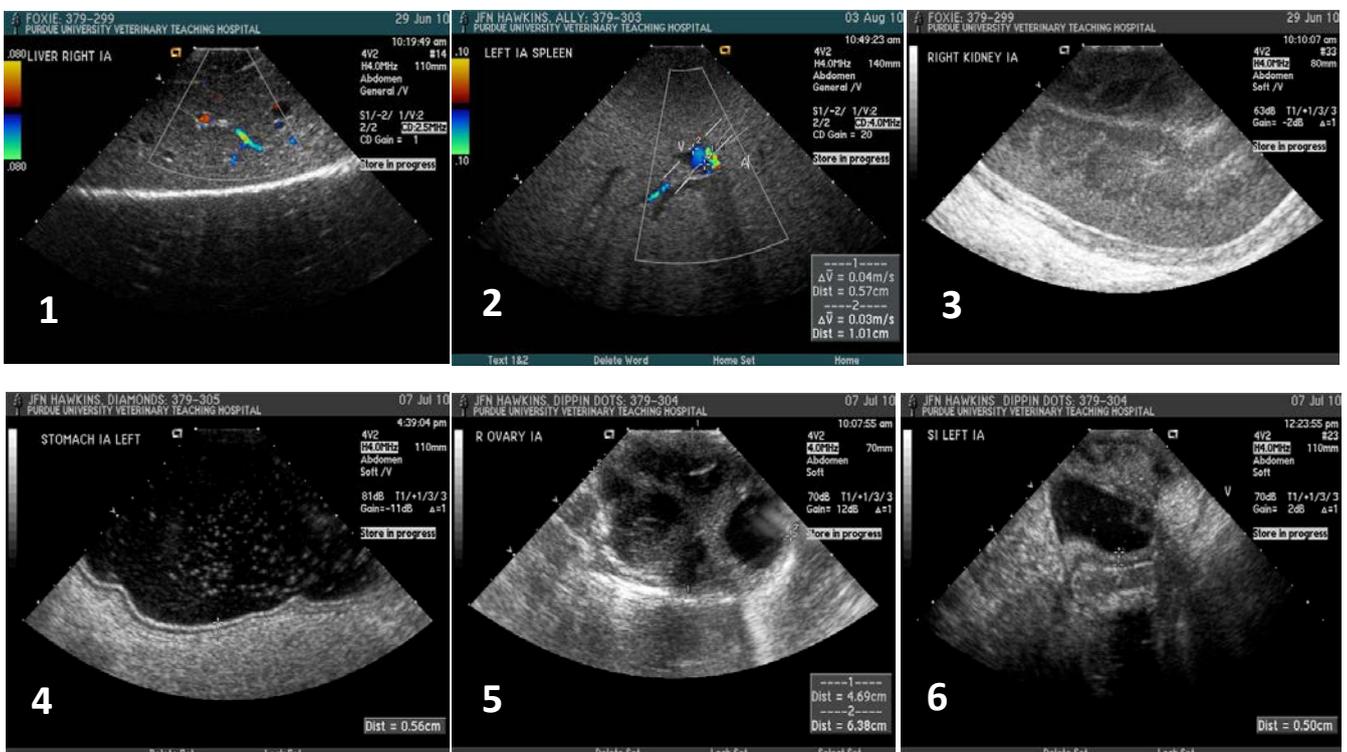


Figure 2. HALU Doppler ultrasonographic pictures of the liver (1), Spleen (2), right kidney (3), stomach (4), Ovary (5) & jejunum (6) using a 4 MHz convex transducer covered with a sterile plastic sleeve.

This study documented the superiority of HALU over TC ultrasonography by determining that resolution scoring was statistically significant for HALU compared to TC and that measurement accuracy revealed that HALU was significantly better than TC. HALU allowed for a complete examination of the entire organ/viscus where TC does not. This was particularly apparent for imaging of the cranial abdominal organs particularly the liver, stomach, and both kidneys. Finally, HALU allows for simultaneous comparison between the surface information provided by laparoscopy and the structural examination of the parenchyma provided by direct application of the ultrasound probe on the organ/viscus of interest. Even though the same ultrasound probe with the frequency of (4 MHz) was used for TC and HALU the image quality obtained with HALU was significantly better than TC. This is not unexpected as the ultrasound probe is positioned directly on the organ/viscus during HALU while the probe is often positioned far away from the organ during TC ultrasonography. Our image resolution could have been improved even more if a higher frequency probe (> 4MHz) was used for HALU. We would certainly recommend that a higher resolution probe (7-10 MHz) be used if this technique was being used for clinical cases.

The question arises, which technique would be preferred when evaluating the pathology of the equine abdomen? This study would recommend that TC be used as an initial screening method to evaluate the abdominal viscera but if more detail regarding organ structure is needed HALU should be performed without reservation. The morbidity associated with HALU was low and excellent diagnostic images were obtained. The better image resolution and accuracy associated with HALU could make a substantial impact on the decision making regarding the diagnosis and treatment of pathology within the equine

## 5. Conclusion

The results of this study using the hand-assisted laparoscopic ultrasonography for the examination of the equine abdominal structures proved that the hand-assisted laparoscopic ultrasonography is significantly better than transrectal and transcutaneous ultrasonography in equine abdominal examination and suggest a potential for the use of this method for diagnosis and therapy in equine medicine and surgery. With increased experience and an open attitude towards the incorporation of HALU in decision making of disorders of the equine abdomen advances paralleling those in human medicine can be expected.

### Conflict of interest statement

The authors declare no conflict of interest in the current research work

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