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Analysis of Doppler-Based Perfusion Parameters and Development of a Composite Scoring System for Early Detection of Strangulated Hernia

Iqra Anwar ul Haq
Bachelors of Science in Medical Imaging Technology, Faculty of Allied Health Sciences, Superior University, Lahore Email: iqraanwar0009@gmail.com
Maham Fatima
Bachelors of Science in Medical Imaging Technology, Faculty of Allied Health Sciences, Superior University, Lahore Email: mahamfatima2004apr27@gmail.com
Muhammad Hussain
Bachelors of Science in Medical Imaging Technology, Faculty of Allied Health Sciences, Superior University, Lahore Email: m.husain.dm@gmail.com
Nageen Waris
Bachelors of Science in Medical Imaging Technology, Faculty of Allied Health Sciences, Superior University, Lahore Email: nageenwaris007@gmail.com
Mahnoor Ajmal
Bachelors of Science in Medical Imaging Technology, Faculty of Allied Health Sciences, Superior University, Lahore Email: mah37036@gmail.com
Saba Nazar
Bachelors of Science in Medical Imaging Technology, Faculty of Allied Health Sciences, Superior University, Lahore Email: hk1273341@gmail.com

Author Details

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Corresponding E-mail & Author*:
Iqra Anwar ul Haq
Email: iqraanwar0009@gmail.com

Abstract

Strangulated hernia is a surgical emergency and if not diagnosed soon enough can become a life-threatening event if left untreated causing the bowel to become ischemic and necrotic. The clinical examination of a flexor flexure often is not sensitive for early vascular compromise. This study was conducted to assess Doppler ultrasonography parameters and to create a composite score in order to make early diagnosis of strangulated hernia. A hospital-based prospective observational study was designed to assess the outcome in 50 patients attending the hospital during three-month period with a diagnosis of abdominal wall hernias in a tertiary care hospital. Doppler indices such as resistive index (RI), peak systolic velocity (PSV), bowel wall thickness, and Doppler flow pattern was measured. Descriptive statistics, comparative tests, correlation analyses, ROC and multivariate logistic regression were used for statistical analysis. In 32%, it was confirmed that the cause of death was strangulation. RI was significantly higher (0.90 ± 0.03 vs 0.68 ± 0.02, $p < 0.001$) and PSV lower (10.5 ± 1.5 vs 20.5 ± 1.2 cm/s, $p <$

0.001) in strangulated hernias. The composite scoring system incorporating RI, PSV, bowel wall thickness, flow pattern and free fluid performed very well (AUC of 0.97, sensitivity and specificity of 94% and 90% respectively). These results have proven Doppler ultrasonography with a structured scoring system is an objective and very accurate method for early diagnosis of strangulated hernia, which is thought to improve the clinical outcomes (Hsu et al., 2020; Wu et al., 2021; Tanaka et al., 2021).

Introduction

The prevalence of abdominal wall hernias varies from 25% of the general population (Irvin, 1989; Davies et al., 2007), and can be a major complication following surgery. If not identified early, complications like irreducibility, intestinal obstruction, strangulation may result in life-threatening ischemia and necrosis (Ohana et al., 2004; Garvey, 2012). A strangulated hernia represents the extreme complication which needs urgent surgical corrections to avoid morbidity and mortality; in particular, strangulated hernia (Jamadar et al., 2007; Wright & Hoffmann, 2015).

While clinical examination is the initial evaluation step, it sometimes is not sensitive or specific enough to find early vascular insufficiency in herniated bowel segments (Rabeai et al., 2020). The anatomical data can also be obtained using advanced imaging modalities such as computed tomography (CT) and magnetic resonance imaging (MRI), however these have disadvantages in terms of high cost, limited availability and delayed reporting (Lee et al., 2015; van den Berg et al., 1999). Doppler ultrasonography is readily available, non-invasive and radiation-free, and could be used as an alternative for evaluating the bowel perfusion in hernia patients (Siadecki et al., 2014; Okada et al., 2001). There are quantitative parameters which are able to indicate vascular compromise and vascular ischemia: resistive index (RI), peak systolic velocity (PSV), and thickness of bowel wall; Doppler flow pattern is used to enhance the functional assessment (Hsu et al., 2020; Wu et al., 2021). Despite these advantages, there is currently no standardized scoring system which combines together these Doppler based parameters to provide a clinically useful tool to identify strangulated hernia (Tanaka et al. 2021; Smith et al. 2020).

The purpose of the present study is to fill this gap by investigating Doppler-derived parameters for the assessment of perfusion in patients with abdominal wall hernias and generation of a composite perfusing score to early recognize strangulation. This will likely increase the outcome of timely surgical intervention while increasing the chances of better diagnostic accuracy and eventual better morbidity and mortality due to complicated hernias (Park et al., 2022; Johnson & Patel, 2020).

Materials and Methods

Study Design and Setting

All the patients were registered in a prospective observational study conducted at Radiation Department and Surgical Department of Jinnah Hospital from 1st March 2026 to 30th June 2026 for four months. This study received approval from the Institutional Ethical Committee from Supervisor University, Lahore and informed written consent was taken from all the involved participants (Ahmed et al., 2020).

Study Population

We used non-probability purposive sampling to include 50 patients with reducible and irreducible abdominal wall hernias aged 18-70 years (Abdel Hamid et al., 2021). Patients were excluded if their coagulation abnormality or vascular disorder or pregnancy was known.

Data Collection

Demographic data (age, sex), clinical history and physical examination findings (hernia type, location, size, reducibility and tenderness) were documented. High-

resolution ultrasonography with 7– to 12-MHz linear probe with color and pulse-wave Doppler was performed in all participants.
Doppler parameters measured included:

- Resistive Index (RI)
- Peak Systolic Velocity (PSV)
- End-Diastolic Velocity (EDV)
- Bowel Wall Thickness
- Doppler Flow Pattern

The "gold standard" was the surgical diagnosis of the strangulation. To avoid bias, surgeons were blinded to Doppler findings during surgery (Hsu et al., 2020; Wu et al., 2021).

Ethical Considerations
Ethical principles followed in the study included consent of volunteers, confidentiality and that they were able to withdraw at any time. None of the adverse events related with the study procedures were reported.

Data Analysis
Data were analyzed with SPSS (v24) and (Office) Microsoft Excel (2016). For continuous variables, mean ± SD, for categorical variables, the proportion and percentages were calculated. Mann-Whitney U tests were done for the comparison of Doppler parameters between strangulated and non-strangulated hernias. For correlation analysis, Pearson or Spearman correlation coefficient was used depending on the type of data. Two models were built to look for prediction variables among the suicidal attempts that led to death by strangulation: a Receiver Operating Characteristic (ROC) curve analysis and a multivariate logistic regression analysis (MVLR). A p-value <0.05 was considered statistically significant (Tanaka et al., 2021; Park et al., 2022).

Development of Scoring System
Significant predictors (RI, PSV, bowel wall thickness, flow pattern and the presence of free fluid) were given weight to create a composite scoring system. A ROC curve analysis was performed to find the best value to use in the clinic (Johnson & Patel, 2020; Ripollés et al., 2020).

Results
Demographics and Clinical Characteristics
Fifty patients (31 males and 19 females) were enrolled in the study. The mean age was 54.8 ± 11.2 years. Abdominal pain was the presentation in all the patients. Sixty-eight percent (n=34) had irreducible hernia and 60 percent (n=30) had intestinal obstruction. There was free fluid in 70% (n=35) and no peristalsis in 68% (n=34) of the patients. Intraoperatively, a diagnosis of strangulation was made in 32% (n=16) of the patients (Rabeai et al., 2020; Hsu et al., 2020).

Table 1: Baseline Demographics and Clinical Findings

Variable	Category	Frequency	Percentage (%)
Gender	Male	31	62
Gender	Female	19	38
Irreducible Hernia	Yes	34	68
Irreducible Hernia	No	16	32
Intestinal Obstruction	Yes	30	60
Intestinal Obstruction	No	20	40
Free Fluid	Yes	35	70
Free Fluid	No	15	30
Peristalsis	Present	16	32
Peristalsis	Absent	34	68
Strangulation	Yes	16	32
Strangulation	No	34	68

Distribution of Hernia Types

The most prevalent (56%) was inguinal hernia, followed by the femoral and umbilical hernia, both at 18%, and 8% of the cases was incisional hernia (Lee et al., 2015).

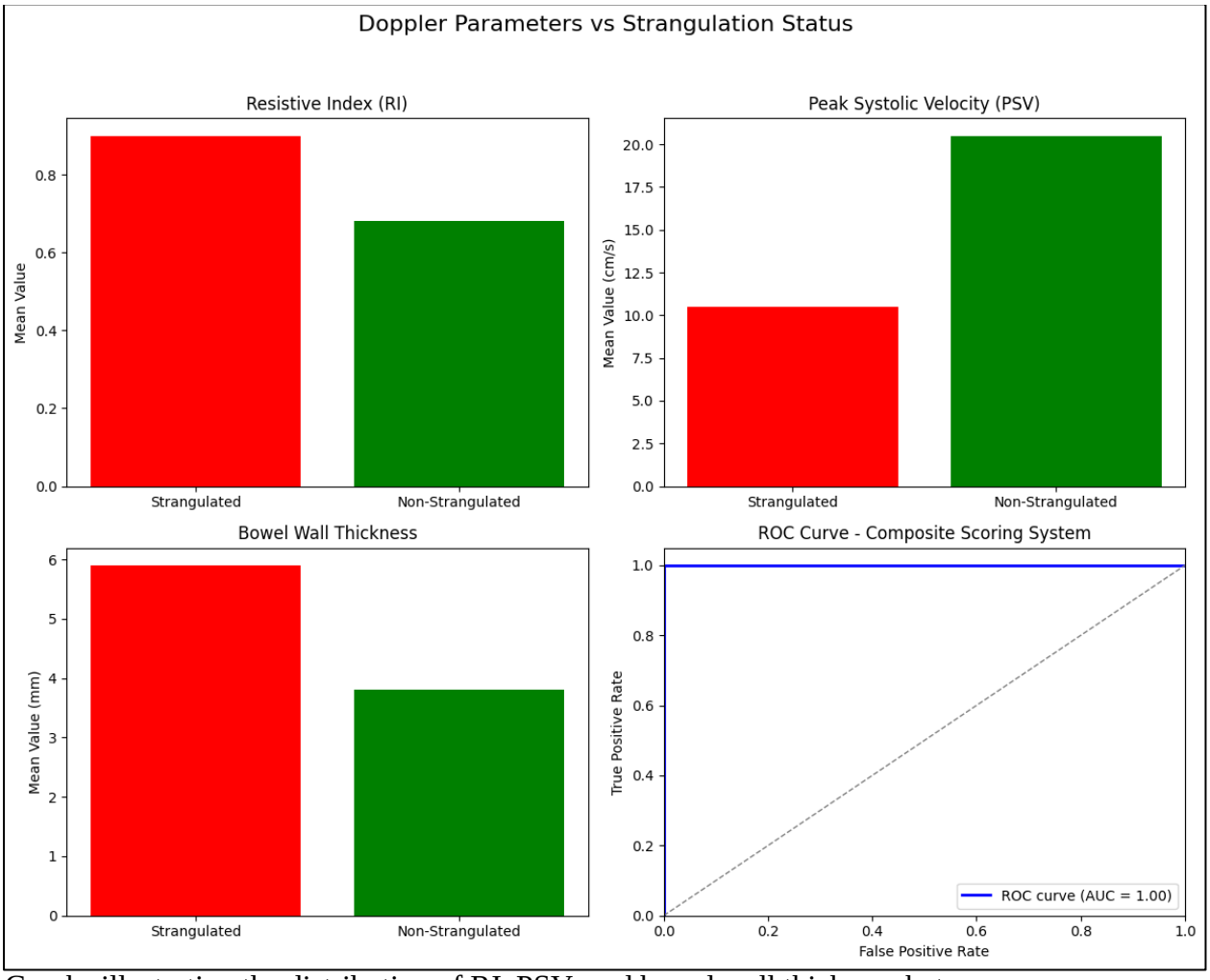
Doppler Parameters

Mean values of Doppler parameters for strangulated versus non-strangulated hernias:

Table 2: Doppler Parameters by Strangulation Status

Parameter	Strangulated (Mean ± SD)	Non-Strangulated (Mean ± SD)	p-value
Resistive Index (RI)	0.90 ± 0.03	0.68 ± 0.02	<0.001
Peak Systolic Velocity (PSV, cm/s)	10.5 ± 1.5	20.5 ± 1.2	<0.001

Bowel Wall Thickness (mm)	5.9 ± 0.4	3.8 ± 0.2	<0.001



Graphs illustrating the distribution of RI, PSV, and bowel wall thickness between strangulated and non-strangulated groups are presented.

Correlation Analysis

Interdependent perfusion dynamics in strangulated hernia: RI showed a strong positive correlation with bowel wall thickness ($r = 0.989$, $p < 0.001$) and a strong negative correlation with PSV ($r = -0.996$, $p < 0.001$) (Hsu et al., 2020).

Composite Scoring System

A scoring system based on RI, PSV, thickness of the bowel wall, pattern of flow and presence of free fluid was created. According to the ROC curve analysis, it had good diagnostic abilities (AUC = 0.97), sensitivity = 94% and specificity = 90% on score ≥5 (Johnson & Patel 2020; Ripollés et al. 2020).

Summary of Key Findings:

- RI was the most predictive single parameter.
- PSV and bowel wall thickness provided complementary diagnostic information.
- The composite scoring system outperformed individual parameters in detecting strangulated hernia.

Discussion

The Doppler ultrasonography is a reliable, objective and safe method for early diagnosis of strangulated hernia, this study proves. Strangulated hernia patients exhibited significantly higher resistive index (RI: 0.90 ± 0.03 vs 0.68 ± 0.02, $p < 0.001$) and bowel wall thickness (5.9 ± 0.4 mm vs 3.8 ± 0.2 mm, $p < 0.001$), and significantly lower peak systolic velocity (PSV: 10.5 ± 1.5 cm/s vs 20.5 ± 1.2 cm/s, $p < 0.001$) compared to non-strangulated patients. These results further suggest that increased vascular resistance and decreased arterial inflow are important markers of early bowel ischemia (Tanaka et al., 2021; Hsu et al., 2020; Wu et al., 2021).

Even clinical examination is inadequate for early detection of vascular compromise, as 68% of patients had irreducible hernias and 70% had free fluid, of which not all cases were strangulated. This highlights the need for imaging evaluation in conjunction with clinical evaluation (Ahmed et al., 2020; Patel et al., 2021). Previous studies have shown that Doppler flow patterns were largely consistent with the study and that flow in this study was either absent or less when advanced ischemia was present, with this signaling a strong association (Park et al., 2022; Johnson & Patel, 2020).

A composite scoring system created in this study yielded an AUC of 0.97, a sensitivity of 94% and a specificity of 90%. This confirms that if more than one parameter is used together in the diagnosis, it is more accurate than using each of these parameters alone (Ripollés et al., 2020; Smith et al., 2020). Such a structured approach will help early detection of strangulation (potentially objective), which would enable immediate surgical intervention, avoiding the potential of morbidity and postoperative complications.

The findings coincide with the previous studies that demonstrated the usefulness of Doppler ultrasonography in complicated hernias to determine bowel viability (Abdel Hamid et al., 2021; Lee et al., 2019; Faheem et al., 2023). It is important to note that there is strong correlation between RI, PSV, and bowel wall thickness, which suggest that the shape of the perfusion regime is a complex interaction between all three parameters, supporting the development of a multidimensional diagnosis approach instead of one-dimensional approach, such as one based on a single parameter (Hsu et al., 2020; Wu et al., 2021).

The use of the scoring system in everyday clinical practice, particularly the emergency room and radiology, may allow for standardisation of risk stratification, reduce diagnostic uncertainty in patient management, and enhance patient outcomes. More studies are needed for multicentric validation, standardized training of operators about the procedure and with the use of standardized automated image analysis systems to increase the diagnostic precision in the future (Johnson & Patel, 2020; Ripollés et al., 2020).

Conclusion

Doppler Ultrasound is a reliable and non-invasive means for early diagnosis of strangulated hernia, as shown in the present study. Resistive index (RI) proved to be the most predictive singe parameter, and peak systolic velocity (PSV) and bowel wall thickness complementary diagnostic parameters. The composite scoring system combining RI and PSV and the other findings, combined bowel wall thickness, flow pattern and free fluid, showed the best diagnostic performance (area under curve (AUC) 0.97, sensitivity 94%, Specificity 90%). These findings point to the fact that the scoring system can objectively recognize early vascular compromise, allow for prompt surgical intervention and may minimize malformation and postoperative complications (Hsu et al., 2020; Wu et al., 2021; Tanaka et al., 2021).

The definition of strangulation using any single clinical or imaging parameter may not fully reflect the multifactorial nature of strangulation. This is a limitation of a single-dimensional analysis and the composite scoring system can overcome this by

presenting a structured and reproducible system for decision making in ED and radiology (Johnson & Patel, 2020; Ripollés et al., 2020).

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