Author's Accepted Manuscript

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PII: S0022-5347(17)45410-3
DOI: 10.1016/j.juro.2017.03.134
Reference: JURO 14667

To appear in: *The Journal of Urology*
Accepted Date: 30 March 2017

Please cite this article as: Schlomer BJ, Keays MA, Grimsby GM, Granberg CF, DaJusta DG, Menon VS, Ostrov L, Sheth KR, Hill M, Sanchez EJ, Harrison CB, Jacobs MA, Huang R, Burgu B, Hennes H, Baker LA, Trans-scrotal Near Infrared Spectroscopy as a Diagnostic Test for Testis Torsion in Pediatric Acute Scrotum: A Prospective Comparison to Gold Standard Diagnostic Test Study, *The Journal of Urology*® (2017), doi: 10.1016/j.juro.2017.03.134.

Trans-scrotal Near Infrared Spectroscopy as a Diagnostic Test for Testis Torsion in Pediatric Acute Scrotum: A Prospective Comparison to Gold Standard Diagnostic Test Study

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Funding Source: Research reported in this publication was supported by the National Institutes of Diabetes and Digestive and Kidney Diseases of the National Institutes of Health under Award Number R21DK092654 (PI: Linda Baker, MD). The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

Clinical Trial Registration:

Registry name: Near-infrared Spectroscopy for Pediatric Acute Scrotum and Testicular Torsion; Registration number: NCT01812109;
https://clinicaltrials.gov/ct2/show/NCT01812109?term=NCT01812109&rank=1

Abstract

Purpose

A rapid test for testicular torsion in children may obviate delay for testicular ultrasound. This study assessed testicular tissue percent saturation of oxygen (%StO2) measured by trans-scrotal near-infrared spectroscopy (NIRS) as a diagnostic test for pediatric testicular torsion.

Methods and Findings

This was a prospective comparison to a gold standard diagnostic test study that evaluated NIRS %StO2 readings to diagnose testicular torsion. Gold standard for torsion diagnosis was standard clinical care. From 2013-2015 males with acute scrotum > 1 month and < 18 years old were recruited. NIRS %StO2 readings were obtained for affected and unaffected testes. NIRS Δ%StO2 was calculated as unaffected minus affected reading. Utility of NIRS Δ%StO2 to diagnose testis torsion was described with receiver operating characteristic curves.

Results

Of 154 eligible patients, 121 had NIRS readings. Median NIRS Δ%StO2 in 36 with torsion was 2.0 (IQR -4.2 to 9.8) compared to -1.7 (IQR -8.7 to 2.0) in 85 without torsion (p=0.004). Area under curve (AUC) for NIRS as diagnostic test was 0.66 (95% CI 0.55 to 0.78). NIRS Δ%StO2 ≥ 20 had a positive predictive value of 100% and sensitivity of 22.2%. Tanner stage 3-5 patients without scrotal edema or with pain duration ≤ 12 hours had an AUC of 0.91 (95% CI 0.86-1.0) and 0.80 (95% CI 0.62-0.99) respectively.

Conclusions

In all children, NIRS readings had limited utility to diagnose torsion. However, in Tanner 3-5 patients without scrotal edema or with pain duration ≤ 12 hours, NIRS discriminated well between torsion and non-torsion.

Clinical Trial Registration

Registry name: Near-infrared Spectroscopy for Pediatric Acute Scrotum and Testicular Torsion; Registration number: NCT01812109; https://clinicaltrials.gov/ct2/show/NCT01812109?term=NCT01812109&rank=1

Introduction

Testis torsion is the spontaneous twisting of the testis and spermatic cord which contains the blood supply to the testis. Torsion occurs in 1 in 4000 males younger than 25 and is primarily seen in newborns or 10-25 years of age.[1, 2] Testis torsion is the most common diagnosis in a pubertal patient with acute scrotal pain.[3] Other presenting symptoms and findings include nausea, vomiting, high riding testis, hard testis, absent cremasteric reflex, and red scrotal skin changes.[4, 5] Risk of testis loss or atrophy is significant 4-8 hours after pain onset.[6, 7] Using national datasets, around 30% of torsed testes are removed at surgery signifying delayed care.[1, 8] Testis torsion is a common diagnoses for litigation in children age 12-17 with delayed diagnosis a typical area for liability.[9, 10]

Preventing testis loss from torsion requires prompt presentation, diagnosis and surgery. A diagnosis of testis torsion can often be made by history and physical exam but diagnosis and care can be delayed due to atypical history or physical exam, ultrasound testing, inter-hospital transfer, or inexperience of emergency room providers.[11]

There have been studies on decreasing the time to diagnosis and surgery for torsion. Uniform surgical exploration in cases of acute scrotal pain without scrotal ultrasound led to negative exploration rates up to 49%.[2] A score based on presenting signs and symptoms (TWIST score) has been reported to improve diagnosis of testis torsion and could decrease routine use of scrotal ultrasound.[12, 13] Use of pulse oximetry on scrotum has been reported to diagnose torsion in a small study, but was limited by absence of a non-torsion control group.[14] A test that is rapid, accurate, non-invasive, able to be used by emergency room providers as extension of physical exam, and removes delay for scrotal ultrasound would be ideal for diagnosis of testis torsion.

Near Infrared Spectroscopy (NIRS) uses infrared light to obtain continuous, transcutaneous monitoring of tissue oxygen saturation (%StO2).[15, 16] In contrast to pulse oximetry which requires a strong systolic capillary pressure, NIRS remains useful in low pressure and low flow states in children to monitor cerebral blood flow and oxygenation during cardiac surgery[17], to monitor cerebral blood flow in newborns[18], and to assess skeletal muscle oxygenation in compartment syndrome.[19] Three animal models studies and one in young adults have reported on NIRS for diagnosis of testis torsion with promising results.[20-23] One small human study comparing 17 non-torsion and 5 torsion in young adults reported that NIRS was not effective in the diagnosis of testis torsion.[24]

This study investigated the utility of trans-scrotal NIRS measurements in the ED as a diagnostic test for testis torsion in children presenting with acute scrotum. Our hypothesis was trans-scrotal NIRS %StO2 measurements in a torsed testis would be lower than the NIRS %StO2 measurements in the contralateral non-torsed testis and clinically useful values could be identified to diagnose and rule out testis torsion. The utility of NIRS as a diagnostic test for testis torsion was described using receiver operating characteristic (ROC) curves.

Methods

After approval by institutional review board, enrollment in this single center, NIH prospective trial began March 19, 2013 and ended March 25, 2015. Males 1 month of age to 18 years from who presented to Children's Medical Center ED in Dallas, TX with acute scrotum were recruited. Acute scrotum was defined as painful scrotum or testis with or without abdominal pain and/or waddling gait from painful scrotum. Patients with bilateral torsion or previously known testicular or scrotal pathology, chronic respiratory, hematological or vascular problems that could affect total body tissue oxygenation levels were excluded. Informed consent was obtained from guardians on behalf of participants and assent obtained from participants > 10 years old.

Potential subjects were approached by emergency medical technician (EMT) personnel and screened for inclusion. Patients had standard of care treatment. Scrotal ultrasound and surgical exploration results were used as the gold standard for diagnosis of testicular torsion. Measurements obtained on ultrasound included testis size, distance from skin to testis (which encompassed scrotal wall edema and any hydrocele), and presence /absence of blood flow.

Near Infrared Spectroscopy

NIRS measurements were obtained with Hutchison Technology InSpectra^{TM} StO2 Spot Check Device (Model 300, Hutchison Technology, Inc., Hutchison, MN, USA) with thenar clip probe (Model 1315, modified by clip removal). Equipment cost was $5000/unit. The probe was placed anteriorly over each testis. Measurements were done at 1, 5, and 10 seconds to account for inter-assay variability which is expected to be < 3 %StO2. The average of the 3 readings was defined as NIRS %StO2 reading for that testis. The NIRS readings in affected testis were

normalized to the contralateral normal testis to formulate a NIRS Δ%StO2 (%StO2 of unaffected testis - %StO2 of affected testis).[20] If the affected testis had lower %StO2 readings than the contralateral normal testis, NIRS Δ%StO2 would be positive.

Statistical analysis

Data were collected using a REDCap database (CTSA NIH Grant UL1TR001105). According to Obuchowski's method[25, 26], a sample size of 150 patients with acute scrotum would be required to show the sensitivity of NIRS readings to diagnose torsion is significantly higher than 0.8 with 80% power and 2-sided type 1 error of 0.05. Receiver operating characteristic (ROC) curves were used to analyze performance of NIRS Δ%StO2 readings as a diagnostic test for torsion. Potential clinically useful cut-off values were assessed using ROC curve analysis. NIRS Δ%StO2 values were compared by Wilcoxan rank-sum. Area under the curve (AUC) between different ROC curves were compared by method of DeLong.[27] Statistical analysis was performed with Stata 12 (College Station, TX).

Results

There were 316 patients assessed and 154 enrolled (Figure 1). Of the 154 enrolled patients, 16 patients were excluded because they did not have NIRS readings attempted due to research personnel delays. In the remaining 138 patients, NIRS readings were attempted and obtained in both testes in 121. Thus, 121 patients were included in analysis of which 36 (29.8%) were diagnosed with torsion. Table 1 shows the demographics of patients included in analysis. Patients with torsion were older, had higher Tanner stages, and had lower median duration of pain prior to arrival (Table 1). Median NIRS Δ%StO2 was -1.7 (range -31 to +15.3, interquartile range (IQR) -8.7 to +2.0) in those without torsion and 2.0 (range -19.0 to +56.0, IQR -4.2 to +9.8) in those with torsion signifying that overall patients with torsion had lower %StO2 readings in the affected testis (p=0.004).

ROC curve analysis

To evaluate performance of NIRS Δ%StO2 readings as a diagnostic test for testicular torsion for all patients, a ROC curve analysis was performed (Figure 2). The AUC was 0.66 (95% CI 0.55-0.78). A cut-off value of Δ%StO2 ≥ 20 had a PPV of 100% and sensitivity of 22.2% to diagnose torsion (Figure 2).

Effect of Tanner Stage

Tanner stage was recorded in 118/121 patients. The effect of Tanner stage on NIRS readings was investigated by ROC curve analysis for the 68 Tanner 1-2 versus the 50 Tanner 3-5 patients (Figure 3). In the Tanner 3-5 group, 26/50 patients had torsion with AUC = 0.64 (95% CI 0.48-0.80). A Δ%StO2 ≥ 10 cutoff was associated with a 100% PPV and 27.8% sensitivity for diagnosing torsion in Tanner 3-5. For the Tanner 1-2 group, 9/68 patients had torsion with

AUC = 0.61 (95% CI 0.38-0.84). The AUC for Tanner 3-5 vs 1-2 patients was not significantly different (p=0.8).

Effect of Scrotal Edema

Due to concerns that scrotal edema affected NIRS Δ%StO2 readings, an analysis was performed comparing patients who did and did not have scrotal edema on exam (Figure 3). Of the 121 patients included in analysis, 118 had presence (52) or absence (66) of scrotal edema recorded. There was no statistically significant (p=0.8) difference between the AUC in those without scrotal edema (AUC 0.75 95%CI 0.50-1.0) versus those with scrotal edema (AUC 0.72 95%CI 0.58-0.86).

In Tanner stage 3-5 patients, NIRS Δ%StO2 discriminated between torsion and non-torsion better (p=0.08) in those without edema with AUC of 0.91 (95% CI 0.86-1.0) (Figure 4). In this subgroup, the NIRS Δ%StO2 values in the 4 with torsion (median 8.8, IQR 5.0 to 17.0) were higher than the 20 without torsion (median -0.5, IQR -2.3 to 3.2) (p=0.01). NIRS Δ%StO2 values ≥ 10 had a PPV of 100% and sensitivity of 50% to diagnose torsion and NIRS Δ%StO2 <2.5 had a NPV of 100% and specificity of 70.0% to rule out torsion.

Effect of Duration of Pain

To evaluate the impact of duration of pain on NIRS testing, analysis was performed comparing patients who had pain ≤ 12 hours (n=42) and those with pain > 12 hours (n=79) (Figure 3). NIRS Δ%StO2 discriminated between torsion and non-torsion better in those with duration of pain ≤ 12 hours (AUC 0.76; 95% CI 0.60-0.92) compared to those with duration of pain > 12 (AUC 0.56; 95% CI 0.42-0.70) with p=0.07.

In Tanner 3-5, Δ%StO2 discriminated between torsion and non-torsion better (p=0.007) in those with pain ≤ 12 hrs with AUC of 0.80 (95% CI 0.62-0.99). In this subgroup, NIRS Δ%StO2 values in 15 with torsion (median 8.7, IQR 5.3 to 24.0) were higher than in 10 without torsion (median 0.8, IQR -2 to 4.7) (p=0.01). NIRS Δ%StO2 values ≥ 20 had a PPV of 100% and sensitivity of 46.7% to diagnose torsion and NIRS Δ%StO2 values < 0 had a NPV of 80.0% and specificity of 40.0% to rule out torsion (Figure 4).

Testis Measurements

Testis measurements by scrotal ultrasound were available in 107/121 patients. The mean affected testis length increased from 2.2 cm (SD 0.7) in Tanner 1-2 to 4.0 cm (SD 0.6) in Tanner 3-5. Affected testis width and height were 1.4 cm (SD 0.4) and 1.6 cm (SD 0.6) respectively in Tanner 1-2 and 2.5 cm (SD 0.6) and 2.4 cm (SD 0.5) respectively in Tanner 3-5. The mean skin to testis distance in affected testis was 0.4 cm (minimum 0.2 cm, maximum 1.5 cm) and those with scrotal edema had higher values (0.6 vs 0.3 cm, p <0.001).

Discussion

In this study we hypothesized NIRS Δ%StO2 readings in pediatric patients with torsion would be higher than in pediatric patients without torsion. In addition, we hypothesized that NIRS Δ%StO2 values could be identified by ROC curve analysis that could diagnose and rule out torsion in pediatric patients. NIRS Δ%StO2 readings were significantly higher in those with torsion compared to those without torsion (p=0.004), however there was significant overlap between the groups which limited any diagnostic utility. For the entire cohort, NIRS Δ%StO2 values ≥ 20 had a PPV value of 100% to diagnose torsion and was the only clinically useful cut-off value with a sensitivity of only 22.2%. In subgroup analysis, NIRS Δ%StO2 appeared to perform best in Tanner 3-5 patients without scrotal edema or with duration of pain ≤ 12 hours. NIRS Δ%StO2 discriminated well between torsion and non-torsion in these subgroups with AUC of 0.91 and 0.80 respectively and the distribution of NIRS Δ%StO2 values had less overlap. NIRS did not discriminate well in Tanner stage 1-2 patients.

NIRS was reported to diagnose torsion accurately in adult patients in a pilot study.[20] In that study of 16 adult patients, those with NIRS Δ%StO2 ≥ 11.5 had testis torsion while those with NIRS Δ%StO2 < 11.5 did not have torsion.[20] In our study, NIRS as a diagnostic test for torsion did not perform well in pre-pubertal children. This may be related to small testis size as the NIRS device measures a specific width and depth of tissue. The NIRS device used in this study has a distance between emitter and detector points of 15 mm which leads to a mean tissue depth measured of 7.5 mm and maximum length measured of 15 mm (Figure 5).[28] These distances are too large for pre-pubertal testes which would lead to surrounding tissue being measured by the NIRS device. Pre-pubertal children often present later with more scrotal edema which also may affect NIRS readings. Based on our testis measurements, in future NIRS studies

a longer distance than 15mm between emitter and detector may improve performance in Tanner 3-5 patients and a shorter distance may improve performance in Tanner 1-2 patients.

Torsion has a bimodal age distribution with first peak in the neonatal period and second peak around puberty.[29] While postpubertal children usually present with severe testicular pain, identifying typical torsion symptoms to diagnose torsion is challenging in prepubescent children who seem to have less pain.[1, 30] The TWIST clinical scoring system for testis torsion discriminated between torsion and non-torsion very well in our cohort, which calls into question the usefulness of NIRS or Doppler US except in certain subgroups.[12, 13] The subgroups in our study in which NIRS appeared to perform best was Tanner 3-5 patients without scrotal edema or with duration of pain ≤ 12 hours. This population of patients would be more similar to the prior pilot study and supports those results.[20] This observation is worth further study because in this population (peripubertal or post pubertal with short pain duration) avoiding delay for scrotal ultrasound would most likely lead to increased rate of testis salvage. Once there is significant scrotal edema from a significant duration of torsion, the testis is usually not viable.[6, 7] Scrotal edema can affect NIRS readings because the edematous scrotal tissue would be sampled by the NIRS device in addition to testis tissue. Based on our results, once there is significant scrotal edema or delay in presentation, NIRS readings are not useful for diagnosing testis torsion.

Strengths and Limitations

Strengths of this study include prospective design, inclusion of pre-pubertal patients, inclusion of a non-torsion study group, consecutive patient enrollment and full study enrollment meeting targeted enrollment calculations.

NIRS performed well in certain subgroups in our study, but these results are limited by small subgroup sizes. This limits applicability of results but supports further research in these subgroups. Different NIRS probes may be needed for prepubertal versus postpubertal testis and further research is needed to optimize NIRS device configuration. There were 17 patients (12% of cohort) in whom NIRS readings were attempted but a reading was not obtained in both testes.

EMT personnel obtaining the NIRS readings were not blinded to scrotal ultrasound results in all patients. Given the emergent nature of torsion, NIRS readings were obtained while clinical care was happening and blinding to diagnosis of torsion was not possible. However, measurements using the NIRS machine are not subjective which is less susceptible to operator bias.

Conclusion

NIRS Δ%StO2 readings were higher in pediatric patients with testis torsion compared to those without testis torsion. When all Tanner groups were combined, NIRS Δ%StO2 readings had limited utility to reliably diagnose torsion and could not rule out torsion. In Tanner 1-2 patients NIRS could not reliably discriminate between torsion and non-torsion. However, in Tanner 3-5 patients without scrotal edema or with pain duration ≤ 12 hours, NIRS discriminated between torsion and non-torsion well. More research is warranted in these subgroups that could most benefit from expeditious treatment of torsion with increased testis salvage rates.

References

1. Cost, N. G., Bush, N. C., Barber, T. D. et al.: Pediatric testicular torsion: demographics of national orchiopexy versus orchiectomy rates. J Urol, 185: 2459, 2011
2. Molokwu, C. N., Somani, B. K., Goodman, C. M.: Outcomes of scrotal exploration for acute scrotal pain suspicious of testicular torsion: a consecutive case series of 173 patients. BJU Int, 107: 990, 2011
3. Dogra, V., Bhatt, S.: Acute painful scrotum. Radiol Clin North Am, 42: 349, 2004
4. Kadish, H. A., Bolte, R. G.: A retrospective review of pediatric patients with epididymitis, testicular torsion, and torsion of testicular appendages. Pediatrics, 102: 73, 1998
5. Rabinowitz, R.: The importance of the cremasteric reflex in acute scrotal swelling in children. J Urol, 132: 89, 1984
6. Kapoor, S.: Testicular torsion: a race against time. Int J Clin Pract, 62: 821, 2008
7. Visser, A. J., Heyns, C. F.: Testicular function after torsion of the spermatic cord. BJU Int, 92: 200, 2003
8. Zhao, L. C., Lautz, T. B., Meeks, J. J. et al.: Pediatric testicular torsion epidemiology using a national database: incidence, risk of orchiectomy and possible measures toward improving the quality of care. J Urol, 186: 2009, 2011
9. Matteson, J. R., Stock, J. A., Hanna, M. K. et al.: Medicolegal aspects of testicular torsion. Urology, 57: 783, 2001
10. Selbst, S. M., Friedman, M. J., Singh, S. B.: Epidemiology and etiology of malpractice lawsuits involving children in US emergency departments and urgent care centers. Pediatr Emerg Care, 21: 165, 2005
11. Ciftci, A. O., Senocak, M. E., Tanyel, F. C. et al.: Clinical predictors for differential diagnosis of acute scrotum. Eur J Pediatr Surg, 14: 333, 2004
12. Barbosa, J. A., Tiseo, B. C., Barayan, G. A. et al.: Development and initial validation of a scoring system to diagnose testicular torsion in children. J Urol, 189: 1859, 2013
13. Sheth, K. R., Keays, M., Grimsby, G. M. et al.: Diagnosing Testicular Torsion before Urological Consultation and Imaging: Validation of the TWIST Score. J Urol, 195: 1870, 2016
14. Chen, H. W., Weng, L. C., Wang, T. M. et al.: Potential use of pulse oximetry for the diagnosis of testicular torsion. JAMA Pediatr, 168: 578, 2014
15. Mittnacht, A. J.: Near infrared spectroscopy in children at high risk of low perfusion. Curr Opin Anaesthesiol, 23: 342, 2010
16. Myers, D. E., Anderson, L. D., Seifert, R. P. et al.: Noninvasive method for measuring local hemoglobin oxygen saturation in tissue using wide gap second derivative near-infrared spectroscopy. J Biomed Opt, 10: 034017, 2005
17. Hirsch, J. C., Charpie, J. R., Ohye, R. G. et al.: Near-infrared spectroscopy: what we know and what we need to know--a systematic review of the congenital heart disease literature. J Thorac Cardiovasc Surg, 137: 154, 2009
18. Hyttel-Sorensen, S., Pellicer, A., Alderliesten, T. et al.: Cerebral near infrared spectroscopy oximetry in extremely preterm infants: phase II randomised clinical trial. BMJ, 350: g7635, 2015
19. Ubbink, D. T., Koopman, B.: Near-infrared spectroscopy in the routine diagnostic work-up of patients with leg ischaemia. Eur J Vasc Endovasc Surg, 31: 394, 2006
20. Burgu, B., Aydogdu, O., Huang, R. et al.: Pilot feasibility study of transscrotal near infrared spectroscopy in the evaluation of adult acute scrotum. J Urol, 190: 124, 2013

21. Capraro, G. A., Mader, T. J., Coughlin, B. F. et al.: Feasibility of using near-infrared spectroscopy to diagnose testicular torsion: an experimental study in sheep. Ann Emerg Med, 49: 520, 2007
22. Aydogdu, O., Burgu, B., Gocun, P. U. et al.: Near infrared spectroscopy to diagnose experimental testicular torsion: comparison with Doppler ultrasound and immunohistochemical correlation of tissue oxygenation and viability. J Urol, 187: 744, 2012
23. Hallacoglu, B., Matulewicz, R. S., Paltiel, H. J. et al.: Noninvasive assessment of testicular torsion in rabbits using frequency-domain near-infrared spectroscopy: prospects for pediatric urology. J Biomed Opt, 14: 054027, 2009
24. Schoenfeld, E. M., Capraro, G. A., Blank, F. S. et al.: Near-infrared spectroscopy assessment of tissue saturation of oxygen in torsed and healthy testes. Acad Emerg Med, 20: 1080, 2013
25. Obuchowski, N. A.: Sample size calculations in studies of test accuracy. Stat Methods Med Res, 7: 371, 1998
26. Li, J., Fine, J.: On sample size for sensitivity and specificity in prospective diagnostic accuracy studies. Stat Med, 23: 2537, 2004
27. DeLong, E. R., DeLong, D. M., Clarke-Pearson, D. L.: Comparing the areas under two or more correlated receiver operating characteristic curves: a nonparametric approach. Biometrics, 44: 837, 1988
28. Cui, W., Kumar, C., Chance, B.: Experimental study of migration depth for the photons measured at sample surface. Presented at the Proc SPIE 1431, Time-Resolved Spectroscopy and Imaging of Tissues, 1991
29. Sharp, V. J., Kieran, K., Arlen, A. M.: Testicular torsion: diagnosis, evaluation, and management. Am Fam Physician, 88: 835, 2013
30. Patriquin, H. B., Yazbeck, S., Trinh, B. et al.: Testicular torsion in infants and children: diagnosis with Doppler sonography. Radiology, 188: 781, 1993

Figure Legends

Figure 1: Consort flow diagram.

Figure 2: ROC curve for all patients (A). ROC curve with NIRS Δ%StO2 ≥ 20 as cutoff value (B).

Figure 3: ROC curve for Tanner stage 1-2 vs 3-5 (A). ROC curve for those with and without scrotal wall edema (B). ROC curve for those with pain duration ≤ 12 hours and > 12 hours (C).

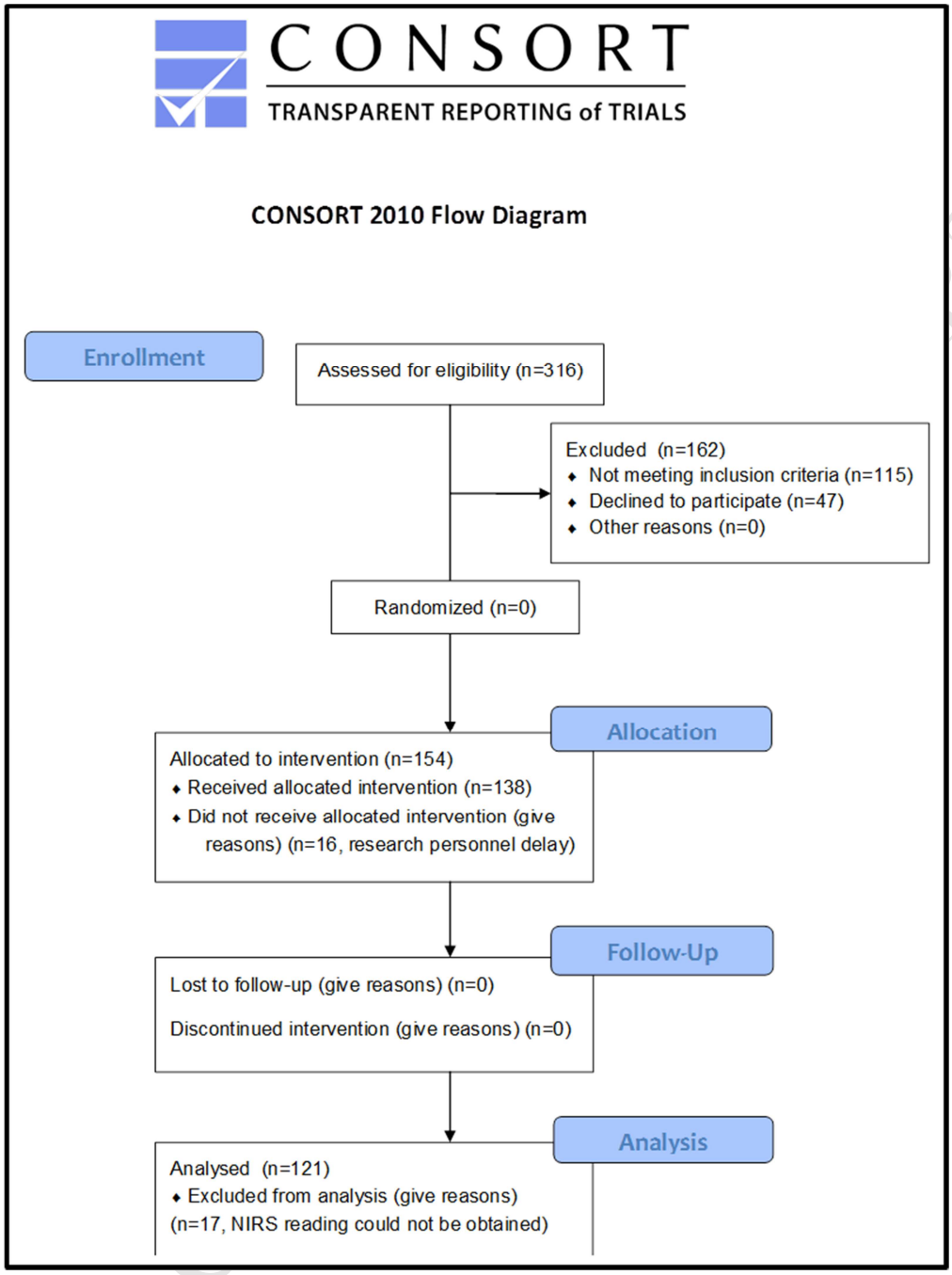
Figure 4: ROC curves for Tanner 3-5 patients with and without edema (A) and Tanner 3-5 patients with pain duration ≤ 12 hours and > 12 hours (B).

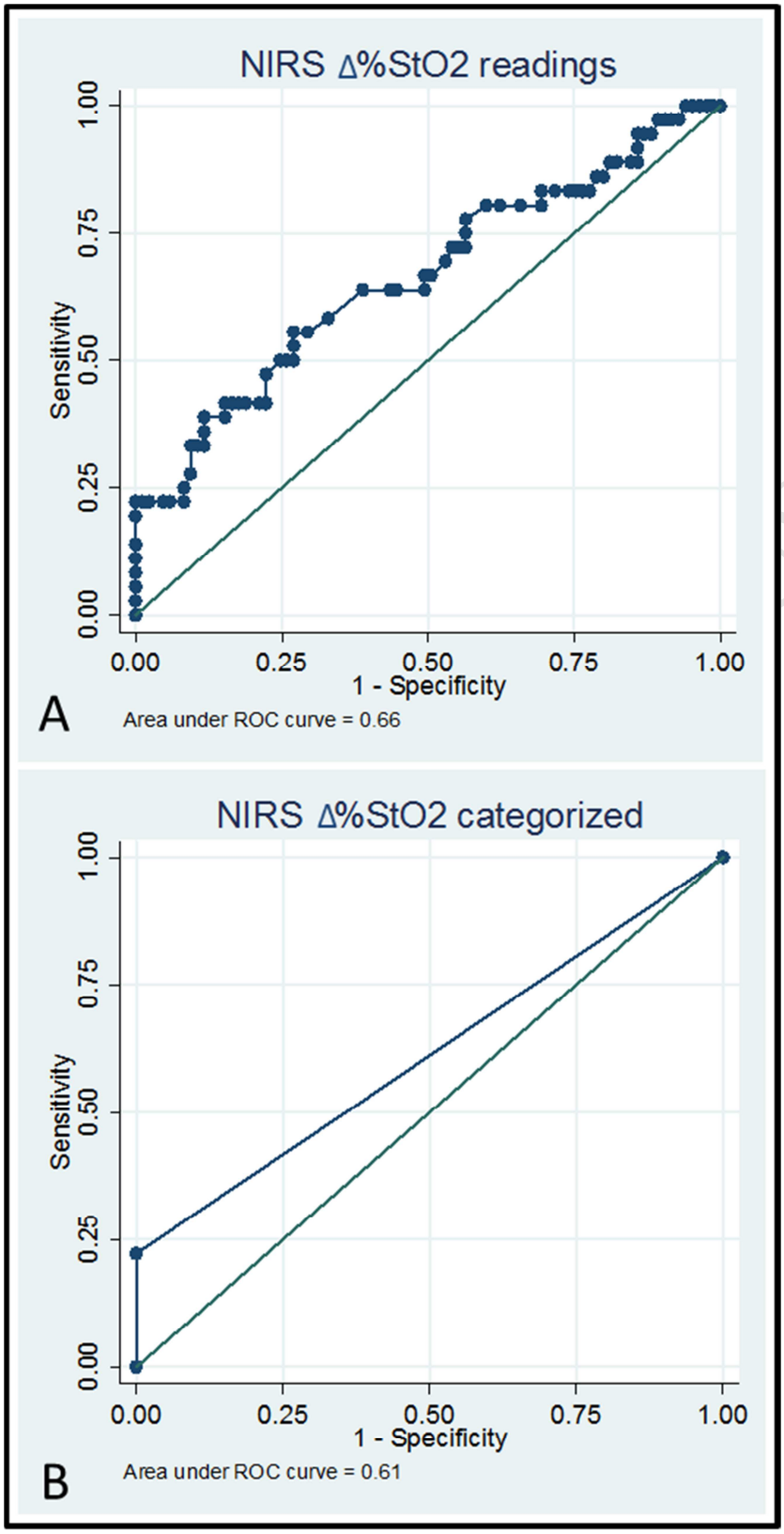
Figure 5: Near Infrared Spectroscopy Device (right) and probe (left).

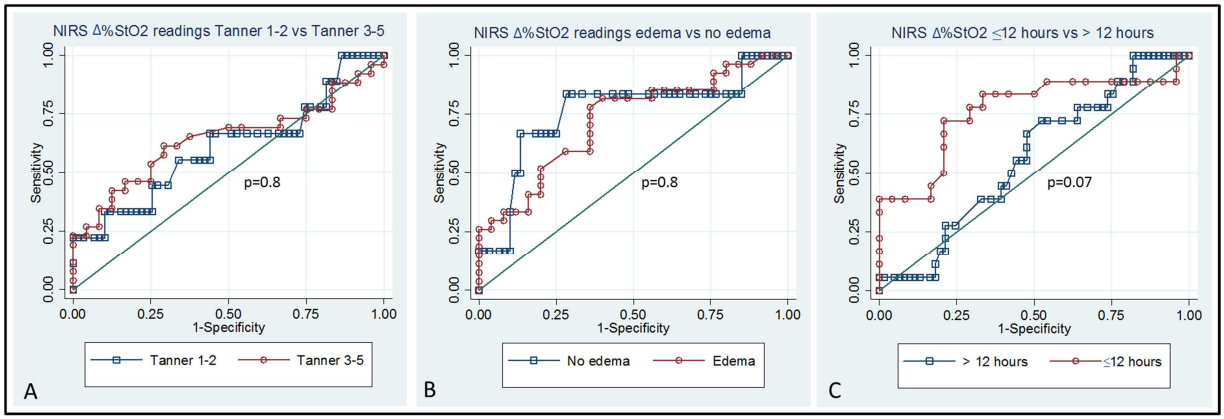
Table 1: Patient characteristics

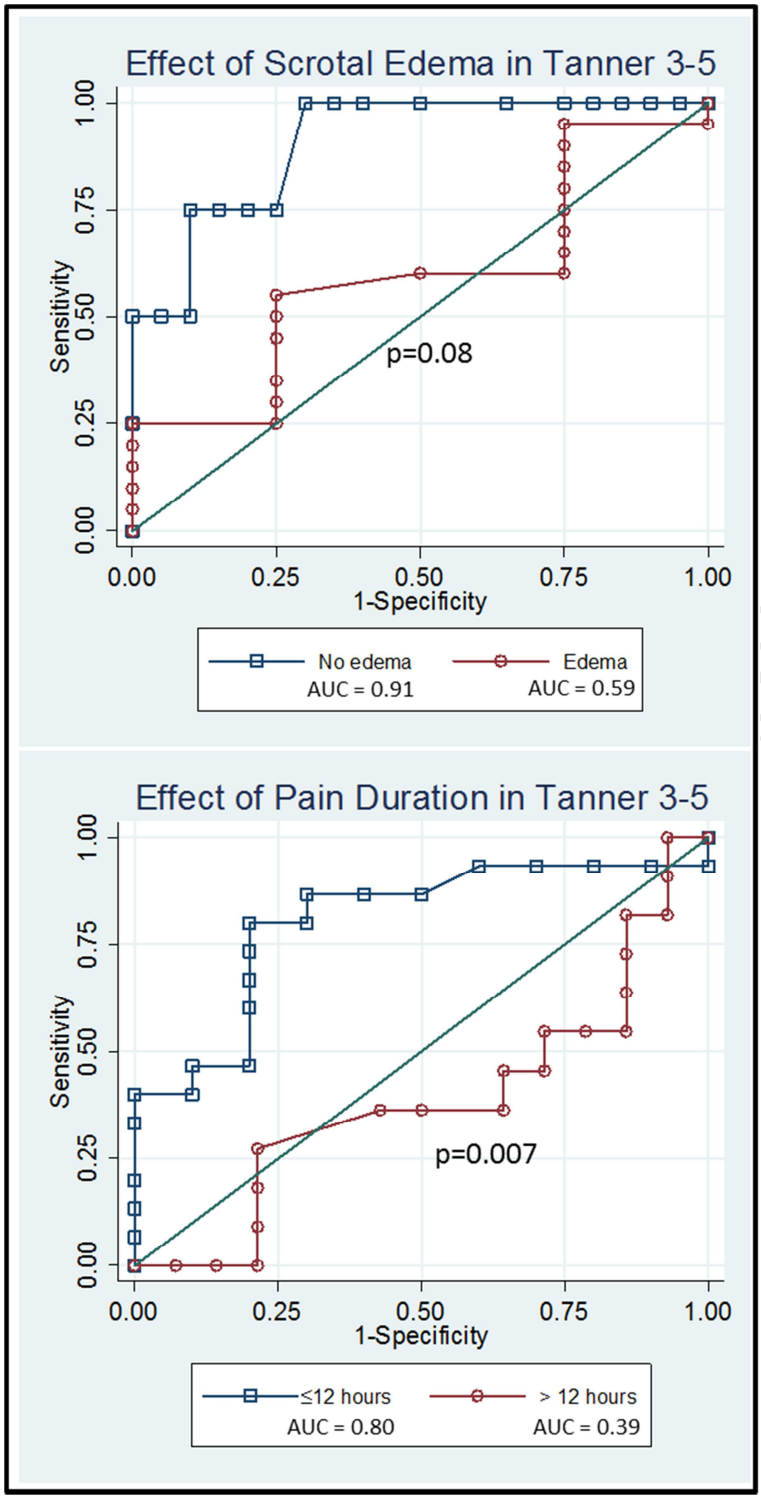
		Torsion (n=36)	No torsion (n=85)	p-value
Mean age (SD)		12.9 (3.8)	10.7 (3.8)	0.004[1]
Race				
	White	9 (25.0%)	14 (16.5%)	0.025[2]
	Hispanic	17 (47.2%)	62 (72.9%)	
	Black	7 (19.4%)	8 (9.4%)	
	Asian	1 (2.8%)	0	
	Other	2 (5.6%)	1 (1.2%)	
Tanner stage[3]				
	1	5 (14.3%)	27 (32.5%)	<0.001[4]
	2	4 (11.4%)	32 (38.6%)	
	3	8 (22.9%)	10 (12.1%)	
	4	14 (40.0%)	10 (12.1%)	
	5	4 (11.4%)	4 (4.8%)	
Median hours of pain prior to arrival (range)		12.0 (0.6-129.3)	33.2 (0.9-346.1)	0.009[4]

[1]Two-tailed t-test
[2]Fisher exact test
[3]Tanner stage missing in 2 patients without torsion and 1 with torsion
[4]Wilcoxon rank sum test


CONSORT
TRANSPARENT REPORTING of TRIALS
CONSORT 2010 Flow Diagram
Enrollment
Assessed for eligibility (n=316)
Excluded (n=162)
Not meeting inclusion criteria (n=115)
Declined to participate (n=47)
Other reasons (n=0)
Randomized (n=0)
Allocation
Allocated to intervention (n=154)
Received allocated intervention (n=138)
Did not receive allocated intervention (give reasons) (n=16, research personnel delay)
Follow-Up
Lost to follow-up (give reasons) (n=0)
Discontinued intervention (give reasons) (n=0)
Analysis
Analysed (n=121)
Excluded from analysis (give reasons)
(n=17, NIRS reading could not be obtained)


NIRS Δ%StO2 readings
Sensitivity
0.00
0.25
0.50
0.75
1.00
1 - Specificity
A
Area under ROC curve = 0.66
NIRS Δ%StO2 categorized
Sensitivity
0.00
0.25
0.50
0.75
1.00
1 - Specificity
B
Area under ROC curve = 0.61




Effect of Scrotal Edema in Tanner 3-5
Sensitivity
0.00
0.25
0.50
0.75
1.00
1-Specificity
p=0.08
No edema
AUC = 0.91
Edema
AUC = 0.59
Effect of Pain Duration in Tanner 3-5
Sensitivity
0.00
0.25
0.50
0.75
1.00
1-Specificity
p=0.007
≤12 hours
AUC = 0.80
> 12 hours
AUC = 0.39

Abbreviations

%StO2 = percent saturation of oxygen

NIRS = Near-infrared spectroscopy

ROC = receiver operating characteristic

AUC = area under curve

CI = confidence interval

ED = emergency department

IQR = interquartile range