Published in final edited form as:

J Urol. 2017 September ; 198(3): 694–701. doi:10.1016/j.juro.2017.03.134.

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

Bruce J. Schlomer*, Melise A. Keays, Gwen M. Grimsby, Candace F. Granberg, Daniel G. DaJusta, Vani S. Menon, Lauren Ostrov, Kunj R. Sheth, Martinez Hill, Emma J. Sanchez, Clanton B. Harrison, Micah A. Jacobs, Rong Huang, Berk Burgu, Halim Hennes, Linda A. Baker

University of Texas Southwestern Medical Center (BJS, VSM, KRS, CBH, MAJ, HH, LAB) and Children's Health (BJS, VSM, LO, MH, EJS, CBH, MAJ, RH, HH, LAB), Dallas, Texas, Children's Hospital of East Ontario, Ottawa, Ontario (MAK), Phoenix Children's Hospital, Phoenix, Arizona (GMG), Mayo Clinic, Rochester, Minnesota (CFG), Nationwide Children's Hospital, Columbus, Ohio (DGD), and Ankara Universitesi Tip Fakültesi, Ankara, Turkey (BB)

Abstract

Purpose: A rapid test for testicular torsion in children may obviate the delay for testicular ultrasound. In this study we assessed testicular tissue percent oxygen saturation (%StO₂) measured by transscrotal near infrared spectroscopy as a diagnostic test for pediatric testicular torsion.

Materials and Methods: This was a prospective comparison to a gold standard diagnostic test study that evaluated near infrared spectroscopy %StO₂ readings to diagnose testicular torsion. The gold standard for torsion diagnosis was standard clinical care. From 2013 to 2015 males with acute scrotum for more than 1 month and who were less than 18 years old were recruited. Near infrared spectroscopy %StO₂ readings were obtained for affected and unaffected testes. Near infrared spectroscopy %StO₂ was calculated as unaffected minus affected reading. The utility of near infrared spectroscopy %StO₂ to diagnose testis torsion was described with ROC curves.

Results: Of 154 eligible patients 121 had near infrared spectroscopy readings. Median near infrared spectroscopy %StO₂ in the 36 patients with torsion was 2.0 (IQR –4.2 to 9.8) vs –1.7 (IQR –8.7 to 2.0) in the 85 without torsion (p=0.004). AUC for near infrared spectroscopy as a diagnostic test was 0.66 (95% CI 0.55–0.78). Near infrared spectroscopy %StO₂ of 20 or greater had a positive predictive value of 100% and a sensitivity of 22.2%. Tanner stage 3-5 cases without scrotal edema or with pain for 12 hours or less had an AUC of 0.91 (95% CI 0.86–1.0) and 0.80 (95% CI 0.62–0.99), respectively.

*Correspondence: University of Texas Southwestern Medical Center, Dallas, Texas (bruce.schlomer@childrens.com). The corresponding author certifies that, when applicable, a statement(s) has been included in the manuscript documenting institutional review board, ethics committee or ethical review board study approval; principles of Helsinki Declaration were followed in lieu of formal ethics committee approval; institutional animal care and use committee approval; all human subjects provided written informed consent with guarantees of confidentiality; IRB approved protocol number; animal approved project number.

No direct or indirect commercial incentive associated with publishing this article.

Clinical Trial Registration [NCT01812109](https://clinicaltrials.gov/ct2/show/study/NCT01812109) (www.clinicaltrials.gov).

Conclusions: In all children near infrared spectroscopy readings had limited utility in diagnosing torsion. However, in Tanner 3-5 cases without scrotal edema or with pain 12 hours or less, near infrared spectroscopy discriminated well between torsion and nontorsion.

Keywords

pediatrics; spermatic cord torsion; spectroscopy, near-infrared; diagnostic techniques and procedures

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 4,000 males less than 25 years old and is primarily seen in newborns or those 10 to 25 years old.^{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 to 8 hours after the onset of pain.^{6,7} Using national data sets approximately 30% of torsed testes are removed at surgery, signifying delayed care.^{1,8} Testis torsion is a common diagnosis for litigation in children age 12 to 17 years old, 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 examination, but diagnosis and care can be delayed due to atypical history or physical examination, ultrasound testing, inter-hospital transfer or inexperience of emergency room providers.¹¹

Studies have been conducted 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 of up to 49%.² The TWIST (Testicular Workup for Ischemia and Suspected Torsion) score, based on presenting signs and symptoms, has been reported to improve the 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 it was limited by the absence of a nontorsion control group.¹⁴ A test that is rapid, accurate, noninvasive, usable by emergency room providers as an extension of physical examination, and capable of eliminating delay for scrotal ultrasound would be ideal for the diagnosis of testis torsion.

Near infrared spectroscopy uses infrared light to obtain continuous, transcutaneous monitoring of tissue oxygen saturation.^{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 newborns¹⁸ and to assess skeletal muscle oxygenation in compartment syndrome cases.¹⁹ Three animal models studies and 1 in young adults have reported on NIRS for the diagnosis of testis torsion with promising results.²⁰⁻²³ One small human study comparing 17 cases of nontorsion and 5 of torsion in young adults reported that NIRS was not effective in the diagnosis of testis torsion.²⁴

We investigated the usefulness of transscrotal NIRS measurements in the emergency department as a diagnostic test for testis torsion in children presenting with acute scrotum. Our hypothesis was that transscrotal NIRS %StO₂ measurements in a torsed testis would be lower than the NIRS %StO₂ measurements in the contralateral nontorsed testis, and that clinically useful values could be identified to diagnose and rule out testis torsion. The usefulness of NIRS in diagnosing testis torsion was described using ROC curves.

METHODS

After institutional review board approval, enrollment in this single center, NIH prospective trial began March 19, 2013 and ended March 25, 2015. Males 1 month to 18 years old who presented to Children's Medical Center emergency department in Dallas, Texas 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, or chronic respiratory, hematological or vascular problems that could affect total body tissue oxygenation levels were excluded from analysis. Informed consent was obtained from guardians on behalf of participants and assent obtained from participants more than 10 years old.

Potential subjects were approached by emergency medical technician 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™ StO₂ Spot Check Device (Model 300) with thenar clip probe (Model 1315, modified by clip removal). The equipment cost was \$5,000 per unit. The probe was placed anteriorly over each testis. Measurements were done at 1, 5 and 10 seconds to account for interassay variability, which is expected to be less than 3 %StO₂. The average of the 3 readings was defined as the NIRS %StO₂ reading for that testis. The NIRS readings in the affected testis were normalized to the contralateral normal testis to formulate a NIRS %StO₂ (%StO₂ of unaffected testis and %StO₂ of affected testis).²⁰ If the affected testis had lower %StO₂ readings than the contralateral normal testis, NIRS %StO₂ would be positive.

Statistical Analysis

Data were collected using a REDCap (Research Electronic Data Capture) database (CTSA NIH Grant UL1TR001105). According to Obuchowski's method a sample size of 150 patients with acute scrotum would be required to show that 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.^{25,26} ROC curves were used to analyze the performance of NIRS %StO₂ readings as a diagnostic test for torsion. Potential clinically useful cutoff values were assessed using ROC curve analysis. NIRS %StO₂ values were compared using the Wilcoxon rank sum

test. AUC among ROC curves was compared using the DeLong method.²⁷ Statistical analysis was performed with Stata® 12.

RESULTS

Overall 316 patients were assessed and 154 were enrolled in the study (fig. 1). Of the 154 enrolled patients 16 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 the analysis, of whom 36 (29.8%) were diagnosed with torsion. The table shows the demographics of the patients included in the analysis. Patients with torsion were older, had a higher Tanner stage and had a lower median pain duration before arrival. Median NIRS %StO₂ was -1.7 (range -31 to 15.3, 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 those patients with torsion had lower %StO₂ readings in the affected testis (p=0.004).

ROC Curve Analysis

To evaluate the performance of NIRS %StO₂ readings as a diagnostic test for testicular torsion for all patients, a ROC curve analysis was performed (fig. 2). AUC was 0.66 (95% CI 0.55–0.78). A cutoff value of %StO₂ of 20 or greater had a PPV of 100% and a sensitivity of 22.2% to diagnose torsion.

Effect of Tanner Stage

Tanner stage was recorded in 118 of 121 patients. The effect of Tanner stage on NIRS readings was investigated by ROC curve analysis for the 68 Tanner 1-2 vs the 50 Tanner 3-5 cases (fig. 3). In the Tanner 3-5 group 26 of the 50 patients had torsion with AUC 0.64 (95% CI 0.48–0.80). A %StO₂ cutoff of 10 or greater was associated with a 100% PPV and 27.8% sensitivity for diagnosing torsion in Tanner 3-5 cases. For the Tanner 1-2 group 9 of the 68 patients had torsion with AUC 0.61 (95% CI 0.38–0.84). The AUC for Tanner 3-5 vs 1-2 cases was not significantly different (p=0.8).

Effect of Scrotal Edema

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

In Tanner stage 3-5 cases NIRS %StO₂ discriminated between torsion and nontorsion better in those without edema with an AUC of 0.91 (95% CI 0.86–1.0, p=0.08) (fig. 4). In this subgroup the NIRS %StO₂ values in the 4 with torsion (median 8.8, IQR 5.0 to 17.0) were higher than in the 20 without torsion (median -0.5, IQR -2.3 to 3.2) (p=0.01). NIRS %StO₂ values of 10 or greater had a PPV of 100% and a sensitivity of 50% to diagnose

torsion, and NIRS %StO₂ less than 2.5 had a negative predictive value of 100% and a specificity of 70.0% to rule out torsion.

Effect of Pain Duration

To evaluate the impact of pain duration on NIRS testing we compared patients who had pain for 12 hours or less (42) vs those with pain for more than 12 hours (79) (fig. 3). NIRS %StO₂ discriminated between torsion and nontorsion better in those with pain for 12 hours or less (AUC 0.76, 95% CI 0.60–0.92) than in those with pain lasting longer than 12 hours (AUC 0.56, 95% CI 0.42–0.70, $p=0.07$).

In Tanner 3-5 cases %StO₂ discriminated between torsion and nontorsion better in those with pain 12 hours or less with an AUC of 0.80 (95% CI 0.62–0.99, $p=0.007$). In this subgroup NIRS %StO₂ values in 15 patients 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 %StO₂ values of 20 or greater had a PPV of 100% and a sensitivity of 46.7% to diagnose torsion, and NIRS %StO₂ values less than 0 had a negative predictive value of 80.0% and a specificity of 40.0% to rule out torsion (fig. 4).

Testis Measurements

Testis measurements by scrotal ultrasound were available in 107 of 121 patients. 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 cases. Affected testis width and height were 1.4 cm (SD 0.4) and 1.6 cm (SD 0.6), respectively, in Tanner 1-2 cases, and 2.5 cm (SD 0.6) and 2.4 cm (SD 0.5), respectively, in Tanner 3-5 cases. Mean skin to testis distance in the 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 that NIRS %StO₂ readings in pediatric patients with torsion would be higher than in pediatric patients without torsion. In addition, we hypothesized that NIRS %StO₂ values could be identified by ROC curve analysis to diagnose and rule out torsion in pediatric patients. NIRS %StO₂ readings were significantly higher in those with torsion than in those without torsion ($p=0.004$). However, there was significant overlap between the groups, which limited the diagnostic utility. For the entire cohort NIRS %StO₂ values of 20 or greater had a PPV of 100% to diagnose torsion and this was the only clinically useful cutoff with a sensitivity of only 22.2%. In subgroup analysis NIRS %StO₂ appeared to perform best in Tanner 3-5 cases without scrotal edema or with pain for 12 hours or less. NIRS %StO₂ discriminated well between torsion and nontorsion in these subgroups with an AUC of 0.91 and 0.80, respectively, and the distribution of NIRS %StO₂ values had less overlap. NIRS did not discriminate well in Tanner stage 1-2 cases.

NIRS was reported to diagnose torsion accurately in adult patients in a pilot study.²⁰ In that study of 16 adult patients those with a NIRS %StO₂ of 11.5 or greater had testis torsion while those with NIRS %StO₂ less than 11.5 did not have torsion. In our study NIRS as a diagnostic test for torsion did not perform well in prepubertal 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 results in a mean tissue depth measured of 7.5 mm and a maximum length measured of 15 mm (fig. 5).²⁸ These distances are too large for prepubertal testes, which would lead to the surrounding tissue being measured by the NIRS device.

Prepubertal children often present later with more scrotal edema, which also may affect NIRS readings. Based on our testis measurements, in future NIRS studies a distance longer than 15 mm between emitter and detector may improve performance in Tanner 3-5 cases and a shorter distance may improve performance in Tanner 1-2 cases.

Torsion has a bimodal age distribution with the first peak in the neonatal period and the second peak around puberty.²⁹ While postpubertal children usually present with severe testicular pain, identifying typical 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 well between torsion and nontorsion in our cohort, which calls into question the usefulness of NIRS or Doppler ultrasound except in certain subgroups.^{12,13} The subgroups in our study in which NIRS appeared to perform best were Tanner 3-5 cases without scrotal edema or those with pain 12 hours or less. This population of patients would be more similar to that of the prior pilot study and supports those results.²⁰ This observation is worth further study because in this population (peri-pubertal or postpubertal with short pain duration) avoiding delay for scrotal ultrasound would most likely lead to an 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 the 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 of this study include the prospective design, inclusion of prepubertal patients, inclusion of a nontorsion 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 the small subgroup size. This limits the applicability of the results but supports further research in these subgroups. Different NIRS probes may be needed for prepubertal vs postpubertal testis and further research is needed to optimize NIRS device configuration. There were 17 patients (12% of cohort) for whom NIRS readings were attempted but a reading was not obtained in both testes.

Emergency medical technician personnel who obtained NIRS readings were not blinded to scrotal ultrasound results in all patients. Given the emergent nature of torsion, NIRS readings were obtained during clinical care and blinding to diagnosis of torsion was not possible. However, measurements using the NIRS machine are not subjective and, thus, are less susceptible to operator bias.

CONCLUSION

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

Acknowledgments

Supported by the National Institutes of Diabetes and Digestive and Kidney Diseases of the NIH 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.

Abbreviations and Acronyms

%StO₂	percent oxygen saturation
NIH	National Institutes of Health
NIRS	near infrared spectroscopy
PPV	positive predictive value

REFERENCES

1. Cost NG, Bush NC, Barber TD et al.: Pediatric testicular torsion: demographics of national orchiopexy versus orchiectomy rates. *J Urol* 2011; 185: 2459. [PubMed: 21527194]
2. Molokwu CN, Somani BK and Goodman CM: Outcomes of scrotal exploration for acute scrotal pain suspicious of testicular torsion: a consecutive case series of 173 patients. *BJU Int* 2011; 107: 990. [PubMed: 21392211]
3. Dogra V and Bhatt S: Acute painful scrotum. *Radiol Clin North Am* 2004; 42: 349. [PubMed: 15136021]
4. Kadish HA and Bolte RG: A retrospective review of pediatric patients with epididymitis, testicular torsion, and torsion of testicular appendages. *Pediatrics* 1998; 102: 73. [PubMed: 9651416]
5. Rabinowitz R: The importance of the cremasteric reflex in acute scrotal swelling in children. *J Urol* 1984; 132: 89. [PubMed: 6726967]
6. Kapoor S: Testicular torsion: a race against time. *Int J Clin Pract* 2008; 62: 821. [PubMed: 18412935]
7. Visser AJ and Heyns CF: Testicular function after torsion of the spermatic cord. *BJU Int* 2003; 92: 200. [PubMed: 12887467]
8. Zhao LC, Lautz TB, Meeks JJ 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* 2011; 186: 2009. [PubMed: 21944120]
9. Matteson JR, Stock JA, Hanna MK et al.: Medicolegal aspects of testicular torsion. *Urology* 2001; 57: 783. [PubMed: 11306405]
10. Selbst SM, Friedman MJ and Singh SB: Epidemiology and etiology of malpractice lawsuits involving children in US emergency departments and urgent care centers. *Pediatr Emerg Care* 2005; 21: 165. [PubMed: 15744194]
11. Ciftci AO, Senocak ME, Tanyel FC et al.: Clinical predictors for differential diagnosis of acute scrotum. *Eur J Pediatr Surg* 2004; 14: 333. [PubMed: 15543483]

12. Barbosa JA, Tiseo BC, Barayan GA et al.: Development and initial validation of a scoring system to diagnose testicular torsion in children. *J Urol* 2013; 189: 1859. [PubMed: 23103800]
13. Sheth KR, Keays M, Grimsby GM et al.: Diagnosing testicular torsion before urological consultation and imaging: validation of the TWIST score. *J Urol* 2016; 195: 1870. [PubMed: 26835833]
14. Chen HW, Weng LC, Wang TM et al.: Potential use of pulse oximetry for the diagnosis of testicular torsion. *JAMA Pediatr* 2014; 168: 578. [PubMed: 24781314]
15. Mitnacht AJ: Near infrared spectroscopy in children at high risk of low perfusion. *Curr Opin Anaesthesiol* 2010; 23: 342. [PubMed: 20421789]
16. Myers DE, Anderson LD, Seifert RP et al.: Noninvasive method for measuring local hemoglobin oxygen saturation in tissue using wide gap second derivative near-infrared spectroscopy. *J Biomed Opt* 2005; 10: 034017. [PubMed: 16229661]
17. Hirsch JC, Charpie JR, Ohye RG 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* 2009; 137: 154. [PubMed: 19154918]
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* 2015; 350: g7635. [PubMed: 25569128]
19. Ubbink DT and Koopman B: Near-infrared spectroscopy in the routine diagnostic work-up of patients with leg ischaemia. *Eur J Vasc Endovasc Surg* 2006; 31: 394. [PubMed: 16359878]
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* 2013; 190: 124. [PubMed: 23376606]
21. Capraro GA, Mader TJ, Coughlin BF et al.: Feasibility of using near-infrared spectroscopy to diagnose testicular torsion: an experimental study in sheep. *Ann Emerg Med* 2007; 49: 520. [PubMed: 16997426]
22. Aydogdu O, Burgu B, Gocun PU et al.: Near infrared spectroscopy to diagnose experimental testicular torsion: comparison with Doppler ultrasound and immunohistochemical correlation of tissue oxygenation and viability *J Urol* 2012; 187: 744. [PubMed: 22177196]
23. Hallacoglu B, Matulewicz RS, Paltiel HJ et al.: Noninvasive assessment of testicular torsion in rabbits using frequency-domain near-infrared spectroscopy: prospects for pediatric urology. *J Biomed Opt* 2009; 14: 054027. [PubMed: 19895129]
24. Schoenfeld EM, Capraro GA, Blank FS et al.: Near-infrared spectroscopy assessment of tissue saturation of oxygen in torsed and healthy testes. *Acad Emerg Med* 2013; 20: 1080. [PubMed: 24127717]
25. Obuchowski NA: Sample size calculations in studies of test accuracy. *Stat Methods Med Res* 1998; 7: 371. [PubMed: 9871953]
26. Li J and Fine J: On sample size for sensitivity and specificity in prospective diagnostic accuracy studies. *Stat Med* 2004; 23: 2537. [PubMed: 15287083]
27. DeLong ER, DeLong DM and Clarke-Pearson DL: Comparing the areas under two or more correlated receiver operating characteristic curves: a nonparametric approach. *Biometrics* 1988; 44: 837. [PubMed: 3203132]
28. Cui W, Kumar C and Chance B: Experimental study of migration depth for the photons measured at sample surface. Presented at SPIE 1431, Time-Resolved Spectroscopy and Imaging of Tissues, Los Angeles, California, May 1, 1991.
29. Sharp VJ, Kieran K and Arlen AM: Testicular torsion: diagnosis, evaluation, and management. *Am Fam Physician* 2013; 88: 835. [PubMed: 24364548]
30. Patriquin HB, Yazbeck S, Trinh B et al.: Testicular torsion in infants and children: diagnosis with Doppler sonography. *Radiology* 1993; 188: 781. [PubMed: 8351347]

CONSORT 2010 Flow Diagram

Figure 1.
CONSORT (Consolidated Standards of Reporting Trials) flow diagram.

Figure 2.
ROC curve for all patients (A) and with NIRS $\Delta\%StO_2$ of 20 or greater as cutoff value (B)

Figure 3.

ROC curve for Tanner stage 1-2 vs 3-5 (A), for those with vs without scrotal wall edema (B) and for those with pain 12 hours or less vs more than 12 hours (C).

Figure 4.

ROC curves for Tanner 3-5 cases with vs without edema (*A*) and those with pain 12 hours or less vs greater than 12 hours (*B*)

Figure 5.
Near infrared spectroscopy device and probe

Patient characteristics

	Torsion		No Torsion		p Value
No. pts	36		85		
Mean yrs age (SD)	12.9 (3.8)		10.7 (3.8)		0.004 (2-tailed t-test)
No. race (%):					
White	9 (25.0)		14 (16.5)		0.025 (Fisher exact test)
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)		
No. Tanner stage (%): *					
1	5 (14.3)		27 (32.5)		<0.001 (Wilcoxon rank sum test)
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 hrs pain before arrival (range)	12.0 (0.6–129.3)		33.2 (0.9–346.1)		0.009 (Wilcoxon rank sum test)

*. Tanner stage missing in 2 patients without torsion and in 1 with torsion.