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AWARD NUMBER: W81XWH-15-1-0709

TITLE: Management of Noncompressible Hemorrhage Using Vena Cava Ultrasound

PRINCIPAL INVESTIGATOR: Donald Jenkins, M.D.

CONTRACTING ORGANIZATION: National Trauma Institute
San Antonio, TX 78230

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14. ABSTRACT
The Combat Casualty Care Research Program, through the JWMRP, is specifically interested in testing and refining techniques for early intervention in life-threatening battle injuries. The purpose of this study was to determine the utility of ultrasonic assessment protocol of inferior vena cava vena cava diameter and collapsibility to detect and aid in management of non-compressible hemorrhage in major trauma victims. A modification for a 12-month no cost extension was executed on September 12, 2017 to allow more time for subject accrual and data analyses. During year 3, 424 patients were screened and 29 were enrolled. Study results were presented at the American Association the Surgery for Trauma (AAST) conference San Diego, California in September 2018.

15. SUBJECT TERMS
Trauma; hypovolemia; inferior vena cava; IVC; internal jugular; IJ; collapsibility; injury; ultrasound; hemorrhagic shock

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TABLE OF CONTENTS

Introduction:
The National Trauma Institute (NTI) proposed to utilize $ 498,269 in Joint Warfighter Medical Research Program Funding to extend the work previously completed at academic trauma centers using bedside ultrasound to identify patients with evidence of hypovolemia as determined by inferior vena cava (IVC) and internal jugular (IJ) collapsibility. Prior small studies of ultrasonographic assessment of IVC and IJ diameters and collapsibility demonstrated it to be a sensitive detector of blood volume loss and hemorrhagic shock. The specific aims of this study are: (1) determine the sensitivity, specificity and accuracy of ultrasonic assessment (USA) of IVC diameters in detecting traumatic shock at admission as compared to vital signs, (2) determine the ability of USA of IVC diameters to detect preclinical shock states defined by elevated arterial blood gas (ABG) Base Deficit or lactate in trauma patients without hypotension (SBP less than 90) at admission, (3) correlate the restoration of IVC diameters and collapsibility to achievement of endpoints of shock resuscitation in the ICU, such as correction of Base Deficit or lactate, evidence of improved organ perfusion such as urine output, limited echocardiography and avoidance of multiple organ dysfunction or death. The initial four clinical sites for this study are University of California at San Diego (UCSD), Virginia Commonwealth University (VCU), University of Utah (Utah), and Emory University at Grady Memorial Hospital (Emory). In Year 2 Quarter 2, Emory University was replaced as a site by the University of Maryland (UMD). During Year 3, subject enrollment was completed, data were analyzed and study results were presented at the AAST annual scientific conference in September 2018.

Keywords:
Trauma; hypovolemia; inferior vena cava; IVC; internal jugular; IJ; collapsibility; injury; ultrasound

Accomplishments:
The major goals of this project as identified in the Statement of Work are below with percent completion determinations and completion dates as appropriate.

Aims and Major Goals	**Timeline in Months**	**Actual completion date**	**% of completion**
Specific Aim 1: Prepare for Clinical Trial			
If Applicable, coordinate with Sites for CRADA* submission	1-3	N/A	N/A
If Applicable, coordinate with Sites for material transfer agreements (MTAs) or clinical trial agreements (CTAs) submission	1-3	N/A	N/A
Refine eligibility criteria, exclusion criteria, screening protocol	1-3	17/09/2015	100%
Finalize consent form & human subjects protocol	1-3	17/09/2015	100%
Coordinate with Sites for IRB** protocol submission	1-3	01/10/2015	100%
Coordinate with Sites for UCSD IRB review	1-6	06/07/2016	100%
Start-up activities	1-6	14/06/2017	100%
Coordinate with Sites for Military 2nd level IRB** review (ORP/HRPO)	1-6	06/04/2017	100%

Submit amendments, adverse events and protocol deviations as needed	As Needed		0%
Coordinate with Sites for annual IRB** report for continuing review	Annually		100%
*Milestone Achieved: Local IRB** approval at VCU, Utah and Emory*	1-6	19/01/2017	100%
*Milestone Achieved: HRPO*** approval for all protocols*	6	06/04/2017	100%
*Milestone Achieved: local IRB** approval for all protocols through UCSD.*	6	06/07/2016	100%
Specific Aim 2: Coordinate Study Staff for Clinical Trial			
Sites identify or hire SRAs, Train clinician sonographers	3-6	03/05/2017	100%
Milestone Achieved: Research staff trained	3-6	02/09/2017	100%
Specific Aim 3: Randomized Controlled Trial - Conduct Study, Report Findings			
(1) determine the sensitivity, specificity and accuracy of ultrasonic assessment (USA) of IVC diameters in detecting traumatic shock at admission as compared to vital signs, (2) determine the ability of USA of IVC diameters to detect preclinical shock states defined by elevated arterial blood gas (ABG) Base Deficit or lactate in trauma patients without hypotension (SBP less than 90) at admission, (3) correlate the restoration of IVC diameters and collapsibility to achievement of endpoints of shock resuscitation in the ICU, such as correction of Base Deficit or lactate, evidence of improved organ perfusion such as urine output, limited echocardiography and avoidance of multiple organ dysfunction or death.	6-24	01/09/2018	100%
Demonstrate equivalency of pocket ultrasound devices for IVC exam	12-18	Pending	100%
Milestone Achieved: 1st participant consented, screened and enrolled in study	6	29/07/2016	100%

Subject Enrollment Information is detailed in the tables below:

Study Subjects Screened										
SCREENED	**Y1**	**Y2Q1**	**Y2Q2**	**Y2Q3**	**Y2Q4**	**Y3Q1**	**Y3Q2**	**Y3Q3**	**Y3Q4**	**Total**
UCSD	105	121	112	111	134	116	*57*	*0*	*0*	*756*
VCU	-	-	7	9	2	0	*20*	*0*	*0*	*38*
Utah	-	-	-	0	2	85	*60*	*0*	*0*	*147*
Emory (Closed)	-	-	-	-	-	-	-	*0*	*0*	
Maryland (Replacement)	-	-	12	20	0	66	*20*	*0*	*0*	*118*
Target Enrollment (cumulative)	105	121	131	140	138	267	*157*	*0*	*0*	*1,059*

Study Enrollment										
ENROLLED/TARGET	**Y1**	**Y2Q1**	**Y2Q2**	**Y2Q3**	**Y2Q4**	**Y3Q1**	**Y3Q2**	**Y3Q3**	**Y3Q4**	**Total**
UCSD	8	5	10	10	8	6	*2*	*0*	*0*	*49*
VCU	0	0	6	1	2	0	*11*	*0*	*0*	20
Utah	0	0	0	0	2	1	*3*	*0*	*0*	6
Emory (Closed)	0	0	-	-	-	-	-	*0*	*0*	-
Maryland (Replacement)	-	-	1	20	0	4	*2*	*0*	*0*	*27*
Target Enrollment (cumulative)	8	5	17	31	12	11	*18*	*0*	*0*	*102*

Training of research staff and sonographers has been completed at all sites which included research ethics, consent procedures, and IVC and IJ ultrasound examinations.

UCSD, VCU, Utah, and Emory were the initial sites for this project. However, Emory withdrew from the project (08 Aug 2016) due to internal research infrastructure limitations. UMD who was a participating site under the earlier project, agreed to reopen the study to participate as the fourth site. A request for a modification of the Statement of Work for the site change was submitted and approved during the second quarter of Year 2.

With respect to training opportunities associated with this study, Dr. Doucet has produced “Protocol Video USA-IVC Study (Version 5)” that is posted on youtube: https://youtu.be/54-Z6fiJpPY This video describes study design and procedures, inclusion/exclusion criteria and includes a demonstration to train clinical sonographers on correct techniques to measure IVC diameter in research participants.

The study found that a second generation of low cost, handheld pocket-sized ultrasound devices that are wireless or connect to personal smartphones are already available. These promise to make US assessment ubiquitous inside and outside the hospital by multiple disciplines and provider types.

The National Trauma Institute continues to work on site closure submission. At the time of this report, site closures are pending for UCSD and Utah. UCSD site closure documentation was submitted to HRPO on 12-13-2018 and is pending approval. Utah is pending IRB closure letter from their respective institution.

At the time of this final report, the Final Learning Toolkit is still pending and will be submitted once complete.

Impact:
Study findings were presented at the AAST Conference in September 2018. These results will be published in the Journal of Trauma and Acute Care Surgery in 2019. Impact on the assessment and acute resuscitation of trauma patients is included in publications.

Results and Conclusions from Publications

- FAST-IVC was useful in predicting 24 hour fluid resuscitation requirements.

- eFAST ultrasound IVC but not IJ diameter response to initial trauma resuscitation was useful in predicting 24 hour fluid resuscitation requirements. Combined models using ultrasonic

assessment of the IVC and SI after 40-60 minutes of resuscitation, improved the C-index for IVCDMIN from 0.74 (CI: 0.65-0.84, p<0.0001) to 0.79 (CI: 0.71-0.88, p<0.0001) and the C-index for IVCCI improved from 0.76 (CI: 0.66-0.86, p<0.0001) to 0.80 (CI:0.71-0<88, p<0.0001). A simplified IVC-SI score based on regression coefficients, using 0-3 points for IVCDMIN and 0-5 points for SI had a C-index of 0.78 (CI: 0.69-0.86, p<0.0001) using the FAST-IVC dataset. For major trauma patients, a regression model combining post-resus SI and IVCDMIN or IVCCI improves predictive ability for 24FR from good to strong. A simplified post-resus IVC-SI score was created, however this score will require clinical validation.

- In an article that has been accepted pending final revisions in the Journal of Trauma (see attached draft), the study found that US assessment of IVC diameter and collapsibility provides a rapid, non-invasive way to determine the 24-hour FR of major trauma victims within one hour of admission. The study was unable to show that IJV diameter and collapsibility were predictive of 24-hour FR in supine major trauma victims receiving standard of care resuscitation without other provocative maneuvers. Future clinical research should focus on rapid, reproducible and easy to perform non-invasive imaging approaches that limit the harm from either unrecognized hypovolemia or over-resuscitation. Already available are a second generation of low cost, handheld pocket-sized ultrasound devices that are wireless or connect to personal smartphones. These promise to make US assessment ubiquitous inside and outside the hospital by multiple disciplines and provider types. In the near future, low cost, disposable, conformal ultrasound bandages may be worn in austere, prehospital and hospital environments to provide continuous recording of hemodynamic parameters. We can easily predict there will be a continuing search to find the optimal non-invasive US hemodynamic measure for FR.

Changes/Problems:
The project was awarded a 12-month no cost extension to close out project activities and reach target enrollment. In August 2017, Dr. Doucet determined that a lower sample size was required to achieve study aims and objectives. He estimated that a sample of approximately 125 study subjects would be sufficient to produce clinically significant results. These data were analyzed and presented at the American Association for the Surgery of Trauma Conference in the Fall 2018.

Products:

1. Dr. Doucet has produced “Protocol Video USA-IVC Study (Version 5) that is posted on youtube: https://youtu.be/54-Z6fiJpPY This video contains study design, procedures, inclusion/exclusion criteria and a demonstration to train clinical sonographers on correct techniques to measure IVC diameter in research participants. This video is used for ongoing training.

2. Jay Doucet, M.D., Paula Ferrada M.D., Ram Nirula M.D., Andrew Singleton M.D., Christopher Dente M.D., Rondi Gelbard M.D., Seda Bourikian, Giovanna Casola, M.D., Raul Coimbra, M.D., Ph.D. THE IVC-FAST AAST MIT / NTI STUDY. Abstract Submitted March, 2015.

3. How to Measure for IVC FAST Study. PowerPoint Presentation. August, 2018.

4. PowerPoint of Patient Usable Images. September, 2018.

5. Jay Doucet, M.D., Paula Ferrada M.D., Ram Nirula M.D., Andrew Singleton M.D., Katie Birkas M.Sc., Sarah Murthi M.D., Daniel Haase M.D., Sara Edwards M.D., Giovanna Casola, M.D., Raul Coimbra, M.D., Ph.D. Ultrasonographic IVC Diameter Response to Trauma Resuscitation

After One Hour Predicts 24 Hour Fluid Requirement. Abstract accepted for Podium Presentation at AAST Meeting in San Diego California. September, 2018.

6. Improved Ultrasonographic 24 Hour Fluid Requirement Prediction – The IVC Shock Index Score. Accepted for Presentation at the Trauma Association of Canada Annual Scientific Meeting and Conference March, 2019.

7. Jay Doucet, M.D., Paula Ferrada M.D., Sarah Murthi M.D., Ram Nirula M.D., Sara Edwards M.D., Emily Cantrell, M.D., Jinfeng Han, Daniel Haase M.D., Andrew Singleton M.D., Katie Birkas M.Sc., Giovanna Casola, M.D., Raul Coimbra, M.D., Ph.D. Ultrasonographic IVC Diameter Response to Trauma Resuscitation After One Hour Predicts 24 Hour Fluid Requirement. Journal of Trauma. *Pending Publication*, 2019.

Participants & Other Collaborating Organizations:

Participants

Name	Project Role	Nearest person month worked	% Effort	Contribution to the project
Donald Jenkins	Principal Investigator	1	5%	Oversight of entire project
Michelle Price	Director of Research Operations	1	13%	Regulatory oversight and program coordination
Amy Flores	Controller	1	10%	Manage subawards
Lizette Villarreal	Program Manager	1	14%	Managing regulatory reviews and reporting

Other Collaborating Organizations

Organization	Location	Contribution to Project
University of California San Diego	200 W Arbor Drive, #8896, San Diego, CA 92103	Lead clinical site, protocol design, data analyses (PI: Jay Doucet, MD)
Virginia Commonwealth University	1200 Broad Street, Richmond VA 23298	Clinical site (PI: Paula Ferrada, MD)
University of Utah	30 North 1900 East, 3B110, Salt Lake City, UT 84132	Clinical site (PI: Ram Nirula, MD)
University of Maryland	620 West Lexington Street, Room 5124, Baltimore, MD 21201-1531	Clinical Site (PI: Sarah, Murthi, MD)

Special Reporting Requirements:
The Quad Chart for this project follows.

Detection and Management of Non-Compressible Hemorrhage by Vena Cava Ultrasonography (USA-IVC)

ERMS/Log Number: JW140026
Award Number: W81XWH-15-1-0709

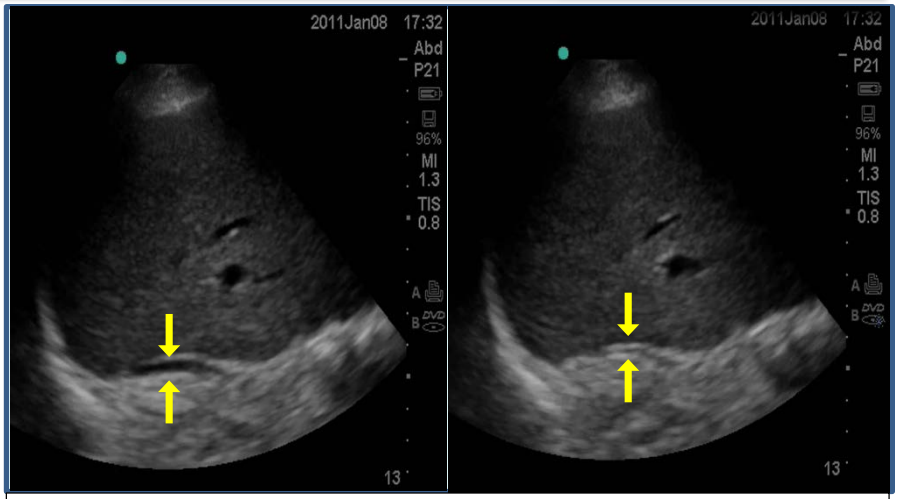
Grant PI: Donald Jenkins **PI:** Jay Doucet **Org:** NTI/UCSD **Award Amount:** $498,269

Study

1. Determine if ultrasonic assessment (USA) of Inferior Vena Cava (IVC) or Internal Jugular Vein (IJ) diameters is sensitive and specific in detecting hypovolemia at admission by predicting transfusion requirements.
2. Correlate the restoration of IVC diameters and collapsibility to achievement of endpoints of shock resuscitation in the ICU phase at 8-24 hours.

Approach

This is a randomized prospective clinical trial performed at 4 academic Level I trauma centers. Major trauma patients undergo a FAST abdominal ultrasound with USA of the IVC at admission and after minutes resuscitation. Patients with continued IVC collapse at the 2nd exam are considered Non-Responders to resuscitation. Their need for interventions and outcomes is compared to those with collapsible IVCs at admission that respond to initial resuscitation.



In our prior work, Clinician-performed FAST ultrasound detected persistent IVC Collapsibility in Major Trauma Victims which predicted 24 hour ongoing intravenous fluid requirements

Timeline

Activities CY	16	17	18
Patient Enrollment			
Develop standardized technique and training for USA-IVC exam			
Promulgate USA-IVC technique			

Updated: 12/14/2018

Goals/Milestones:

CY17-18 Goal – Patient Enrollment
☑Start patient enrollment at 4 Level I Trauma Centers
CY18 Goal – Data Analysis
☑ Analyze data and disseminate findings via NTI meeting, abstract and peer review publication
CY18 Goal – Promulgate USA-IVC technique
☑ Develop learning toolkit to allow providers to learn USA-IVC technique and QA process, including for pocket sized ultrasound devices. (Final toolkit pending publication)

As of 1/2012 Initial Protocol http://www.youtube.com/watch?v=bpaMTqqqGdw&feature=youtu.be

As of 2/2013 Amendment 2 http://youtu.be/gIIQuTMyJFE

As of 3/10/2013 Amendment 3 http://www.youtube.com/watch?v=-y6sPLpFIOM

As of 7/11/2016 Amendment 5 https://youtu.be/54-Z6fiJpPY

Protocol Video

Detection and Management of Non-Compressible Hemorrhage by Vena Cava Ultrasonography (USA-IVC)

NTI-NCH-10-016

PI: Jay Doucet MD, UC San Diego

Version 1/12

NATIONAL TRAUMA INSTITUTE

UNIVERSITY OF CALIFORNIA SAN DIEGO

Study Hypothesis

- The hypothesis of the proposed study is that an ultrasonic assessment (USA) protocol of inferior vena cava (IVC) diameter and collapsibility can detect and aid management of non-compressible hemorrhage in major trauma victims.

Inclusion Criteria

- Major Trauma Victims at Level I Trauma Center
- Significant IVC collapsibility (>75%) on initial FAST

Exclusion Criteria

- Pregnancy after 20 weeks gestation,
- Less than 18 years of age,
- Prisoners and others prohibited from participating in clinical trials and
- Patients with severe Traumatic Brain Injury who at admission are deemed by treating surgeons as having non-survivable brain injuries.

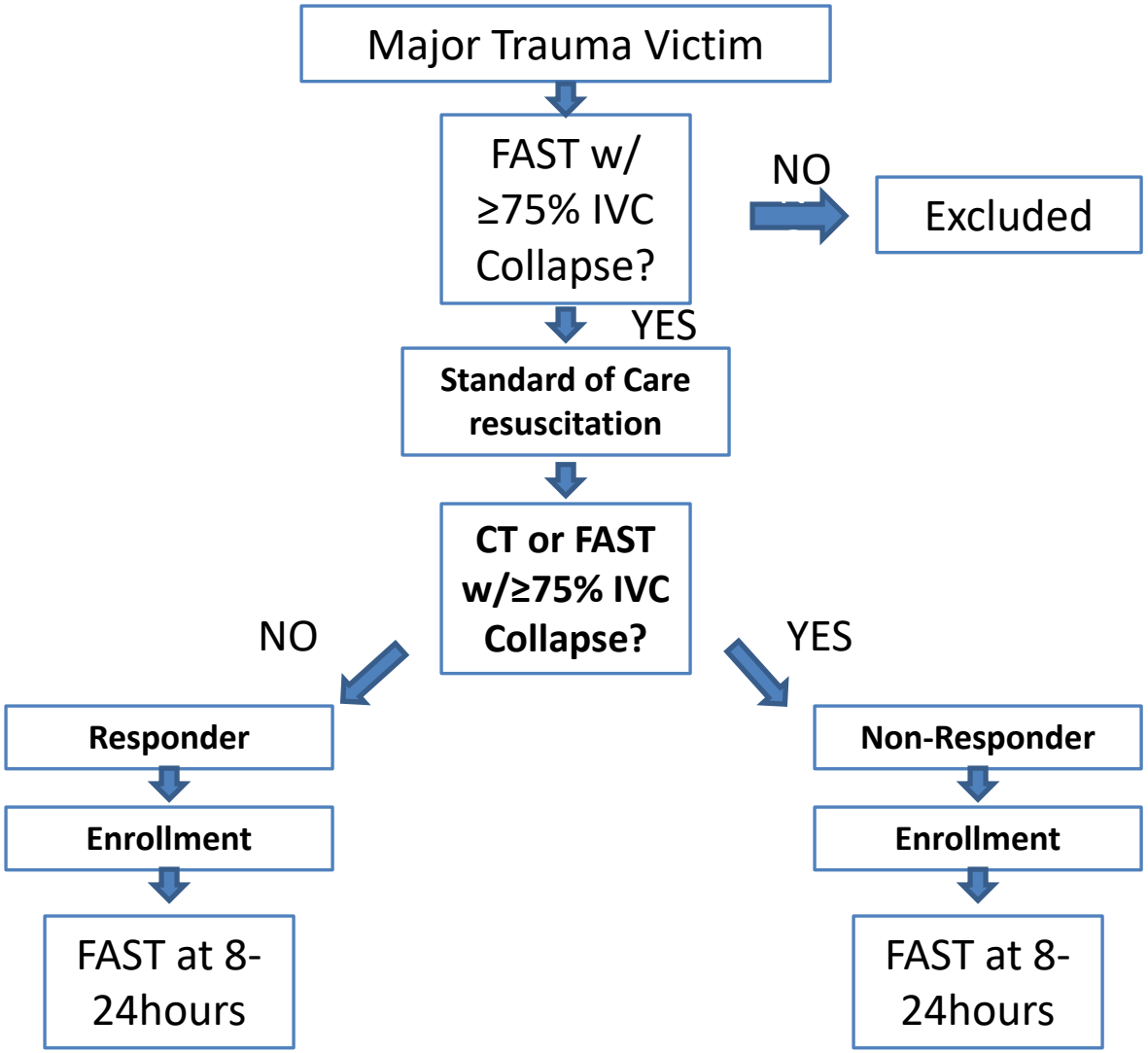
Study Procedures I

- All Major Trauma Victims (ISS ≥ 15) undergoing FAST have IVC diameters measured
- If significant IVC collapsibility seen (≥ 75%) with respiration, patient is study candidate
- Standard of care resuscitation
- CT abdomen and/or repeat FAST after 40 minutes

Study Procedures II

- Patients with continued collapsibility (≥ 75%) are non-responders, those with decreased collapsibility (< 75%) are responders
- Enrollment procedures, consent obtained
- Followup FAST after consent, 8-24 hours after admission when patient considered “resuscitated”, but NLT 24 hours.

Study Design I



Study Design II

- Total enrollment planned: 600
- Up to four centers (~ 125 enrollees each)
- Requires modified FAST during study period
- Data entered via AAST MITC website
- Images, video uploaded to website
- Quarterly reports

Ultrasound Procedure

- Record IVC diameter for two respiratory cycles
- Record in transverse plane and sagittal plane
- Probe can be placed on epigastrium or under right flank
- Record IVC diameters 2cm below IVC-hepatic vein confluence
- Save images as video clip (.avi, .mpg)

Questions?

- Study PI:
  - Jay Doucet MD FACS RDMS
  - jdoucet@ucsd.edu
- Study Coordinator:
  - Terry Curry RN
  - tcurry@ucsd.edu

THE IVC-FAST AAST MIT / NTI STUDY

Jay Doucet, M.D. [*], Paula Ferrada M.D. [**], Ram Nirula M.D. [***], Andrew Singleton M.D. [***], Christopher Dente M.D. [****], Rondi Gelbard M.D. [****], Seda Bourikian[**], Giovanna Casola, M.D.[†], Raul Coimbra, M.D., Ph.D[*].

The AAST-MIT Committee Investigators

Division of Trauma, Critical Care, and Burns[*] and Department of Radiology[†], University of California San Diego.
[**]Division of Trauma, Critical Care and Emergency Surgery, Virginia Commonwealth University.
[***]Department of Surgery, University of Utah.
[****]Department of Surgery, Emory University at Grady Memorial Hospital

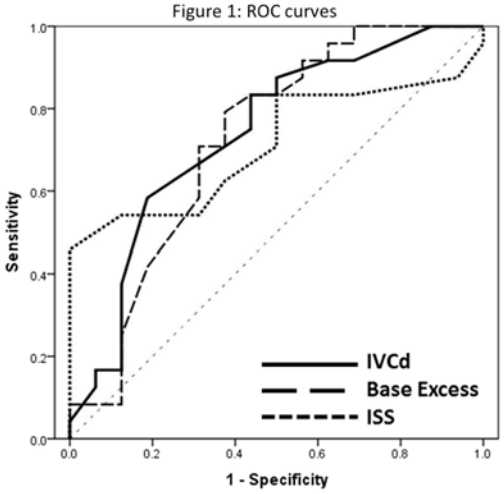
Introduction: Identification of occult hypovolemia in trauma patients at admission can be difficult without additional laboratory evaluation or advanced imaging. We hypothesized that in acute trauma patients, the response of ultrasound-measured inferior vena cava diameter (IVCd) in serial FAST examinations (FAST-IVC) during standard-of-care intravenous fluid resuscitation would predict 24 hour resuscitation intravenous fluid requirements.

Methods: A NTI / AAST-MITC group prospective, multi-institutional cohort trial was conducted at 4 Level I Trauma Centers. Major trauma patients were screened for an IVCd of 7mm or less on the initial FAST examination for enrollment. A second IVCd was obtained 40-60 minutes later, after the patient received standard-of-care fluid resuscitation. Patients whose second measurement IVCd remained less than 7mm were deemed Non-Responders (NON-RESP), those at or greater than 7 mm were Responders (RESP). Prehospital fluid, initial resuscitation fluid and 24 hour fluid requirements were recorded. Demographics, ISS, arterial blood gasses, ICU admission, length-of-stay, interventions and complications were recorded. Means were compared by ANOVA and categorical variables were compared via Chi-square. Receiver-operator characteristic (ROC) curves were used to compare the FAST-IVC test to Base Excess (BE), ISS and other fluid volume predictors.

Results: There were 2336 patients screened by FAST-IVC, 378 were identified with admission IVCd < 7mm, 76 were enrolled, 74 had useable imagery. There were 46 RESP and 28 NON-RESP. Table 1 shows the univariate analysis. NON-RESP needed significantly more fluid at 24 hours, (2887ml ± 1635 vs. 1881ml ± 790, p= 0.002). ROC (Figure 1) analysis indicates IVCd (AUC= 0.74, C.I.: 0.54-0.90) was comparable to ISS (AUC=0.71, C.I.:0.55-0.87) and BE (AUC=0.72, C.I.: 0.55-0.90) in predicting 24 hour fluid requirements.

Table 1: Results	RESP (n=46)	NON-RESP (n=28)	*p* value
Age (yrs)	49.9 ± 22	50.0 ± 25	N.S.
Gender	21F/25M	9F/19M	N.S.
ISS	8.4 ± 7.1	11.8 ± 10.5	N.S.
Base Excess	-0.96 ± 4.4	-2.16 ± 4.9	N.S.
Admission Sys BP (mmHg)	130 ± 25	127 ± 20	N.S.
Prehospital IV Fluids (ml)	129 ± 246	142 ± 279	N.S.
Initial Resus Fluids (ml)	637 ± 614	594 ± 545	N.S.
Post-resus IVCd	3.63 ± 1.96	13.21 ± 5.6	*p< 0.0001*
24-hour Fluids (ml)	1881 ± 790	2887 ± 1635	*p= 0.002*
Mortality	1/46	1/28	N.S.

Figure 1: ROC curves

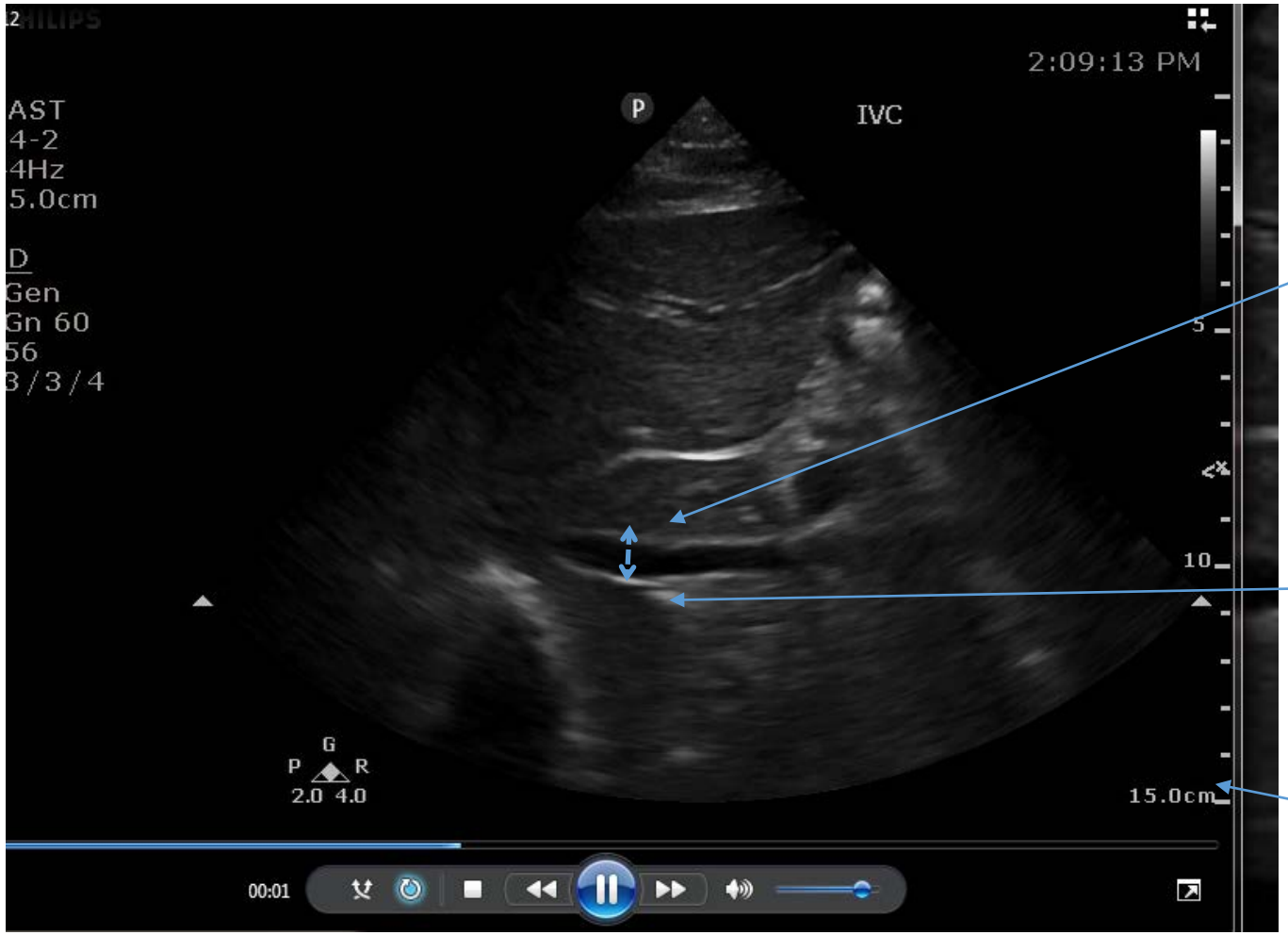


Conclusion: FAST-IVC was useful in predicting 24 hour fluid resuscitation requirements. A larger study with a pre-hospital FAST-IVC examination is planned.

How to measure for IVC FAST study

8/20/2018

IVC Long View

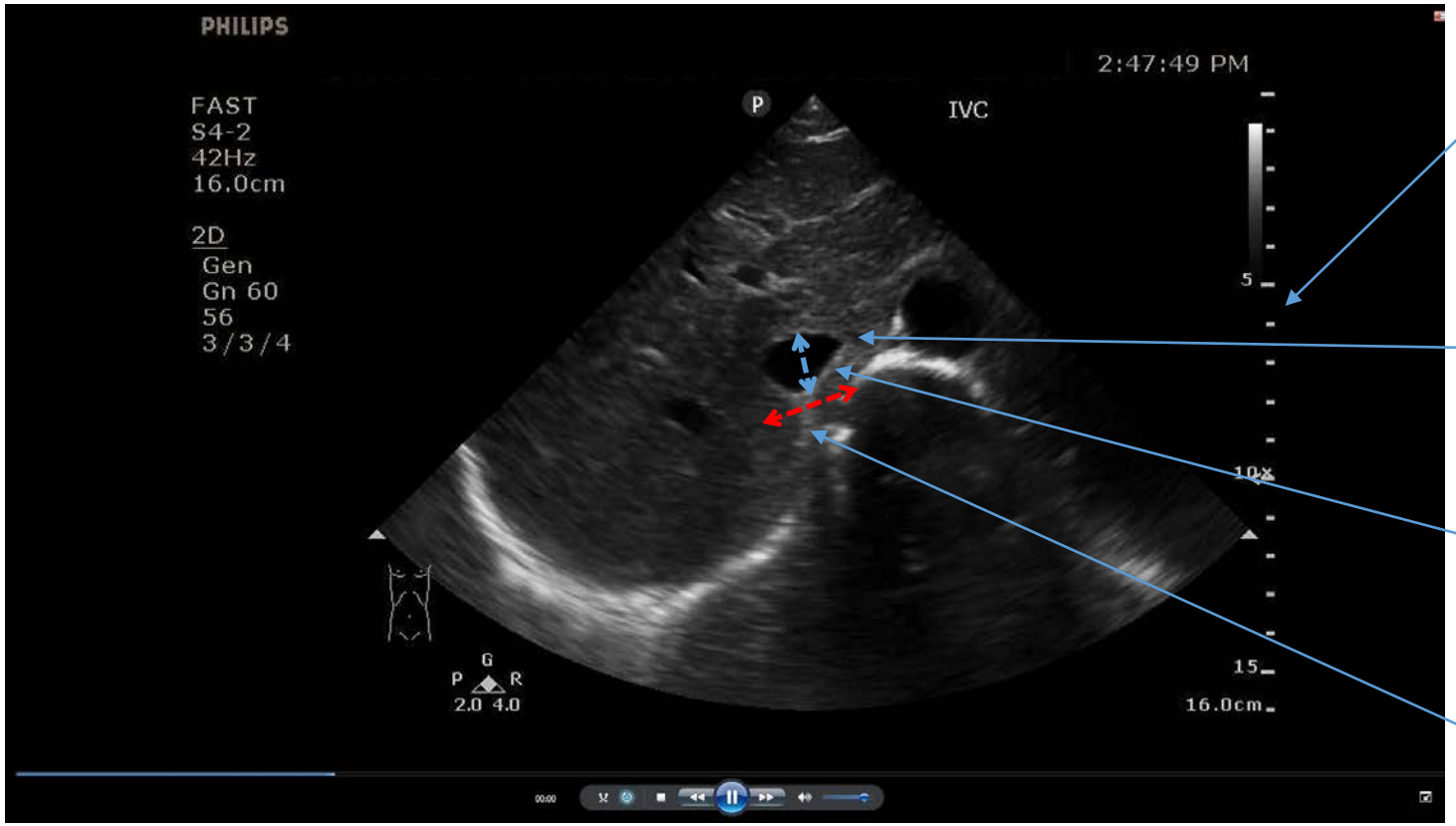


Measure smallest distance in IVC during respiration about 2cm below diaphragm – this is “Short Axis Minimum”

Measure largest distance in IVC during respiration about 2cm below diaphragm – this is “Short Axis Maximum”

Use scale (in cm) on screen

IVC Transverse View (15)



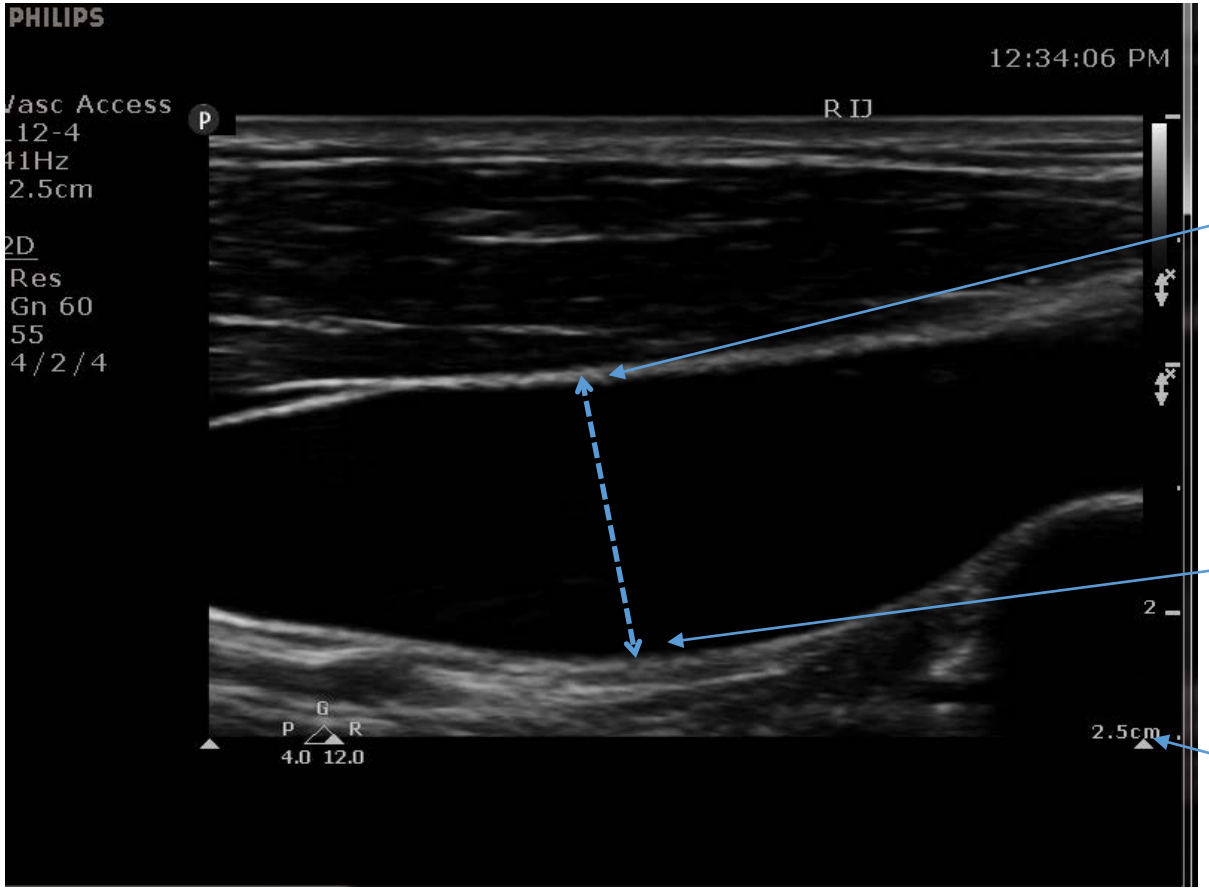
Use scale (in cm) on screen

Measure smallest distance of center of vein during respiration – this is "Short Axis Minimum"

Measure largest distance of center of vein during respiration during respiration – this is "Short Axis Maximum"

Measure widest part of vein respiration – this is "Long Axis Maximum"

Internal Jugular Long View (10)

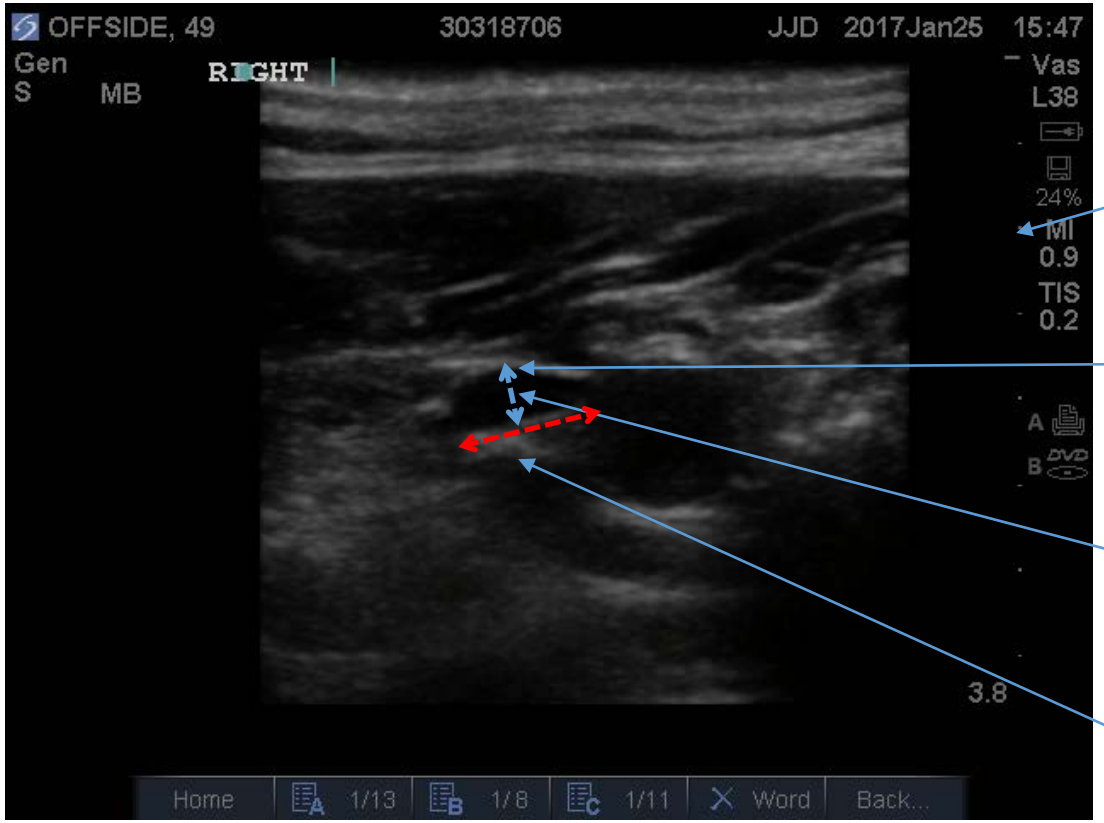


Measure smallest distance in IVC during respiration in widest part of vein – this is “Short Axis Minimum”

Measure largest distance in IVC during respiration in widest part of vein – this is “Short Axis Maximum”

Use scale (in cm) on screen

Internal Jugular Transverse View (10)



Use scale (in cm) on screen

Measure smallest distance of center of vein during respiration – this is "Short Axis Minimum"

Measure largest distance of center of vein during respiration during respiration – this is "Short Axis Maximum"

Measure widest part of vein respiration – this is "Long Axis Maximum"

Quality of Study

Please rank each studies quality from 1- 5

1. Unusable
2. Bad
3. Average
4. Better that average
5. Excellent (textbook)

Summary

- You can submit measurements in Excel form or on paper
- Let me know what questions you have
- Contact
- Jay Doucet
  - jdoucet@ucsd.edu
  - 619 929 5060.

ULTRASONGRAPHIC IVC DIAMETER RESPONSE TO TRAUMA RESUSCIATION AFTER ONE HOUR PREDICTS 24 HOUR FLUID REQUIREMENT

Jay Doucet, M.D., Paula Ferrada M.D., Ram Nirula M.D., Andrew Singleton M.D., Katie Birkas M.Sc., Sarah Murthi M.D., Daniel Haase M.D., Sara Edwards M.D., Giovanna Casola, M.D., Raul Coimbra, M.D., Ph.D.
The AAST-MIT Committee Investigators

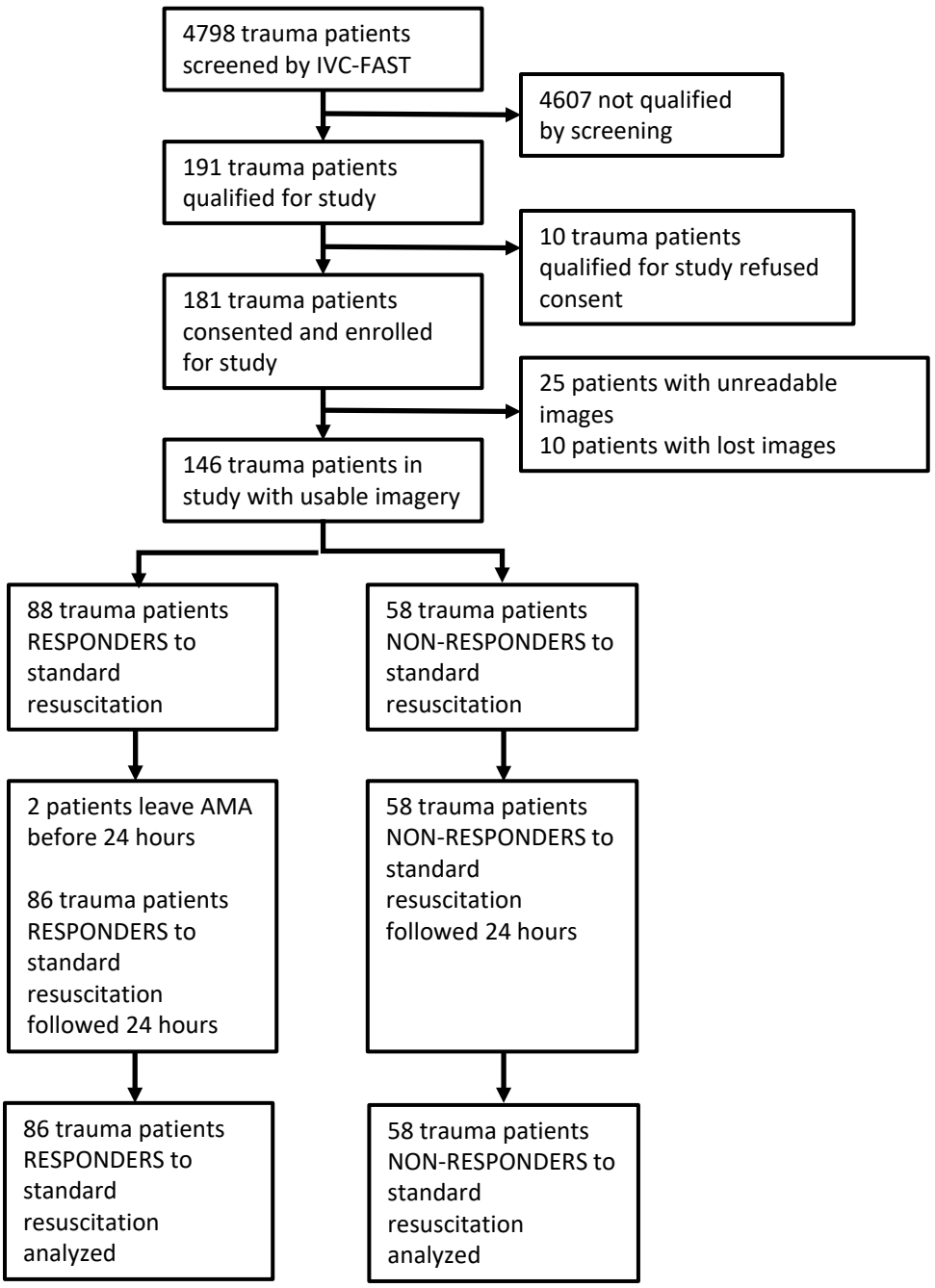
Introduction: Identification of occult hypovolemia in trauma patients at admission can be difficult without additional laboratory evaluation or advanced imaging. We hypothesized that in acute trauma patients, the response of ultrasound-measured inferior vena cava diameter (IVCd) or mean internal jugular diameter (IJd) in repeated eFAST examinations (USA-IVC) during standard-of-care intravenous fluid resuscitation would predict 24 hour resuscitation intravenous fluid requirements.

Methods: An interim analysis of the NTI / AAST-MITC group prospective, multi-institutional IVC-FAST cohort trial was conducted at 4 Level I Trauma Centers. Major trauma patients were screened in the supine position for an IVCd of 12 mm or less on the initial FAST examination for enrollment. A second IVCd was obtained 40-60 minutes later, after the patient received standard-of-care fluid resuscitation. Patients whose second measurement IVCd remained less than 10mm were deemed Non-Responders (NON-RESP), those at or greater than 10mm were Responders (RESP). Prehospital fluid, initial resuscitation fluid and 24 hour fluid requirements were recorded. Demographics, ISS, arterial blood gasses, ICU admission, length-of-stay, interventions and complications were recorded. Means were compared by ANOVA and categorical variables were compared via Chi-square. Receiver-operator characteristic (ROC) curves were used to compare the FAST-IVC test to Base Excess (BE), ISS and other fluid volume predictors.

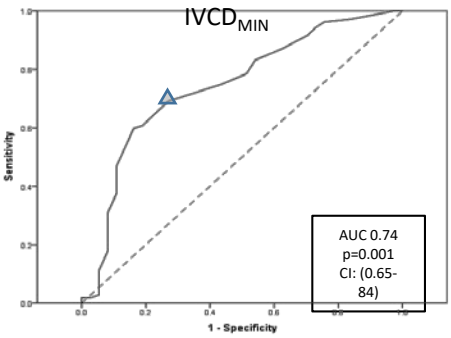
Results: There were 4798 patients screened by FAST-IVC, 378 were identified with admission IVCd < 12mm, 127 were enrolled and had useable imagery. There were 80 RESP and 47 NON-RESP. Table 1 shows the univariate analysis. NON-RESP needed significantly more fluid at 24 hours. ROC analysis indicates IVCd (AUC= 0.63, C.I.: 0.51-0.74, p=0.037) but not IJd (AUC= 0.42, C.I.: 0.24-0.60, p=N.S.) was comparable to ISS (AUC=0.75, C.I.:0.60-0.90, p=0.002) in predicting 24 hour fluid requirement.

Table 1: Results	**RESP (n=80)**	**NON-RESP (n=47)**	***p* value**
Age (yrs)	51.9 ± 24	57.9 ± 22	N.S.
Gender (% Male)	58% M	69% M	N.S.
ISS	8.4 ± 7.4	11.9 ± 8.6	p=0.045
Base Excess	-0.09 ± 3.2	-1.12 ± 5.1	N.S.
Admission Sys BP (mmHg)	136 ± 18	133 ± 25	N.S.
Prehospital IV Fluids (ml)	95 ± 227	80 ± 242	N.S.
Initial Resus Fluids (ml)	433 ± 519	410 ± 466	N.S.
Post-resus min IVCd (mm)	12.45 ± 5.7	6.19 ± 2.9	p< 0.0001
Post-resus mean min IJd (mm)	7.6 ± 3.9	5.4 ± 3.5	N.S.
24-hour Fluids (ml)	1640 ± 922	2604 ± 1187	p= 0.046
Mortality	1/80	1/47	N.S.

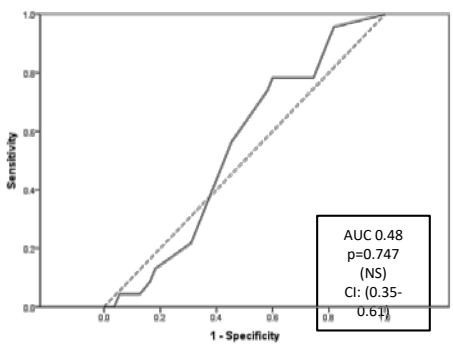
Conclusion: eFAST ultrasound IVC but not IJ diameter response to initial trauma resuscitation was useful in predicting 24 hour fluid resuscitation requirements.


4798 trauma patients screened by IVC-FAST
4607 not qualified by screening
191 trauma patients qualified for study
10 trauma patients qualified for study refused consent
181 trauma patients consented and enrolled for study
25 patients with unreadable images
10 patients with lost images
146 trauma patients in study with usable imagery
88 trauma patients RESPONDERS to standard resuscitation
58 trauma patients NON-RESPONDERS to standard resuscitation
2 patients leave AMA before 24 hours
86 trauma patients RESPONDERS to standard resuscitation followed 24 hours
58 trauma patients NON-RESPONDERS to standard resuscitation followed 24 hours
86 trauma patients RESPONDERS to standard resuscitation analyzed
58 trauma patients NON-RESPONDERS to standard resuscitation analyzed

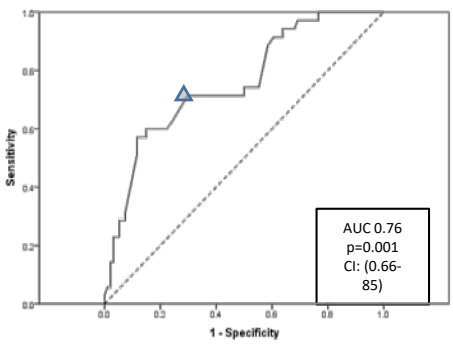
A. $IVCD_{MIN}$



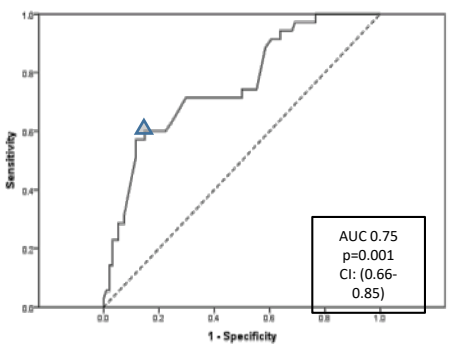
C. $IJVD_{MIN}$



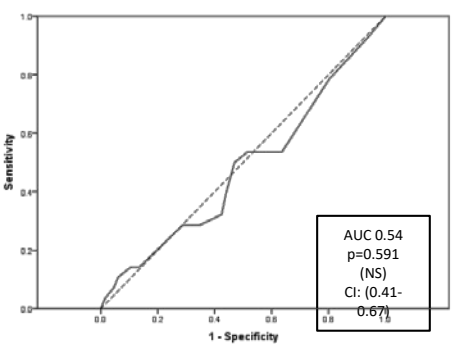
E: $IVCD_{MIN}$ + IVCCI



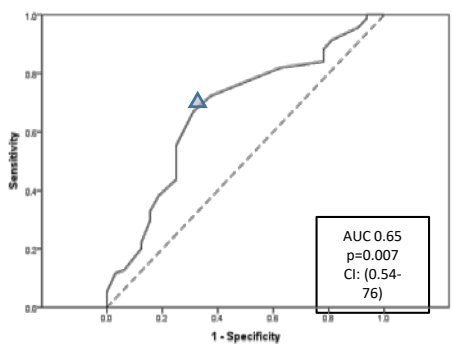
B. IVCCI

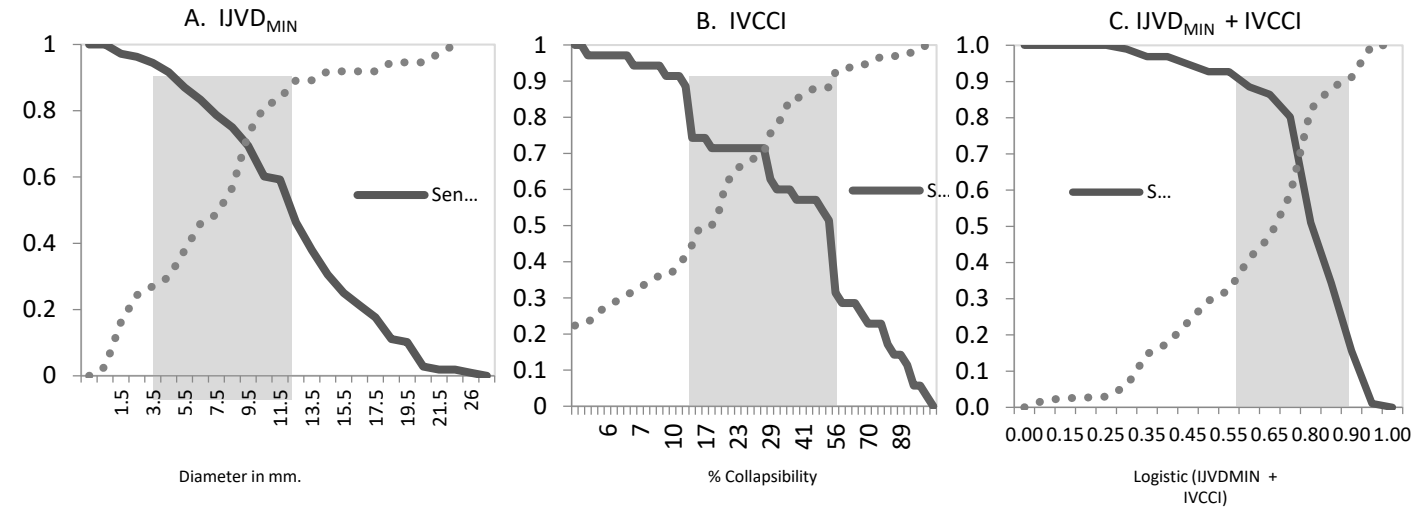


D. IJVCI



F. ISS




A. IJVD$_{MIN}$
1
0.8
0.6
0.4
0.2
0
Sen…
1.5
3.5
5.5
7.5
9.5
11.5
13.5
15.5
17.5
19.5
21.5
26
Diameter in mm.
B. IVCCI
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
S…
6
7
10
17
23
29
41
56
70
89
% Collapsibility
C. IJVD$_{MIN}$ + IVCCI
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
S…
0.00 0.15 0.25 0.35 0.45 0.55 0.65 0.80 0.90 1.00
Logistic (IJVDMIN + IVCCI)

IMPROVED ULTRASONOGRAPHIC 24 HOUR FLUID REQUIREMENT PREDICTION - THE IVC-SHOCK INDEX SCORE

Background: Identification of occult hypovolemia in trauma patients at admission is challenging. We previously showed response of ultrasonographic (US) respiratory minimum inferior vena cava size ($IVCD_{MIN}$) or IVC Collapsibility Index (IVCCI) in repeated US examinations after 1 hour of intravenous fluid resuscitation is moderately predictive of 24-hour resuscitation intravenous fluid requirements (24FR). We hypothesize combination of $IVCD_{MIN}$ or IVCCI with age, systolic blood pressure (BP), Shock Index (SI), or Revised Trauma Score (RTS) will improve ability to predict 24FR.

Methods: Data from FAST-IVC, a NTI-AAST-MITC prospective cohort trial at 4 Level I Trauma Centers was used. Trauma patients were screened for an $IVCD_{MIN}$ of 12 mm or IVCCI of 50%. 196 patients were enrolled. $IVCD_{MIN}$/IVCCI was obtained after 40-60 min of resuscitation. Regression was used to identify predictors of 24FR to be used as covariates in models with $IVCD_{MIN}$/IVCCI to be used in Receiver-Operator Curve (ROC) analysis. A 24FR predictive score was created..

Results: Combined models using ultrasonic assessment of the IVC and SI after 40-60 minutes of resuscitation, improved the C-index for IVCDMIN from 0.74 (CI: 0.65-0.84, p<0.0001) to 0.79 (CI: 0.71-0.88, p<0.0001) and the C-index for IVCCI improved from 0.76 (CI: 0.66-0.86, p<0.0001) to 0.80 (CI: 0.71-0<88, p<0.0001). A simplified IVC-SI score based on regression coefficients, using 0-3 points for IVCDMIN and 0-5 points for SI had a C-index of 0.78 (CI: 0.69-0.86, p<0.0001) using the FAST-IVC dataset.

Conclusions: For major trauma patients, a regression model combining post-resus SI and $IVCD_{MIN}$ or IVCCI improves predictive ability for 24FR from good to strong. A simplified post-resus IVC-SI score was created, however this score will require clinical validation.

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Ultrasonographic IVC Diameter Response to Trauma Resuscitation after One Hour Predicts 24 Hour Fluid Requirement

--Manuscript Draft--

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9/7/2018

Ernest Moore, MD FACS
Editor, Journal of Trauma and Acute Care Surgery

Subject: 2018 AAST Podium Paper - Ultrasonographic IVC Diameter Response to Trauma Resuscitation after One Hour Predicts 24 Hour Fluid Requirement

Dear Dr Moore:

Please find attached the subject 2018 AAST Podium Paper manuscript, which is an original article and has not been presented or published in any other media or venue.

We hope that our submission will be acceptable and look forward to your reply.

If you have any questions, please do not hesitate to contact me,

Very respectfully,

Jay Doucet

ABSTRACT

Introduction: Identification of occult hypovolemia in trauma patients at admission can be difficult without additional laboratory evaluation or advanced imaging. We hypothesized that in acute trauma patients, the response of ultrasound-measured minimum inferior vena cava diameter ($IVCD_{MIN}$), IVC Collapsibility Index (IVCCI) or minimum internal jugular diameter ($IJVD_{MIN}$) or IJV Collapsibility Index (IJVCI) in repeated ultrasound examinations (USA-IVC) during up to 1 hour of standard-of-care intravenous fluid resuscitation would predict 24-hour resuscitation intravenous fluid requirements (24FR).

Methods: An NTI funded, AAST-MITC group prospective, multi-institutional cohort trial was conducted at 4 Level I Trauma Centers. Major trauma patients were screened in the supine position for an IVCD of 12 mm or IVCCI of 50% or less on the initial FAST examination for enrollment. A second IVCD was obtained 40-60 minutes later, after the patient received standard-of-care fluid resuscitation. Patients whose second measurement IVCD was less than 10mm were deemed Non-Responders (NON-RESP), those at or greater than 10mm were Responders (RESP). Prehospital fluid, initial resuscitation fluid and 24FR were recorded. Demographics, ISS, arterial blood gasses, ICU admission, length-of-stay, interventions and complications were recorded. Means were compared by ANOVA and categorical variables were compared via Chi-square. Receiver-operator characteristic (ROC) curves and gray area analysis were used to compare the IVC and IJV measures and to Base Excess (BE), ISS and other 24FR predictors.

Results: There were 4798 patients screened by FAST-IVC, 196 were identified with admission IVCD of 12 mm or IVCCI of 50% or less, 144 were enrolled and had useable

imagery. After 1 hour of standard of care resuscitation, there were 86 RESP and 58 NON-RESP. There were no significant differences between groups in demographics. initial hemodynamics or laboratory measures. NON-RESP had smaller IVCD (6.0mm ± 3.7 vs.14.2mm ± 4.3, p< 0.001) and higher IVCCI 41.7% ± 30.0 vs. 13.2% ± 12.7, p< 0.001) but no significant difference in IJVD or IJVCCI. RESP had significantly greater 24FR than NON-RESP (2503ml ± 1751 vs. 1243ml ± 1130, p= 0.003). ROC analysis indicates $IVCD_{MIN}$ predicted 24FR (AUC= 0.74, C.I.: 0.64-0.84, p<0.001) as did IVCCI (AUC= 0.75, C.I.: 0.65-0.85, p<0.001) not IJVD (AUC= 0.48, C.I.: 0.24-0.60, p=N.S.) or IVCCI (AUC= 0.54, C.I.: 0.42-0.67, p=N.S.) and more predictive than ISS (AUC=0.65, C.I.:0.54-0.76, p=0.007) in predicting 24FR.

Conclusion: Ultrasound assessed $IVCD_{MIN}$ and IVCCI but not IJ diameter response to initial major trauma patient resuscitation predicts 24-hour fluid resuscitation requirements.

Level of Evidence: II+ **Study Type**: Diagnostic tests or criteria

Key Words: Trauma, Ultrasound, Shock, Resuscitation, Vena Cava

Title Page

Ultrasonographic IVC Diameter Response to Trauma Resuscitation after One Hour Predicts 24 Hour Fluid Requirement

Short header: Ultrasonographic IVC Diameter Response to Trauma Resuscitation

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The authors declare they have no conflicts of interest regarding this work.

This work was not previously presented (it is intended for the 77th Annual Meeting of AAST and Clinical Congress of Acute Care Surgery. September 24-16, 2017. San Diego, CA).

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Author Contributions:

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Paula Ferrada MD: Study design, Data collection, Critical revision.
Sarah Murthi MD: Data collection, Critical revision.
Ram Nirula MD MPH; Study design, Data collection, Critical revision.
Sara Edwards MD: Data collection, Data analysis, Critical revision.
Emily Cantrell MD: Data collection, Data analysis, Critical revision.
Jinfeng Han BSN: Data collection, Critical revision.
Daniel Haase MD: Data collection, Critical revision.
Andrew Singleton MD: Data collection, Data analysis, Critical revision.
Katie Birkas: Data collection.
Giovanna Casola MD: Critical revision.
Raul Coimbra MD, PhD: Critical revision.

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INTRODUCTION

Determining which major trauma patients are fluid responsive (FR) at admission is often difficult in the absence of overt hypotension. Both clinical assessment and invasive measures such as central venous pressure (CVP) or have a reliability in predicting FR only slightly better than chance. (1, 2) Concern over inadequate resuscitation has led in the past to guidelines supporting aggressive fluid administration with a risk of over-resuscitation. Current approaches recommend early balanced transfusion in overt shock (3) but crystalloid administration when uncertainty exists. Ultrasound (US) has emerged as a non-invasive, rapid, point of care test that may be an attractive option to assess volume status and FR.

US assessment of the IVC diameter (IVCD) and its variation or collapsibility with respiration (IVCCI) is a reproducible and usually easy to perform US examination.(4) US assessment of the minimum IVCD ($IVCD_{MIN}$), maximum IVCD ($IVCD_{MAX}$) or IVCCI measures can be difficult or unobtainable in some cases due to obesity, increased abdominal pressure, bowel gas, air in tissues or if wounds or dressings intervene. US assessment of the internal jugular vein (IJV) and its minimum ($IJVD_{MIN}$) and maximum diameter (IJV_{MAX}) and respiratory variation or collapsibility (IJVCI) is a more recently proposed measure in ventilated and septic ICU patients(5, 6) and blood donors(7, 8), but has not been described in resuscitation of trauma patients.

The primary objective of this study is to determine if repeated ultrasound assessment of $IVCD_{MIN}$, IVCCI and of $IJCD_{MIN}$, IJVCI after standard of care resuscitation in major trauma patients presenting with small or collapsible IVCs will predict FR within 24 hours of admission.

The secondary objective is to compare US measures of FR in order to determine the best measure or best combination of measurements to determine FR in major trauma patients.

METHODS

A prospective, multi-institutional, observational cohort human trial in adult major trauma patients presenting to four U.S. Level I trauma centers was conducted. Institutional Review Board (IRB) and US Army Human Research Protections Office (HRPO, HSRRB Log Number A-18698) approvals were obtained at participating centers. The study was entered in the ClinicalTrials.gov registry with identifier NCT01989273. Because of the short time available to obtain necessary ultrasound images at admission, IRB (UCSD IRB 100326) and HRPO (HSRRB Log Number A-18698) approval was obtained to complete patient consent to participate in the study after the required study imaging was obtained. Patients who refused consent were withdrawn from the study and their study images and data not used. Data was collected in a secure electronic database via the AAST-MITC study data website.

Enrollment and Data Collection

The trial was conducted in two phases, in the first 18-month phase starting June 2012, and a second 18-month phase starting July 2016 and ending in March 2018. Focused assessment sonographic evaluations for trauma including views of the inferior vena cava were performed on major trauma victims as part of standard resuscitation within 30 minutes of admission. Major trauma victims who had evidence of increased IVC collapsibility**:** (IVC-CI $\geq$ 50%) or an IVC diameter of $\leq$ 12 mm on the initial FAST examination were candidates for enrollment. Exclusion criteria were pregnancy after 20 weeks gestation, patients under 18 years of age, prisoners or others prohibited from participating in clinical trials and patients with severe

traumatic brain injury who at admission were deemed by treating surgeons as having non-survivable brain injuries.

Responders (RESP) and Non-responder (NON-RESP) cohorts were selected on IVC diameter (IVCD) response to interventions in the Trauma Bay on a follow-up FAST-IVC obtained after sixty minutes of resuscitation. RESP had restoration $IVCD_{MIN}$ to 10mm or greater after one hour of standard of care resuscitation. NON-RESP were those with an $IVCD_{MIN}$ of less than 10 mm of more after one hour of standard of care resuscitation. During the first 18-month phase starting June 2012, IVC video clips only were obtained. In the second 18-month phase starting July 2016, video clips of right and left internal jugular veins were also obtained at the same time as the FAST-IVC video clips.

Although the ultrasound images obtained were by necessity not blinded to the team members, the actual measurement of the IVC and IJV was performed by the investigators only after patient discharge. No interventions were based on the assigned group, all resuscitation and subsequent treatments were those performed as the standard of care for that trauma center.

The primary dependent variables included hospital mortality, need for hemostatic interventions such as surgery or angiography, need for ICU admission, need for ventilation, crystalloid intravenous fluid and blood product transfusion requirements within 24 hours, mortality and complications. Other variables collected included vital signs, Injury Severity Scale (ISS), and admission arterial blood gases in the first 24 hours including arterial blood gas base deficit.

Sonographic Technique and Equipment

The participating trauma centers routinely utilize clinician-performed Focused Assessment with Sonography for Trauma (FAST) at admission. Sonographers were either clinician-sonographers or registered diagnostic sonographers (RDMS) who perform FAST routinely at their center. Patients undergoing FAST+IVC diameter measurement were examined in the supine position (0 degrees). All examinations were done in a 0-degree, flat bed position and except for standard of care fluid resuscitation, no provocative maneuvers such as bed tilting, straight-leg raising, deep breathing or sniffing were performed. Two FAST+IVC serial exams were performed – the first within 30 minutes of admission and a second within 60 minutes of admission but more than 20 minutes after the first FAST+IVC exam.

Sonographic evaluation of IVC diameters was performed according to a methodology described by the study authors in written and video training materials provided to sonographers participating in the study. IVC views were obtained using a phased array probe via an initial B-mode paramedian longitudinal window of the IVC about 2cm below level of the hepatic veins, within 2.5–5 cm from the right atrium. Alternately, especially if gas obscured the paramedian window, visualization via a liver window along the right posterior axillary line was used. Details of these techniques have been outlined elsewhere. Images were stored as video clips through at least two respiratory cycles.

Internal jugular vein views were obtained by high frequency linear transducer probe. The left and right IJ were imaged in short and long axis in the neck at the level of the cricoid with the patient

supine (0 degrees). The maximal and minimal diameter as a result of respiratory variation was assessed at both positions from the short and long axis view. In cases where the attending surgeon deemed it too unsafe to remove the cervical collar in cases of suspected spine injury, only IVC views were obtained without IJV views. Ultrasound machines used varied by center, these included the M-Turbo (Sonosite, Bothell, WA), CX- 50 (Phillips, Andover, MA), Logiq-e (General Electric, Boston, MA) and the Z.One Pro (Mindray, Mahwah, NJ).

IVC and IJV Collapsibility Index

The inferior vena cava's diameter was measured at its largest diameter (usually at end-expiration, IVCDe) and at its smallest diameter (usually at the end of inspiration (IVCDi). Since some patients would be intubated and on positive pressure ventilation which may invert the relationship between respirations and IVC size, instead of using IVCDe and IVCDi, we simply used the maximal ($IVCD_{MAX}$, $IJVD_{MAX}$) and minimal ($IVCD_{MIN}$, $IJVD_{MIN}$) vessels sizes seen on the recorded video. Collapsibility Index (IVCCI) was calculated as ($IVCCI=[(IVCD_{MAX} - IVCD_{MIN})/ IJVD_{MAX}] \times 100\%$). Similarly, IJV Collapsibility Index (IJVCI) was calculated as ($IJVCI=[(IJVD_{MAX} - IJVD_{MIN})/ IJVD_{MAX}] \times 100\%$). Because of the variation of internal jugular sizes between sides in the same patient, the left and right IJVs were recorded as separate images for each patient and treated as separate measurements for each patient.

Data Interpretation and Statistical Analysis

After 18 months an interim analysis was performed to determine the feasibility of the study and measurements and to consider modification by adding the IJV measurements. To determine interobserver variability, three different reviewers (2 clinician-sonographers and 1 RDMS clinician-sonographer) analyzed images from 50 randomized patients and the interrater reliability was determined via two-way mixed consistency average-measures intra-class correlation (ICC) for $IVCD_{MIN}$, IVCCI, $IJVD_{MIN}$ and IJVCI. (9)

Sample size was derived from published data indicating that ultrasound measurement of IVC diameter for a 450ml blood loss in blood donor volunteers is highly sensitive[5]. It was anticipated about 5% of patients admitted to Level I Trauma Centers present would have significant IVC collapsibility on initial FAST. The four participating trauma centers admit 8,000 trauma patients per year, which would mean approximately 400 patients should be admitted annually with IVC collapsibility. A Power calculation determined that to detect a difference of 10% in a binary outcome such as mortality between RESP and NON-RESP groups with a beta-error of 20% or less and alpha of 0.05, about 492 study patients would be required.

Frequencies of categorical variables for the groups (i.e., gender, mortality, need for surgery) were analyzed by Chi-Square. Continuous variables were analyzed by ANOVA. Correlation using Pearson correlation coefficient for total 24-hour FR was obtained for ISS, Base Deficit, $IVCD_{MIN}$, $IVCD_{MAX}$, $IJVD_{MIN}$, $IJVD_{MAX}$, IVCCI and IJVCI. To test the association between the measurements and 24-hour FR, a multivariate logistic regression was also conducted. According to literature and clinical practice, we selected covariates of age, gender, ISS, admission shock

index, (heart rate divided by systolic blood pressure), systolic blood pressure (SBP) on leaving the resuscitation bay and arterial blood gas base deficit.

Receiver operating characteristic (ROC) curves were used to determine the ability of ISS, Base Deficit, $IVCD_{MIN}$, $IVCD_{MAX}$, $IJVD_{MIN}$, $IJVD_{MAX}$, IVCCI and IJVCI to predict the need for 2400ml or more of intravenous fluid in the first 24 hours after admission. Those receiving 2400ml or greater were +24FR and those less than 2400 ml were -24FR. The area under the curve (AUC) for each measure was calculated. Sensitivity, specificity, with 95% confidence intervals were calculated for each measure. The Youden index (=Sensitivity + Specificity – 1) was used to determine the optimal sensitivity and specificity for each measure. Evaluation of these ROC criteria was used to identify upper and lower cut-off values for each measurement. The gray zone approach described by Coste and Pouchot was used to determine the inconclusive range of measurement values.(10, 11) The gray zone was created between the 90% sensitivity and the 90% specificity points on the two sigma curves. The percentage of patients not falling into the gray zone was determined for each predictive measure. ROC curves were created for combinations of variables using the predicted probabilities derived from binary logistic regression.

All statistical analysis were performed used IBM SPSS Statistics, version 25.0 (IBM Corp, Armonk, NY). A P value less than 0.05 (two-tailed) was considered significant.

RESULTS

Over the study period 191 patients were enrolled, and 144 patients completed the study, the CONSORT patient flow diagram is shown at Figure 1. Needed images were lost in 10 patients, and images were found to be unusable in 25 patients. Consent was refused in 15 patients after image acquisition. 2 patients left against medical advice before 24 hours had elapsed. There were no significant differences in age, ISS, gender, BMI, mechanism of injury, hemodynamics, prehospital and initial fluid volumes given, mortality, need for surgery, ICU or hospital LOS or ventilator days between RESP and NON-RESP (Table 1). Bilateral internal jugular views were obtained in 52 patients. The interrater reliability as ICC was good overall (0.92, 95% C.I.: 0.949-0.972, $p<0.001$) and also good for $IVCD_{MIN}$ (0.853, 95% C.I.: 0.717-0.929, $p<0.001$), IVCCI (0.851, 95% C.I.: 0.851-0.925, $p<0.001$), $IJVD_{MIN}$ (0.951, 95% C.I.: 0.897-0.979, $p<0.001$) and IJVCI (0.862, 95% C.I.: 0.714-0.941, $p<0.001$).

After initial resuscitation, RESP did have a significantly larger $IVCD_{MIN}$ than NON-RESP, and they received significantly more intravenous fluids by 24 hours. There was a trend towards increased transfusion in the NON-RESP, but this did not achieve significance. $IJVD_{MIN}$ was not significantly different between the groups.

Correlation tests for 24-hour FR with predictive measures are shown at Table 2. Base Deficit, ISS, $IVCD_{MIN}$, $IVCD_{MAX}$ and IVCCI were all significantly correlated with 24-hour FR, but IJV measures of were not. $IVCD_{MIN}$, $IVCD_{MAX}$ and IVCCI had a moderate correlation with 24-hour fluid requirement and were comparable to ISS but stronger than the weak correlation with base deficit.

The regression analysis is shown at Table 3. After adjusting for age, gender, ISS, admission shock index, SBP on leaving the trauma bay, base deficit, $IVCD_{MIN}$, and IVCCI were significant independent predictors of 24-hour FR.

Examination of the ROC analysis at Figure 3 shows that IVCCI was the most predictive measure for +24FR with an AUC of 0.75 of the single tests, $IVCD_{MIN}$ has a comparable AUC at 0.74. $IJVD_{MIN}$ and IJVCI were not significantly sensitive or specific to have a useful AUC. ISS was also moderately predictive of +24FR at an AUC of 0.65. A binary logistic regression model was used to combine the $IVCD_{MIN}$ and IVCCI measures to attempt to create a more predictive measure, Logistic($IVCD_{MIN}$ + IVCCI), which yielded an AUC of 0.75, a very slight increase in AUC over $IJVD_{MIN}$ but not IVCCI.

Gray zone plots for +24FR were plotted for $IVCD_{MIN}$, IVCCI and Logistic($IJVD_{MIN}$ + IJVCI) (Figure 4). IVCCI at 89% had the most patients outside a gray zone with a CI of 41-51%). Both $IVCD_{MIN}$ and the Logistic($IJVD_{MIN}$ + IJVCI) combined model had 55% of patients outside the gray zone (Table 4), with the combined model having increased PPV but a lower NPV compared to IVCCI and $IVCD_{MIN}$. IJVCI had a high PPV at 81%, but only 27% of patients were outside the gray zone.

DISCUSSION

This study of ultrasound used in major trauma patients during initial resuscitation shows that US assessment of IVC (12) diameter and collapsibility is a useful investigation to determine 24-hour FR, with some limitations. Ultrasound assessment to detect intraabdominal and intrathoracic injuries is well established(13-15), but the use of ultrasonic measures to determine FR is newer and several US examinations and maneuvers have been proposed. Five studies that demonstrated an association of decreased IVC diameter with shock in patients with shock or gastrointestinal bleeding have been subjected to meta-analysis.(16) This showed that there was an overall reduction of IVC diameter in shock states. However, only a small percentage of trauma patients present in overt Class III or greater shock. In patients with lower grades of shock, clinicians have about the same efficacy as a coin-toss in determining fluid responsiveness from examination or CVP alone(1, 2, 17), and concerns regarding the adverse effects of crystalloid over-resuscitation has recently caused the Advanced Trauma Life Support to reduce the initial fluid crystalloid bolus for adult trauma patients from 2 liters to 1 liter(3).

Guidelines from the American Society of Echocardiography support the use of IVC size and IVCCI in the assessment of volume status.(18) IVC diameter may be a reliable indicator of volume status(19), and IVCCI may be predictive of FR in the ICU(20, 21). Most of the studies of US assessment of the IVC for FR are based in ICU patients under mechanical ventilation, which seems to increase sensitivity (12, 22-24). One study of spontaneously breathing ICU patients with straight leg raising or 500ml boluses did not show IVC respiratory variation was predictive (25), while another study using a 500ml bolus showed that it was predictive.(26) Similarly 5

studies on the effect of a blood donation analogous to Class I shock on IVC respiratory variation were contradictory. (27-31) The accuracy of IVC respiratory variation in determining FR was questioned in a study using straight leg raising in a heterogeneous ER patient population.(32) However, these studies did not include major trauma victims who may have ongoing bleeding.

The utility of a single, static ultrasound assessment of the IVC in acute trauma patients was not supported by a study of 140 acute trauma admissions found that a single ultrasonographic or computed tomographic measurement of IVC diameter did not correlate with vital signs, hemorrhage or shock markers.(33) In our study, we also did not see differences in vital signs or shock markers based on IVC_{MIN} or IVCCI at admission. However, the use of repeated US examinations and provocative tests may increase the predictive ability of US assessment of $IVCD_{MIN}$ and IVCCI for FR. We found that $ICVD_{MAX}$ and IVCCI were significantly associated with +24FR. $ICVD_{MIN}$ and IVCCI had AUCs that were moderately predictive, 0.74 to 0.75. Our lower cutoff of 41% for IVCCI is similar to results of other studies for FR. (12, 34, 35)

The combination of a small $ICVD_{MIN}$ and high IVCCI collapsibility has been shown to be predictive of FR in ICU patients.(36) However, when we combined these two measures in a model as Logistic($ICVD_{MAX}$ + IVCCI), this did not significantly increase the AUC (0.75), but did increase PPV with a lower NPV. We recommend that either $ICVD_{MAX}$ or IVCCI can be used to detect FR after initial standard of care initial trauma resuscitation.

The failure of our IJV measurements to predict FR after standard of care initial trauma resuscitation may be due to several factors. Prior studies using IJV measurements either used

ventilated patients (5, 6), employed positional variation in ICU patients (12) or examined ICU patients in semi-recumbent position. (5) However, less than 10% of patients were ventilated and we did not elevate our patient's heads by protocol and could not do so in most of our major trauma patients due to the need for a workup to rule out spinal injury. This may have compromised the utility of our IJV measures. We also only collected IJV measures in the second half of the study, thereby increasing the risk of a type II statistical error, however we did not see any trends toward significance.

Our study has several limitations. We had a failure rate of 19.5% to obtain usable images in qualified patients, although this is similar to similar studies.(11) Only 14% of stored images were unusable, which is better than some comparable studies. Operator experience did not affect the quality of images, as previously seen. (11) A significant issue was lost images, which usually occurred when the correct images were obtained but errors were made in saving the images to the machines' internal memory storage or to the PACS system. While we used a common protocol and training video for all sonographers, each of the centers had different ultrasound machines. Although the imaging techniques and modes were similar between machines, each machine has a different keypress sequence or required text entries to safely store and identify images. These differences should be addressed in training for any future multi-center study. Newer US machines have the ability to instantaneously and wirelessly store studies in a cloud-based PACS system, sometimes with voice enabled dictation, which may alleviate these issues. If we had included the lost and unusable images in our statistics in the same manner as in an-intent-to-treat analysis, the usefulness of the measures would suffer. However, in clinical

practice, decision-making about fluid resuscitation occurs simultaneously with imaging, and so storage problems may be less important.

Another limitation was the low prevalence of small or collapsible IVC at admission of screened major trauma patients. This rarity of IVC collapsibility at admission for major trauma patients led to a low rate of patient accrual during the study. A reason for this may be due to administration of prehospital intravenous fluid, which the large majority of the blunt trauma patients transported by EMS to our centers received but only 47% of enrolled study patients received. The mean prehospital infused volumes for study patients were also quite small, only 212ml. Based on prior literature, we had qualified patients had to have an initial US $IVCD_{MIN}$ of 12mm or less or 50% or greater IVCCI, which we now recognize overlaps the gray zones for these measures and likely reduced recruitment of useable cases.

A further limitation in applying these results is that unlike many laboratory blood tests, in practice US does have broad true gray areas. Determining exactly 41% collapsibility may be difficult for any provider to see at the bedside. Although we had high interrater reliability when measuring recorded images, clinicians will not have the same luxury as researchers making multiple measurements of ultrasound images while seated at a large monitor. In many disciplines, ultrasonographic assessment is often semi-quantitative, using grading scales and ranges to describe physiologic findings. It may be worthwhile to consider the IVCCI and $IVCD_{MAX}$ assessments in trauma resuscitation to reflect ranges of very likely, possibly and unlikely to be FR. Like FAST, US assessment is always made in the context of a dynamic

situation, that is, the resuscitation of an acute major trauma patient, and other clinical and laboratory assessments for FR will continue to be contributory.

By design, we limited our examinations to the IVC and IJV, which reflect the capacity of the venous system supplying the right heart. Other studies have combined these measures with left and right heart echocardiographic assessments, in an attempt to improve the utility of US assessment of hemodynamics. Such techniques may also allow the operator to overcome issues with body habitus, spine precautions, bowel gas and air in tissues that may limit IVC or IJ US assessment. The most common combinations are cardiac ventricular volumes or flows by using Doppler mode velocity time integral (VTI), cardiac output or stroke volume with IVC or IJV sizes and CI. (12, 21, 37, 38) While these techniques may improve the detection of FR, they require the operator-intensivist to be familiar with echocardiography and make quantitative assessments using modes such as VTI, which may limit utility with less trained providers and in environments more austere than the academic center's ICU. Another set of combinations not requiring skills in echocardiography is to combine IVCD, IJVD, IVCCI or IJVCI CI with US assessment of other vessels (39) or with other hemodynamic measurements such as mean arterial pressure(40) or arterial line-derived stroke volume variation(5). These have yet to undergo trials in major trauma patients.

In conclusion, US assessment of IVC diameter and collapsibility provides a rapid, non-invasive way to determine the 24-hour FR of major trauma victims within one hour of admission. We were unable to show that IJV diameter and collapsibility were predictive of 24-hour FR in supine major trauma victims receiving standard of care resuscitation without other provocative

maneuvers. Future clinical research should focus on rapid, reproducible and easy to perform non-invasive imaging approaches that limit the harm from either unrecognized hypovolemia or over-resuscitation. Already available are a second generation of low cost, handheld pocket-sized ultrasound devices that are wireless or connect to personal smartphones. These promise to make US assessment ubiquitous inside and outside the hospital by multiple disciplines and provider types. In the near future, low cost, disposable, conformal ultrasound bandages may be worn in austere, prehospital and hospital environments to provide continuous recording of hemodynamic parameters. (41, 42) We can easily predict there will be a continuing search to find the optimal non-invasive US hemodynamic measure for FR.

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Table 1: Demographics

	RESPONDERS 50% (n=86)	NON-RESPONDERS (n=58)	*p* value
Age (yrs)	50.8 ± 22	50.1 ± 23	N.S.
Gender (% Male)	65% M	69% M	N.S.
BMI	27.5 ± 6.1	27.8 ± 9.5	N.S.
Blunt/Penetrating	78/10	53/5	N.S.
ISS	10.2 ± 9.0	10.3 ± 8.9	N.S.
Base Excess	-0.76 ± 3.8	-1.2 ± 4.6	N.S.
Heart rate (bpm)	91 ± 18	88 ±21	N.S.
Admission Sys BP (mmHg)	138 ± 26	133 ± 22	N.S.
Prehospital IV Fluids (ml)	227 ± 538	191 ± 421	N.S.
Initial Resus Fluids (ml)	433 ± 519	410 ± 466	N.S.
ICU LOS (d)	1.61 ± 3.4	1.55 ± 2.7	N.S.
Ventilator Days	0.52 ± 1.6	0.64 ± 2.5	N.S.
Hospital LOS (d)	4.76 ± 6.1	5.33 ± 8.1	N.S.
Intubated	7/86	5/58	N.S.
Post-resus $IVCD_{MIN}$ (mm)	14.2 ± 4.3	6.0 ± 3.7	$p< 0.001$
Post-resus $IJVD_{MIN}$ (mm)	6.2 ± 3.5	5.6 ± 3.7	N.S.
Post-resus IVCCI (%)	13.2 ± 12.7	41.7 ± 30.0	$p< 0.001$
Post-resus IJVCI (%)	24.5 ± 22.6	26 ± 22.9	N.S.
24-hour Fluids (ml)	1243 ± 1130	2503 ± 1751	$p= 0.003$
Received transfusion by 24 hrs	15/86	8/58	N.S.
Mean transfusion volume (ml)	1023 ± 952	1832 ± 2308	N.S.
Laparotomy Performed	4/86	1/58	N.S.
Mortality	4/86	1/58	N.S.

BMI: Body Mass Index
ISS: Injury Severity Scale
BP: Blood Pressure
IV: Intravenous
Resus: Resuscitation Area
ICU: Intensive Care Unit
LOS: Length of Stay
$IVCD_{MIN}$: Minimum Inferior Vena Cava Diameter
$IJVD_{MIN}$: Minimum Internal jugular Vein Diameter
IJVCI: Internal Jugular Vein Collapsibility Index
IJVCI: Internal Jugular Vein Collapsibility Index

Table 2 – Correlation Analysis with 24-hour IV Fluid requirement

	n	r	P value
Base Deficit	120	-0.132*	0.032
ISS	123	0.366*	0.020
$IVCD_{MIN}$	144	-0.422**	0.0001
$IVCD_{MAX}$	123	-0.340**	0.0001
IVCCI	115	0.440**	0.0001
$IJVD_{MIN}$	103	-0.135	N.S.
$IJVD_{MAX}$	78	-0.066	N.S.
IJVCI	77	-0.107	N.S.

r: Pearson correlation coefficient.
*P<0.05, **P<0.01(Pearson correlation analysis).
IVCD, IJVD, and Base Deficit have negative correlation coefficients.
ISS: Injury Severity Scale
$IVCD_{MIN}$: Minimum Inferior Vena Cava Diameter
$IVCD_{MAX}$: Maximum Inferior Vena Cava Diameter
$IJVD_{MIN}$: Minimum Internal jugular Vein Diameter
$IJVD_{MAX}$: Maximum Inferior Vena Cava Collapsibility Index
IJVCI: Internal Jugular Vein Collapsibility Index

Table 3. Multivariate Logistic Regression of for 24 Hour Fluid Requirement Greater than 2.4L.

Predictors	Regression Coefficient	Odds Ratio	95% Confidence Interval	P value
Constant	-3.687	.025		0.294
Age	-.030	.971	0.940-1.003	0.072
Male gender	-.415	.660	0.172-2.57	0.546
ISS	.119	.888	0.817-0.956	0.005*
Admission Shock Index	-3.665	.026	0.001-0.934	0.046*
SBP on leaving resus bay	.060	1.062	1.01-1.11	0.011*
Base Deficit	-.109	.897	0.745-1.079	0.250
$IVCD_{MIN}$	0.666	1.946	1.17-3.25	0.011*
$IVCD_{MAX}$	-.373	.688	0.470-1.008	0.055
IVCCI	.062	1.064	1.003-1.13	0.038*

*: P< 0.05, ISS: Injury Severity Scale, SBP: Systolic Blood Pressure, $IVCD_{MIN}$: Inferior Vena Cava minimum diameter, $IVCD_{MAX}$: Inferior Vena Cava maximum diameter, IVCC: Inferior Vena Cava Collapsibility Index.

Table 4. Diagnostic Accuracy of Predictive Measures

Measure	n	-24FR	+24FR	% measurable	PPV	NPV	AUC
Base Deficit	120	≥ 3.1	≤ -5.3	22%	62%	17%	0.63
ISS	123	3.5	32	29%	81%	63%	0.65
$IVCD_{MIN}$	144	≤ 5mm	≥ 13mm	55%	55%	88%	0.74
$IVCD_{MAX}$	123	≤ 7.5mm	≥ 20mm	29%	55%	86%	0.69
IVCCI	115	≤ 41%	≥ 51%	89%	53%	81%	0.75
$IJVD_{MIN}$	103	≤ 2mm	≥ 11.5mm	31%	50%	31%	0.48
$IJVD_{MAX}$	78	≤ 3mm	≥ 15mm	23%	65%	24%	0.46
IJVCI	77	≤ 8%	≥ 65%	27%	81%	35%	0.54
$IVCD_{MIN}$ + IVCCI	115	≤ 0.56	≥0.85	55%	82%	65%	0.75

% measurable is the percent of patients not in the gray zone, but in the upper and lower threshold categories. -24FR: fluid requirement < 2.4L at 24 hours, +24FR: fluid requirement ≥ 2.4L at 24 hours, PPV: positive predictive value, NPV: positive predictive value, AUC: Area under receiver-operator characteristic curve, ISS: Injury Severity Scale, $IVCD_{MIN}$: IVC minimum diameter, $IVCD_{MAX}$: IVC maximum diameter, IVCCI: IVC Collapsibility Index, $IJVD_{MIN}$: Internal Jugular Vein minimum diameter, $IJVD_{MAX}$: Internal Jugular Vein maximum diameter, IJVCI: Internal Jugular Vein Collapsibility Index, IVCDMIN + IVCCI: Combined IVC minimum diameter and IVC Collapsibility Index model.

Figure 1

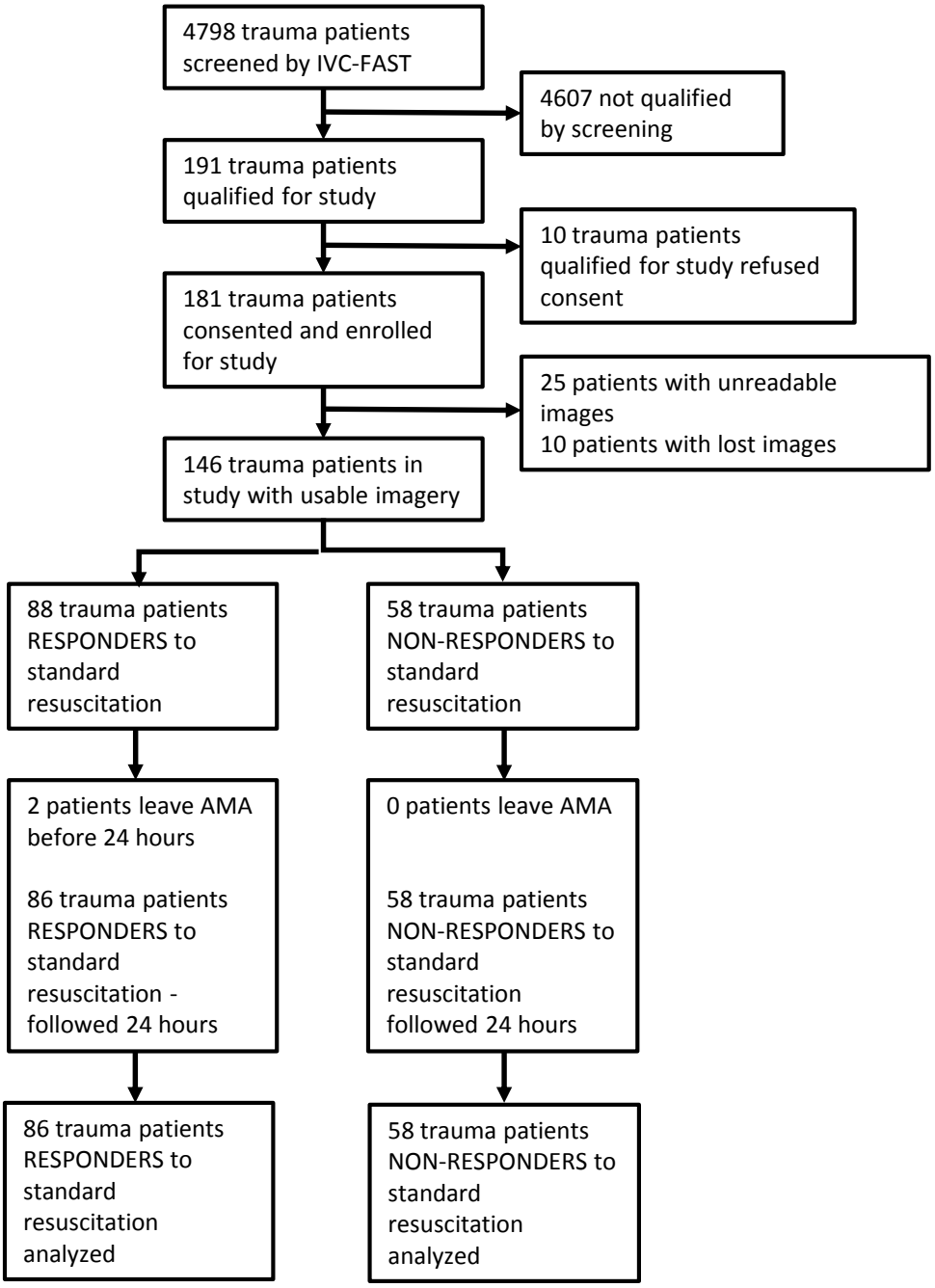

4798 trauma patients screened by IVC-FAST
4607 not qualified by screening
191 trauma patients qualified for study
10 trauma patients qualified for study refused consent
181 trauma patients consented and enrolled for study
25 patients with unreadable images
10 patients with lost images
146 trauma patients in study with usable imagery
88 trauma patients RESPONDERS to standard resuscitation
58 trauma patients NON-RESPONDERS to standard resuscitation
2 patients leave AMA before 24 hours
86 trauma patients RESPONDERS to standard resuscitation - followed 24 hours
0 patients leave AMA
58 trauma patients NON-RESPONDERS to standard resuscitation followed 24 hours
86 trauma patients RESPONDERS to standard resuscitation analyzed
58 trauma patients NON-RESPONDERS to standard resuscitation analyzed

Figure 2

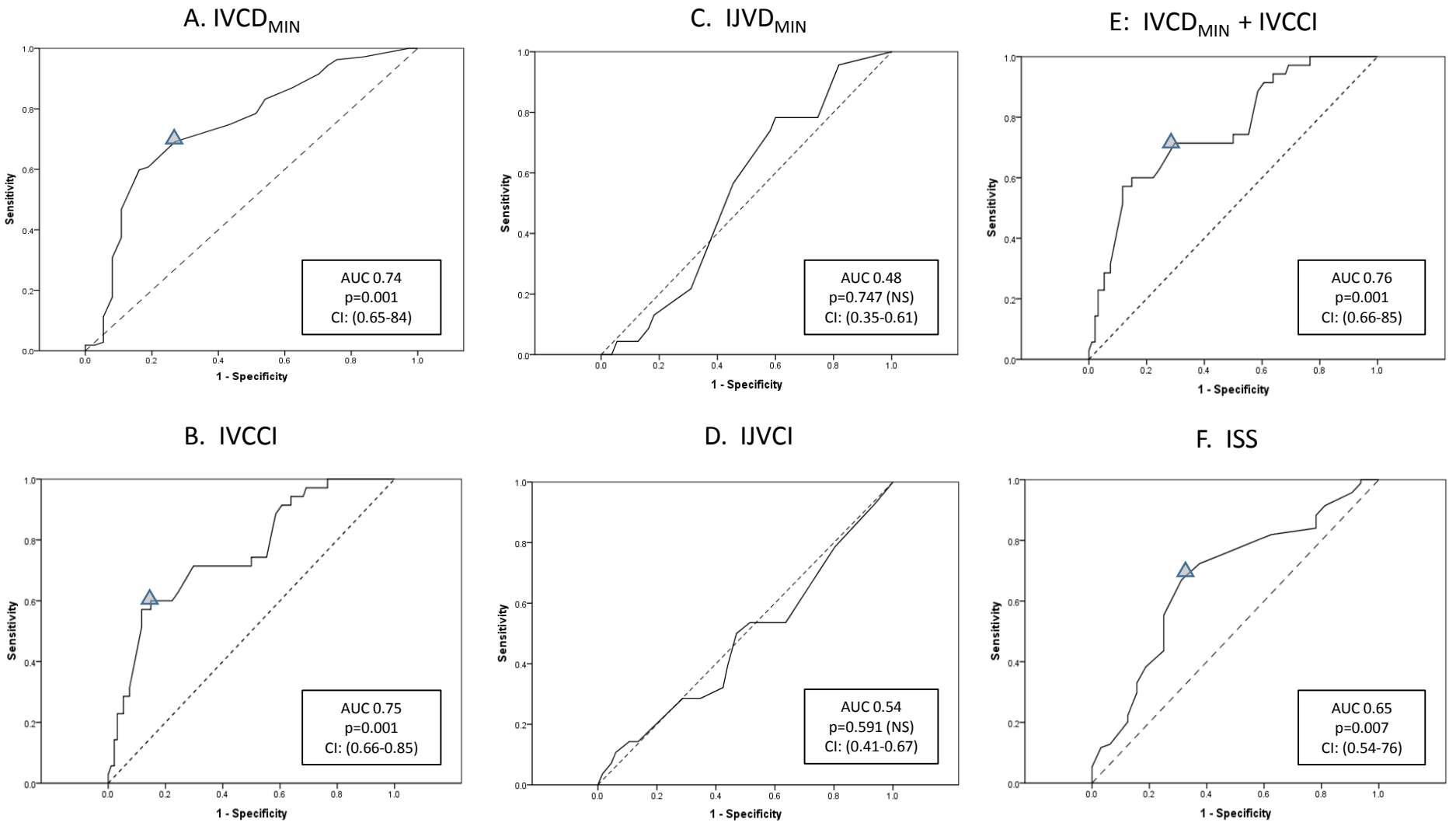
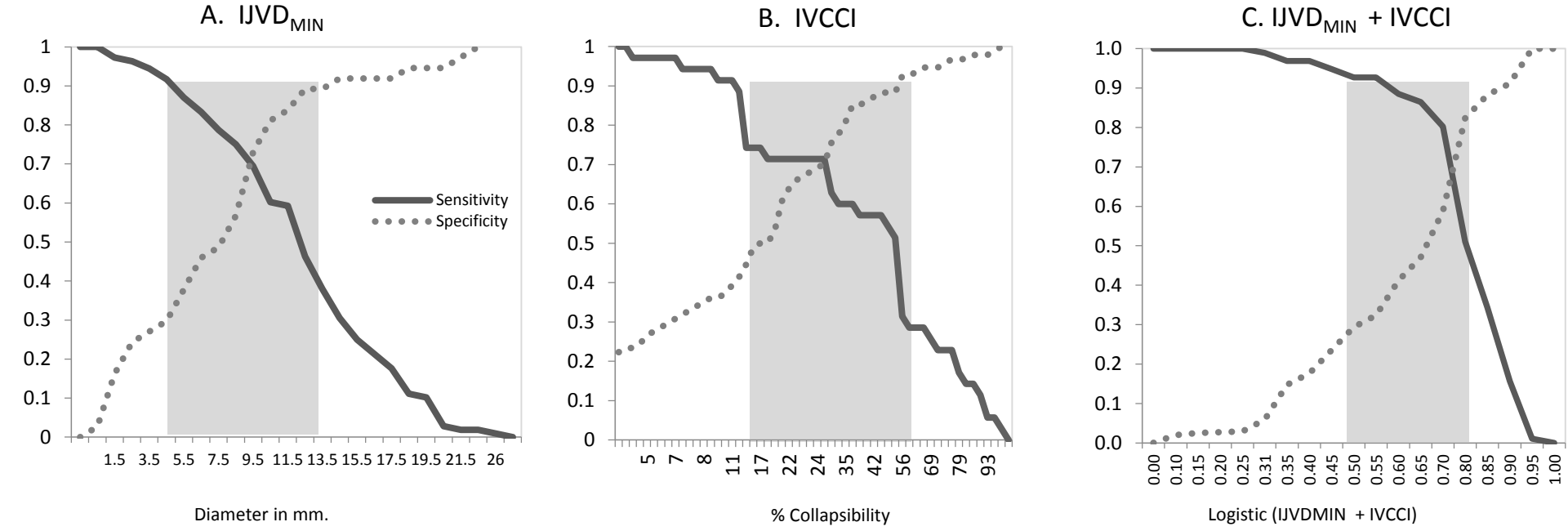

A. IVCD$_{MIN}$
AUC 0.74
p=0.001
CI: (0.65-84)
C. IJVD$_{MIN}$
AUC 0.48
p=0.747 (NS)
CI: (0.35-0.61)
E: IVCD$_{MIN}$ + IVCCI
AUC 0.76
p=0.001
CI: (0.66-85)
B. IVCCI
AUC 0.75
p=0.001
CI: (0.66-0.85)
D. IJVCI
AUC 0.54
p=0.591 (NS)
CI: (0.41-0.67)
F. ISS
AUC 0.65
p=0.007
CI: (0.54-76)
Sensitivity
1 - Specificity

Figure 3


A. IJVD$_{MIN}$
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Sensitivity
Specificity
1.5 3.5 5.5 7.5 9.5 11.5 13.5 15.5 17.5 19.5 21.5 26
Diameter in mm.
B. IVCCI
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
5 7 8 11 17 22 24 35 42 56 69 79 93
% Collapsibility
C. IJVD$_{MIN}$ + IVCCI
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.00 0.10 0.15 0.20 0.25 0.31 0.35 0.40 0.45 0.50 0.55 0.60 0.65 0.70 0.80 0.85 0.90 0.95 1.00
Logistic (IJVDMIN + IVCCI)