

床旁超声评估成年危重症患者血容量状态之应用研究新进展

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[摘要] 急危重症患者常存在血流动力学不稳定,需精细液体管理。床旁超声检查具有准确、及时、迅速等诸多优势,可随病情变化反复检查及评估。随着床旁超声的临床深度应用及其深入研究,目前相关研究发现下腔静脉直径大小可反映机体血容量状态,自主呼吸状态下,下腔静脉塌陷指数 $>50\%$ 提示具有容量反应性,机械通气下,下腔静脉扩张指数 $>26\%$ 提示有容量反应性。妊娠妇女结果则略有不同,妊娠妇女左侧卧位下腔静脉塌陷指数 $>25.64\%$ 提示血容量不足。食管超声下观察上腔静脉塌陷指数 $>37\%$ 提示有容量反应性。床旁超声可全方位监测及评估血容量状态,可及时、有效地指导急危重症患者液体管理。

[关键词] 重症超声;血容量;下腔静脉

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Progress of ultrasound in volume status assessment of critically ill patients

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Summary Critically ill patients often have hemodynamic instability and require fine fluid management. Ultrasound has many advantages, such as accuracy, timeliness, rapidity, etc., and can be repeatedly examined and evaluated of the change of the disease. With the depth of the clinical application and research of ultrasound, the current research found that the inferior vena cava diameter size could responded the blood volume status. In spontaneous breathing state, the collapse of the inferior vena cava index greater than 50% had indicated of volumetric reactivity, and in mechanical ventilation, the inferior vena cava expansion index greater than 26% had indicated of volumetric reactivity. The results were different for pregnant women, and the collapse index in left of inferior vena cava of pregnant women greater than 25.64% had suggested hypovolemia. The collapse index of superior vena cava under esophageal ultrasonography $>37\%$ had been suggested that had volume reactivity. Ultrasound can monitor and assess blood volume status comprehensively, and it can be widely used to guide the liquid management of the patients in time and effectively.

Key words ultrasonography; volume status; inferior vena cava

自1985年Francois Jardin首次应用可移动床旁超声进行临床诊治以来,其应用越来越广,而对于ICU及急诊科而言,床旁超声是其日常诊疗最重要工具之一。床旁超声有诸多优势,具有及时准确、迅速、简便、无创、避免搬运,又可随病情变化反复检查及评估,目前其临床应用广泛,仍为近年研究热点。为了解近年床旁超声在急危重症疾病血

容量评估应用情况及相关研究结果,本文从以下方面进行阐述。

1 经胸超超声之血容量及其反应性评估

1.1 心室腔内径大小与血容量评估

床旁多普勒超声心动图可检测各心脏腔室内径,心脏各腔室内径,尤其左室舒张末期内径,在一定程度上可反映血容量状态。同时床旁超声发现左心室充盈减少,收缩末期左室前后壁几乎贴近,此时临床称为“亲吻征”,可在胸骨旁长轴切面发现,此超声状态高度提示左室充盈欠佳、容量

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不足^[1-2]。

1.2 下腔静脉直径及下腔静脉变异率与血容量评估

下腔静脉(inferior vena cava, IVC)为机体容量血管,当机体血容量减少时,IVC管径会变小甚至塌陷,因此床旁经胸超声可测量 IVC 直径及其变异率评估血容量及容量反应性。

目前在临床应用中,自主呼吸状态下应用塌陷指数(inferior vena cava collapsibility index, IVC-CI)评估机体容量反应性,IVC-CI=(呼气相舒张期最大径-吸气相收缩期最小径)/呼气相舒张期最大径;而在机械通气患者呼气末正压等情况下影响下,则应用扩张指数(distensibility index of the inferior vena cava, dIVC)评估, dIVC=(呼气相舒张期最大径-吸气相收缩期最小径)/吸气相收缩期最小径。

目前临床常用检测的方法取得患者剑突下四腔心二维 B 超图像并旋转平行于肢体躯干得出 IVC 图像,在 M 型模式下将取样线置于其距离右房开口 2 cm 处或肝静脉汇入远心端 1 cm,分别测量呼气相下腔静脉内膜直径和吸气相下腔静脉内膜直径,并计算 IVC 变异率。2020 年 Caplan 等^[3]在法国含 125 例两个中心的研究发现取样线置于其距离右房开口 4 cm 测量 IVC 变异率预测机体容量及容量反应性灵敏度及特异度最好,分别为 98%、85%,而因灵敏度较低,尽可能避免距右房开口 ≤3 cm,特别距右房开口 1 cm 因受呼吸影响大,灵敏度更低。此研究结果为新进研究,具有创新性,距离右房开口 4 cm 测量 IVC 变异率反映危重症患者容量反应性效果可能更好,临床应高度重视,但需今后更多研究验证。

评估血容量研究上,目前临床认为自主呼吸末 IVC<1 cm 及机械通气呼气末 IVC<1.5 cm 均可能提示血容量不足;而 IVC 充盈固定,>2 cm,则可能提示容量过负荷^[1,4-5]。而早期 Orso 等^[6]研究发现 IVC-CI≥60.7%提示低血容量状态。2021 年 Diederich 等^[7]针对含 247 例研究发现 IVC 小于 0.4 cm,提示可能存在低血容量休克,ROC 曲线面积为(AUC)0.73,灵敏度及特异度分别为 80%、50%。在评估机体容量状态上,传统指标如依据液体出入量判断机体有效血容量状态之准确性有时难以保证,可能因低蛋白血症等因素致体液在第三间隙丢失引起;同时依据中心静脉压(CVP)有时难以准确评估机体有效血管容量,因其受胸腹腔高压、右心系统疾病、血栓等因素影响。对于急危重症患者,上述影响因素存在时,临床可依据下腔静脉大小初步了解危重症患者血容量状态。

在评估机体容量反应性研究上,近年 Orso 等^[8]针对 21 项研究荟萃分析发现 IVC 直径变异

率能评估机体容量反应性,其灵敏度及特异度均较高,分别为 71%、75%。2021 年 Kim 等^[9]针对全球各项研究再次进行 Meta 分析,30 项研究(1719 例患者)入选,结果提示 IVC 直径变异率能较好评估机体容量反应性,其灵敏度及特异度分别为 75%、83%,AUC 为 0.86。

具体研究项目如下,各项研究结果有所不同,国内 2019 年李尧炜等^[10]研究报道 IVC-CI 最佳截点值为 42.9%,灵敏度及特异度分别为 86.7%、86.0%。2022 年 Ni 等^[11]研究报道 IVC-CI 最佳截点为 42%,灵敏度及特异度分别为 83.9%、76.3%,AUC 为 0.834。Bortolotti 等^[12]研究报道自主呼吸状态下 IVC-CI>39%时评估容量反应性灵敏度及特异度分别为 93%、88%;Szabó 等^[13]研究报道 IVC-CI≥50%时具有容量反应性,灵敏度仅 45.5%,但特异度高达 90%;Caplan 等^[14]研究报道 IVC-CI≥44%时具有容量反应性,其灵敏度及特异度分别为 93%、98%。因自主呼吸下 IVC-CI 的最佳截点目前仍具有些许争议,依既往研究及以上新研究,结合 Kim 等^[9]荟萃研究结果(表 1),综合分析得出结论对急危重症患者,目前 IVC-CI 预测具有容量反应性的最佳截点区间为 40%~50%,大于 50%则可能具有容量反应性。

机械通气状态下,各项研究报道亦稍有差别,国内高山等^[23]研究发现 dIVC 17.65%为截断值,预测脓毒性休克患者容量反应性灵敏度及特异度分别为 100.0%、87.5%,AUC 为 0.924,但未说明机械通气所用潮气量。Taccheri 等^[24]研究发现潮气量<6 mL/kg, dIVC 可能不能可靠地反映容量反应性。对于潮气量>8 mL/kg 的各项研究中, Ma 等^[15]研究发现 dIVC>13.39%提示有容量反应性, AUC 为 0.80,其灵敏度及特异度均为 85.71%;Kaur 等^[26]发现 dIVC>17.86%提示有容量反应性,其灵敏度及特异度分别为 72.7%、95%。对于潮气量<8 mL/kg 的各项研究中, Yao 等^[27]研究发现潮气量 7.5 mL/kg, dIVC ≥10.2%提示有容量反应性,其灵敏度及特异度分别为 40.0%、97.3%。He 等^[28]研究发现潮气量>12 mL/kg, dIVC 预测容量反应性临床价值下降,其中潮气量 6 mL/kg, dIVC ≥11.1%提示有容量反应性, AUC 0.71,其灵敏度及特异度分别为 68.0%、76.0%;潮气量 9 mL/kg, dIVC ≥15.3%提示有容量反应性, AUC 0.79,其灵敏度及特异度分别为 55.0%、88.0%;潮气量>12 mL/kg, dIVC ≥13.4%提示有容量反应性, AUC 0.73,其灵敏度及特异度分别为 53.0%、88.0%。国外 2019 年来自土耳其的 Sarıtaş 等^[29]研究发现在机械通气下,潮气量 6~8 mL/kg, dIVC ≥12%提示有容量反应性,且 dIVC 可比 IVC-CI 更好地预测容量反应性。

Upadhyay 等^[30]发现潮气量小于 8 mL/kg, dIVC $\geq 25\%$ 提示有容量反应性, AUC 0.66, 其灵敏度及特异度分别为 54%、86.70%。因机械通气下 dIVC 最佳截点目前仍具有些许争议, 依既往研究及

以上新研究, 结合 Kim 等^[9]荟萃研究结果(表 2), 综合分析得出结论对急危重症患者, 目前机械通气下 dIVC 预测具有容量反应性的最佳截点区间为 10%~25%, 大于 26%则相对可能有容量反应性。

表 1 自主呼吸下各研究之 IVC-CI 评估容量反应性灵敏度及特异度

作者	年限	国家	例数	IVC-CI/%	AUROC	灵敏度/%	特异度/%
李年炜等 ^[10]	2019	中国	40	42.9	0.921	86.7	86.0
Ni 等 ^[11]	2022	中国	91	45.0	0.834	83.9	76.3
Bortolotti 等 ^[12]	2018	法国	55	37.0	0.820	86.0	78.0
Marcell 等 ^[13]	2019	匈牙利	102	50.0	0.648	45.5	90.0
Caplan 等 ^[14]	2020	法国	30	25.0	0.464	47.0	64.0
Blavius 等 ^[15]	2021	美国	20	25.0	0.940	89.0	100.0
McGregor 等 ^[16]	2020	英国	175	25.0	0.820	85.0	79.0
Corl 等 ^[17]	2019	美国	124	25.0	0.840	87.0	81.0
Preau 等 ^[18]	2017	法国	90	31.0	0.820	76.0	88.0
Corl 等 ^[19]	2017	美国	124	46.0	0.850	67.0	93.0
Haliloglu 等 ^[20]	2017	土耳其	44	35.0	0.825	78.0	86.0
Airapetian 等 ^[21]	2015	法国	59	49.0	0.620	31.0	97.0
De Valk 等 ^[22]	2014	新西兰	45	36.5	0.741	83.0	67.0

表 2 机械通气下各研究之 dIVC 评估容量反应性灵敏度及特异度值

作者	年限	国家	潮气量	例数	dIVC/%	AUROC	灵敏度/%	特异度/%
Kaur 等 ^[26]	2021	印度	>8 mL/kg	67	17.86	0.80	72.70	95.00
Yao 等 ^[27]	2019	中国	7.5 mL/kg	67	25.60	0.702	46.00	90.00
He 等 ^[28]	2019	中国	6 mL/kg	79	11.10	0.710	68.00	76.00
			9 mL/kg	79	15.30	0.790	55.00	88.00
			12 mL/kg	79	16.00	0.730	88.00	73.0
Saritas 等 ^[29]	2019	土耳其	6~8 mL/kg, PEEP 5 cmH ₂ O	100	12.00	0.835	98.00	68.00
Upadhyay 等 ^[30]	2020	印度	<8 mL/kg	30	25.00	0.660	54.00	86.70
Ma 等 ^[31]	2018	中国	>8 mL/kg	50	13.39	0.80	85.71	85.71
Wang 等 ^[32]	2018	中国	8~12 mL/kg	67	25.60	0.702	46.00	90.00
Piskin 等 ^[33]	2017	土耳其	8 mL/kg	72	23.00	0.928	80.00	88.00
Lu 等 ^[34]	2017	中国	8~10 mL/kg	49	20.00	0.805	67.00	77.00
Theerawit 等 ^[35]	2016	泰国	>8 mL/kg, PEEP 8~10 cmH ₂ O	29	18.00	0.688	75.00	77.00
Sobczak 等 ^[36]	2016	波兰	8 mL/kg, PEEP 4, 5 cmH ₂ O	35	18.00	0.739	83.00	73.00
De Oliveira 等 ^[37]	2016	巴西	>8 mL/kg	20	16.00	0.43	38.00	61.00
Charboneau 等 ^[38]	2014	法国	>8 mL/kg	44	21.00	0.43	38.00	61.00
Machare-Delgado 等 ^[39]	2011	美国	8 mL/kg, EEP(6.8±2.8)cmH ₂ O	25	12.00	0.816	100.00	53.00
Moretti 等 ^[40]	2010	意大利	8 mL/kg PEEP 5 cmH ₂ O	29	16.00	0.902	71.00	100.00

注: 1 cmH₂O=0.098 kPa。

另外, 虽然脉搏指示剂连续心排量监测(PICCO)监测血流动力学指标相对客观, 但在心律失常、主动脉关闭不全等状态下, 其指标评估机体有效血容量及容量反应性亦欠准确, 而床旁超声基本不受以上因素影响, 推荐应用超声评估危重症患者机体血容量及通过计算下腔静脉变异率来评估有无容量反应性^[41-42]。

近年研究报道下腔静脉直径与腹主动脉值比

值(IVC:Ao index)可评估危重症患者有效血容量。研究发现 IVC:Ao index < 1.2, 考虑容量不足, AUC 0.96, 灵敏度 96%, 特异度 88%^[43]; 同时 Bilgin 等^[44]研究发现依 IVC:Ao index 能评估创伤状态下机体失血量。Kusumastuti 等^[45]研究发现 IVC:Ao index < 0.675, 考虑容量不足, 其灵敏度 75.7%, 特异度 61.9%; IVC:Ao index 评估危重症患者有效血容量可能值得推广。同时 NT-proBNP 升高常提示心脏功能不全或容量负荷过重, NT-

proBNP 作为机体容量指标生物标记物,相关研究发现 IVC 均与 NT-proBNP 相关^[46-47],因而在 ICU 中,NT-proBNP 升高时应注意及时了解 IVC 直径及变异率以判断危重患者机体容量状态。

同时,在妊娠妇女研究方面,Oba 等^[48]研究发现下腔静脉直径是评估孕妇分娩失血量有效工具,早年 Singh 等^[49]研究发现自主呼吸状态下妊娠妇女左侧卧位时 IVC-CI>25.64% 提示血容量不足,并存在低血压,灵敏度及特异度分别为 60.9%、35.5%,平卧位时 IVC-CI>20.4% 提示血容量不足,并存在低血压,灵敏度及特异度分别为 60.9%、23.5%。最近 Elbadry 等^[50]研究发现围术期妊娠妇女麻醉过程中反映低血容量的 IVC-CI Cut-off 值为 33%,其灵敏度及特异度分别为 84.6%、93.1%。故应用 IVC 及其变异率可评估围术期妊娠患者血容量状态及容量反应性,以上研究均具有一定的创新性及其临床应用价值,尤其针对危重症妊娠患者,但目前床旁超声之下腔静脉变异系数预测妊娠患者的机液体容量状态及其反应性研究报道仍不多,机械通气下之其状态研究极少,尚待更多相关研究报道。

2 床旁食管超声之血容量及其反应性评估

因经胸心脏超声时有各切面显示不良之缺陷,而难以检测。床旁经食管超声图像相对稳定,为近距离图像,易于观察,可能更利于了解各心脏部位解剖及血流动力学状态,同时因下腔静脉易受腹腔内压影响,如在腹腔感染、腹腔脏器损伤等因素致腹腔高压时依据下腔静脉直径评估容量状态其准确性可能欠佳,而上腔静脉(SVC)常位于胸廓内,因其受腹内压影响相对较小,具有相对优势。临床可通过床旁经食管超声监测左室流出道峰流速、心脏各腔内径、上腔静脉及下腔静脉等指标变化,进而反应机体的容量状态及容量反应性^[51-52],为近年新研究热点。最近 Bubenek-Turconi 等^[53] 266 例经食管超声研究发现 SVC 塌陷指数预测容量反应性的最佳截点为 37%,即 SVC 塌陷指数>37% 提示有容量反应性,其灵敏度达 90%,特异度达到 83%。国内 Cheng 等^[54] 机械通气下 SVC 扩张指数预测容量反应性的最佳截点为 21.1%。最近 Upadhyay 等^[55] SVC 扩张指数预测容量反应性为 35%,灵敏度和特异度均接近为 100%。因此经胸超声检查存在困难时,此时可依据经食管超声监测上腔静脉变化评估危重患者机体容量状态及容量反应性。鉴于通过床旁食管超声研究上腔静脉大小及变化指数反应机体容量反应性报道不多,尚待更多研究报道。

3 超声应用新技术

充血性心力衰竭的容量状态研究中,Kaptein 等^[56] 研究发现自主呼吸状态下,锁骨下静脉变异

度(SCV CI)<22% 及 IVC-CI<20%,提示容量过负荷,其灵敏度及特异度均为 72%。而 SCVCI>33%、IVC-CI>50% 则提示容量不存在负荷,其灵敏度及特异度均为 78%。目前多项研究^[57-58] 提示 IVC-CI<15%,提示容量过负荷及充血性心力衰竭;同时张智玺等^[59] 研究发现 IVC-CI 与 NT-proBNP 联合检测可以更好指导医师对充血性心力衰竭的容量管理。对于心脏舒张功能障碍患者,王春超等^[60] 研究发现下腔静脉内径变异度(VIVC) \geq 19.5% 为预测其液体反应性的可靠指标。以上研究结果均值得临床高度重视。

同时,最近 Gavaud 等^[61] 研究发现肺动脉时间容积积分变异度能较好反应容量反应性,与主动脉时间容积积分变异度、IVC 变异率均相关,其达 14% 可预测容量反应性,其灵敏度为 92%,特异度为 87%。Kumar 等^[62] 研究发现自主呼吸状态下,锁骨下静脉变异系数达 46%,可预测具有容量反应性,其灵敏度 87.88%,特异度 66.67%;与 SCV-CI 的 Spearman 相关系数为 0.59。Güney 等^[63] 研究发现自主呼吸状态下,呼吸二氧化碳数值变异差距达 4 mmHg(1 mmHg=0.133 kPa)具有容量反应性,<2 mmHg 则不具有容量反应性,可以结合下腔静脉变异率评估血容量状态。Parenti 等^[64] 研究报道颈内静脉内径 0.80,下腔静脉直径 0.66,其比例小于 0.68 提示血容量不足。以上新研究结果,值得重视,对于危重患者应用上,仍需更多研究验证。

4 超声缺陷及注意事项

临床需要注意,Zhang 等^[65] 及相关学者研究发现^[56,66-67] 当自主呼吸驱动强(如急性呼吸窘迫综合征等)、高呼吸末正压通气、右心功能不全、三尖瓣反流、肺动脉栓塞等状态时,下腔静脉直径及其变异率评估血容量及容量反应性可能存在“陷阱”,即其结果可能存在误差,此时应结合心脏超声各腔内径大小、中心静脉压及被动直腿抬高试验等多种指标评估机体血容量状态。

总之,急危重症患者血流动力学监测及管理需贯穿整个诊疗过程,因过多的液体治疗可增加不良后果,需要精细的液体管理。因传统各容量评估方法存在相关缺陷,其结果有时不准确,床旁超声不仅能迅速了解心脏功能与结构,同时可监测各腔内径、腔静脉直径及变异率等及时准确反映机体有效血容量状态及容量反应性,为急危重症患者诊治提供重大帮助。随着日后研究进一步深入及技术成熟,床旁超声可全方位监测及评估,更好地帮助临床工作者对急危重症患者实施即时、准确、精细的液体管理及临床诊治。

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