Original Article

An email-based survey of practice regarding hemodynamic monitoring and management in children with septic shock in China

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Background: Understanding current hemodynamic monitoring (HM) practice patterns is essential to determine education and training strategies in China. The survey was to describe the practice of HM and management in children with septic shock in China.

Methods: We conducted an Email-based survey of members of sub-association of pediatric intensive care physicians. The questionnaire consisted of 22 questions and gathered the following information: (I) general information on the hospitals, respective ICUs and participants, (II) the availability of technical equipment and parameters of HM and (III) management simulation of septic shock in three clinical case vignettes.

Results: Surveys were received from 68 institutions (87.2%) and 368 questionnaires (response-rate 45.1%) were included. Basic HM (93–100%) were reported as the most utilized parameters, followed by advanced HM which included central venous pressure (CVP) (56.0%), cardiac output (53.5%), and central venous oxygen saturation (36.7%), 61.1% (225/368) of respondents stated the utilization of non-invasive HM equipment. The factors such as ICU specialist training center (P=0.003) and more than 30 cases of septic shock per year (P=0.002) were related to the utilization of non-invasive monitoring equipment. In the simulated case vignette, 49.7% (183/368) of respondents reported performing fluid responsiveness and volume status (FR-VS) assessment. Despite differences in training centers (P=0.005) and educational backgrounds (P=0.030), FR-VS assessment was not related to the volume expansion decision.

Conclusions: There is a large variability in use advanced HM parameters, an increasing awareness and acceptance of non-invasive HM devices and a potential need for hemodynamic education and training in pediatric intensive care medicine in China.

Keywords: Hemodynamic monitoring (HM); intensive care; septic shock; child; questionnaires

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Introduction

Hemodynamic monitoring (HM) remains an important aspect of critically ill patient care, which originally promoted by Rivers *et al.* for patients with severe sepsis and septic shock (1). Although the use of HM at the bedside faces many challenges (2,3), goal-directed strategies of hemodynamic management based on parameters of extended hemodynamic and metabolic monitoring are increasingly recommended in different national and international guidelines (4-7).

How HM is actually practiced in intensive care units (ICU) has been described by surveys in many countries including Swiss (2,7), Austrian (7,8), Italian (9,10), the United Kingdom (11), USA (12), Brazil (13), France (14,15), German (7,16) and fields (10,12,17,18). To date there is little information about practice of HM in pediatric intensive care units in China.

This email-based survey aimed to study the current situation regarding the utilization of HM devices, the parameters used in HM, and potential individual and hospital differences in China. We present the following article in accordance with the SURGE reporting checklist (available at http://dx.doi.org/10.21037/tp-20-374).

Methods

Survey study and population

We conducted a prospective, multicenter survey in Chinese pediatric intensive care units (ICU) in 2017. The survey was reviewed and approved by the sub-association of pediatric intensive care physicians, Chinese Medical Doctor Association. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the sub-association of pediatric intensive care physicians, Chinese Medical Doctor Association and Shanghai Children's Medical Center (No. SCMCIRB-K2015039) and individual consent for this study was waived.

The structured questionnaire was discussed by experts of the sub-association of pediatric intensive care physicians and was finalized after the pretesting in 5 pediatric intensivists from Shanghai Children's Medical Center, Shanghai. Face validity, content validity, and clinical sensibility were evaluated.

The structure of the survey included a variety of single choice, multiple choice and open-ended questions. None of the questionnaires used a scoring scale. It was designed to take 10-20 minutes to complete. The questionnaire (Appendix 1) consisted of four pages and 22 questions divided in three sections: (I) general information on the hospitals, respective ICUs and participants, (II) the availability of technical equipment and parameters of HM and (III) simulated management of septic shock in three clinical case vignettes. The questionnaire was in Chinese.

National pediatric intensivists were invited to answer an electronic questionnaire at the second academic conference held in Beijing in 2017. We directly contacted members of the aforementioned association via email during a 2-week period from 1–15 May 2017. A cover letter (Appendix 2) explained the background, aims, and methods of the study and requested E-mail addresses of all pediatric intensivists in the member's units. Questionnaire sheets were mailed to all participants on 16–30th May 2017, and the data were collected over a 4-weeek period, which was closed end of June 2017. Responses were voluntary, anonymous and unpaid. If the survey questionnaire was not recovered within the 4-week recycling period, a reminder would be sent by phone or Email.

In the study, junior doctors were young faculty members. Basic HM included electro-cardiogram, peripheral oxygen saturation, blood pressure (invasive and non-invasive), blood lactic acid level, capillary refill time (CRT) and urine output measurement. Advanced HM included central venous pressure (CVP), cardiac output indicators [Cardiac output (CO), Cardiac output index (CI), left ventricular ejection fraction (LVEF), stroke volume (SV), and Velocity time integral of subaortic blood flow (VTI)], Central venous oxygen saturation ($ScvO_2$), fluid responsiveness and volume status (FR-VS) indicators [stroke volume variation (SVV), pulse pressure variation (PPV), inferior vena cava variation (IVC), and passive leg rising (PLR)], systemic vascular resistance (SVR) and index (SVRI), PCO_2 gap between central venous and artery ($Pcv\text{-}aCO_2$), extravascular lung water index (EVLWI), and tissue O_2 pressure/tissue CO_2 pressure ($PtO_2/PtCO_2$). All advanced HM were obtained from non-invasive and/or invasive methods. For example, CO/CI was available from transpulmonary thermodilution and/or bedside ultrasound technology led by intensivists. Bioreactance and ultrasound technology were non-invasive HM methods and transpulmonary thermodilution was an invasive procedure.

Statistical analyses

Data analysis was performed using IBM SPSS Statistics

Table 1 Characterization of the 68 participating hospitals

Parameters	n (%)
Hospital rank	
Tertiary hospital	64 (94.1)
Secondary hospital	4 (5.9)
Type of ward	
General pediatric ICU	55 (80.9)
Mixed (pediatric and neonate)	9 (13.2)
Mixed (pediatric and adult)	2 (2.9)
Surgery ICU	2 (2.9)
Number of beds	
More than 40 beds	6 (8.8)
30–40 beds	15 (22.1)
20–30 beds	22 (32.4)
10–20 beds	17 (25.0)
Less than 10 beds	6 (8.8)
Others (Mixed beds for children and adults)	2 (2.9)
ICU specialist training center	
Yes	27 (39.7)
No	41 (60.3)

n, Number of respondents; ICU, intensive care unit.

for Windows, version 22.0 (IBM Corp., Armonk, NY, USA). Demographic characteristics were summarized by proportions for categorical data. For descriptive statistical analysis, we calculated absolute and relative frequencies (in percentage) to describe categorical data. Categorical variables were analyzed using the chi-square test. All statistical tests were two-sided, and statistical significance was defined as a P value of less than 0.05. Multivariable analyses to identify demographic and professional characteristics associated with the dependent outcomes were performed using binary logistic regression.

According to the questionnaire sample scale, we calculated that 384 respondents were needed, with a sampling error of 5% and a confidence interval of 95%. We estimated that a study period of 4 weeks would be necessary to recover at least 384 questionnaires and reduce the non-response error. Results were analyzed according to the number of responses for each given question. The numerator and denominator for the prevalence calculation came from the survey form. The denominator of the response-rate was the number of emails we had collected and successfully sent. Reply to email and completion of any portion of the survey implied consent to participate. Ten hospitals did not submit any form and 17 people ended the survey incompletely and thus were excluded. There was no missing data.

Results

Response rate

Responses were obtained from 385 of 854 pediatric intensivists (response-rate 45.1%) emailed and 68 of 78 hospitals (response-rate 87.2%) in total. Seventeen people ended the survey incompletely, resulting in 368 fully completed responses. Fifteen questionnaires from the two hospitals were identical, and the other two questionnaires lacked more than 50% of the items, so they were excluded.

Personal and practice characteristics

Tables 1 and *2* showed the demographic characteristics of 68 hospitals and 368 respondents. The health care sites at which respondents primarily practiced were mainly tertiary hospitals (94.1%) and general pediatric ICUs (85.3%), but less ICU specialist training centers (39.7%). The majority of respondents had master degree (58.7%) and intermediate professional title (37.2%), and was aged 30–40 (55.7%), 65.2% respondents reported managing more than 30 cases of septic shock within 1 year. 60.9% respondents stated attending the pediatric advanced life support(PALS) course.

Parameters of HM

Table 3 presents the most available variables of HM. Basic HM (93–100%) were reported as the most utilized parameters, 81.6% (279/342) of the respondents reported starting urine volume measurement within 1 hour of admission, 3.5% (12/342) within 3 hours, and 14.9% (51/342) within 6 hours.

Reported advanced HM were variable. The most frequently advanced HM included CVP (56.0%), CO/CI/LVEF/SV/VTI (53.5%), and $ScvO_2$ (36.7%). The least reported HM was PtO_2/$PtCO_2$ (2.7%).

Utilization of non-invasive advanced HM devices and factors associated with the use of non-invasive advanced HM devices by the 368 respondents, l,225 respondents (225/368, 61.1%) stated that non-invasive advanced monitoring

Table 2 Characterization of the 368 respondents for ICU specialist training center *vs.* non-training center

Parameters	ICU specialist training center (n)		Total (n, %)	P value
	Yes	No		
Gender				0.808
Male	61	58	119, 32.3	
Female	131	118	249, 67.7	
Age groups (year)				0.004
20–30	46	21	67, 18.2	
30–40	109	98	207, 56.3	
40–50	27	23	70, 19.0	
50–60	10	14	24, 6.5	
Academic qualification				0.049
Bachelor	49	65	114, 31.0	
Master	124	93	217, 59.0	
PhD	19	18	37, 10.0	
Professional title				0.000
Junior	82	41	123, 33.4	
Intermediate	63	74	137, 37.2	
Senior	47	61	108, 29.3	
Hospital rank				0.001
Tertiary hospital	192	166	358, 97.3	
Secondary hospital	0	10	10, 2.7	
PALS course				0.009
Yes	129	95	224, 60.9	
No	63	81	144, 39.1	
Cases with septic shock per year				0.000
More than 30	154	86	240, 65.2	
0–29	38	90	128, 34.8	
Type of ward				0.000
General pediatric ICU	154	138	292, 79.3	
pediatric and neonate	37	23	60, 16.3	
pediatric and adult	0	11	11, 3.0	
Surgery ICU	1	4	5, 1.4	

n, Number of respondents; PALS, Pediatric Advanced Life Support.

equipment could be used in their hospitals. Three devices were most commonly available: bedside echocardiography led by intensivists (164/368, 44.6%), ultrasound cardiac output monitor (USCOM) (68/368, 18.5%), and bioreactance (NICOM) (69/368, 18.8%). Respondents were divided into two groups according to the utilization of

Table 3 Hemodynamic monitoring variables used by the 368 respondents

Parameters	Cases, percent of cases (n, %)	Percent of responses (n, %)
Basic HM		
Electro-cardiogram	368, 100	12.7
Peripheral oxygen saturation	368, 100	12.7
Arterial pressure (invasive and non-invasive)	347, 94.3	12.0
Blood lactic acid level	343, 93.2	11.8
CRT	342, 93	11.8
Urine output measurement	342, 93	11.8
Advanced HM		
Central venous pressure	206, 56.0	7.1
CO/CI/LVEF/SV/VTI	197, 53.5	6.8
$ScvO_2$	135, 36.7	4.7
SVV/PPV/IVC/PLR	96, 26.1	3.3
SVR/SVRI	74, 20.1	2.5
$Pcv\text{-}aCO_2$	48, 13.0	1.7
EVLWI	27, 7.3	0.9
$PtO_2/PtCO_2$	10, 2.7	0.3

n, Number of respondents; HM, hemodynamic monitoring; CRT, capillary refill time; CO, cardiac output; CI, cardiac output index; LVEF, left ventricular ejection fraction; SV, stroke volume; VTI, Velocity time integral of subaortic blood flow; $ScvO_2$, central venous oxygen saturation; SVV, stroke volume variation; PPV, pulse pressure variation; IVC, inferior vena cava variation; PLR, passive leg rising; SVR, systemic vascular resistance; SVRI, systemic vascular resistance index; $Pcv\text{-}aCO_2$, PCO_2 gap between central venous and artery; EVLWI, extravascular lung water index; $PtO_2/PtCO_2$, tissue O_2 pressure/tissue CO_2 pressure.

non-invasive HM equipment: yes (n=225) or no (n=143). *Table 4* showed that there were significant differences in academic qualification (P=0.011), number of patients with septic shock per year (P=0.000) and staff of ICU specialist training center (P=0.000) according to the utilization of HM devices. Multivariable analyses identified factors associated with the utilization of HM devices (*Table 5*). More than 30 cases with septic shock per year (P=0.002) and staff of ICU specialist training center (P=0.003) were associated with higher utilization of the devices.

FR-VS assessment in the clinical case vignette and factors associated with FR-VS assessment

We performed a survey study in which the respondents responded to the simulated management of three clinical vignettes with septic shock. 49.7% (183/368) of respondents reported conducting FR-VS assessment. Instruments used in FR-VS assessment include bedside echocardiography led by intensivists [39.4% (145/368)], NICOM [10.3% (38/368)], transpulmonary thermodilution devices [6.3% (23/368)]; 4.9% (18/368) of respondents reported using both non-invasive HM devices, while 6.0% (22/368) reported using both non-invasive and invasive HM devices. Compared with the number of respondents who report using non-invasive instruments in their hospitals, 88.4% (145/164) of respondents reported using bedside echocardiography in the simulated clinical vignettes and 55.1% (38/69) reported using NICOM, with no mention of USCOM.

Table 6 showed that starting FR-VS assessment did not differ regarding age, professional title, hospital rank, PALS course or fluid resuscitation decision. Multivariable analyses identified factors associated with FR-VS assessment (*Table 7*). FR-VS assessment was associated with high academic qualification (P=0.030) and staff of ICU specialist training center (P=0.005).

Table 4 Comparison of variables that influencing the utilization of non-invasive hemodynamic monitoring devices by the 368 respondents

Parameters	Variables	Non-invasive HM (n)		P value
		Yes	No	
Age groups (year)	20–30	41	27	0.490
	30–40	126	79	
	40–50	40	31	
	50–60	18	6	
Professional title	Junior	78	46	0.731
	Intermediate	84	51	
	Senior	63	46	
Academic qualification	Bachelor	57	58	0.011
	Master	142	74	
	PhD	26	11	
Hospital rank	Tertiary	217	141	0.362
	Secondary	8	2	
Staff of ICU training centers	Yes	138	54	0.000
	No	87	89	
PALS course	Yes	143	79	0.185
	No	82	64	
Cases with septic shock per year	More than 30	167	73	0.000
	0–29	58	70	

n, number of respondents; HM, hemodynamic monitoring; ICU, intensive care unit; PALS, Pediatric Advanced Life Support.

Table 5 Factors associated with availability of non-invasive hemodynamic monitoring devices using multivariable analyses

Parameters	B	S.E.	Wald	df	P value	OR (95%CI)
Cases with Septic shock per year (1=more than 30, 0=less than 30)	0.745	0.242	9.465	1	0.002	2.107 (1.311, 3.388)
Staff of ICU specialist training center (1=YES, 0=NO)	0.701	0.235	8.882	1	0.003	2.015 (1.271, 3.195)
Academic qualification			5.071	2	0.079	
1=Bachelor, 0=Master	–0.512	0.246	4.326	1	0.038	0.600 (0.370, 0.971)
1=PhD, 0=Master	0.148	0.399	0.138	1	0.710	1.160 (0.531, 2.534)
Constant	–0.215	0.220	0.950	1	0.330	0.807

ICU, intensive care unit; B, coefficient values; S.E., standard error; Wald, Wald chi-square values; df, degree of freedom; OR, odds ratio.

Discussion

Based on E-mail survey, this study evaluated the practice regarding basic and advanced HM and management in children with septic shock in China.

With no doubt, the survey showed that almost every patient with septic shock performed basic HM, which was similar to the study by Saugel *et al.* (19) and Funcke *et al.* (7). It is encouraging to note that the proportion of urine

Table 6 Comparison of the parameters that start fluid responsiveness and the volume status assessment in clinical vignettes

Parameters	Variables	FR-VS n (%)		P value
		Yes	No	
Age group	20–30	32 (47.8)	35 (52.2)	0.540
	30–40	104 (50.2)	103 (49.8)	
	40–50	32 (45.7)	38 (54.3)	
	50–60	15 (62.5)	9 (37.5)	
Professional title	Junior	54 (43.9)	69 (56.1)	0.285
	Intermediate	72 (52.6)	65 (47.4)	
	Senior	57 (52.8)	51 (47.2)	
Hospital rank	Tertiary	177 (49.4)	181 (50.6)	0.510
	Secondary	6 (60.0)	4 (40.0)	
Academic qualification	Bachelor	47 (41.2)	67 (58.8)	0.008
	Master	110 (50.7)	107 (49.3)	
	PhD	26 (70.3)	11 (29.7)	
Staff of ICU specialist training center	Yes	113 (58.9)	79 (41.1)	0.000
	No	70 (39.8)	106 (60.2)	
Fluid resuscitation	Yes	156 (48.4)	166 (51.6)	0.193
	No	27 (58.7)	19 (41.3)	
PALS course	Yes	120 (53.6)	104 (46.4)	0.066
	No	63 (43.8)	81 (56.3)	
Cases with septic shock per year	More than 30	134 (55.8)	106 (44.2)	0.001
	0–29	49 (38.3)	79 (67.1)	

n, number of respondents; FR-VS, fluid responsiveness and volume status; ICU, intensive care unit; PALS, pediatric advanced life support.

Table 7 Factors associated with start fluid responsiveness and the volume status assessment using multivariable analyses

Parameters	B	S.E.	Wald	df	P value	OR (95% CI)
Cases with Septic shock per year (1=more than 30, 0=less than 30)	0.430	0.241	3.193	1	0.074	1.537 (0.959, 2.463)
Staff of ICU specialist training center (1=YES, 0=NO)	0.634	0.228	7.717	1	0.005	1.885 (1.205, 2.948)
Academic qualification			6.999	2	0.030	
1=Bachelor, 0=Master	–0.265	0.241	1.215	1	0.270	0.767 (0.479, 1.229)
1=PhD, 0=Master	0.834	0.392	4.511	1	0.034	2.302 (1.066, 4.967)
Constant	–0.623	0.224	7.750	1	0.005	0.536

ICU, intensive care unit; B, coefficient values; S.E., standard error; Wald, Wald chi-square values; df, degree of freedom; OR, odds ratio.

output measurement (81.6%) in 1-hour in our survey was significantly higher than that (68.1%) in the survey conducted from May 2011 to January 2012 in three PICUs of tertiary teaching hospitals in Shanghai, China (20).

Extended HM parameters and in particular monitoring of cardiac output (CO/CI/LVEF/SV/VTI) and $ScvO_2$, were used all over in less than 50% of the respondents, which was similar to that in Saugel's and Biancofiore's studies (9,19), but higher than that in Funcke's report (only 24% of all ICU patients' CO monitoring based on individual patient data) (7). These findings might indicate that the pediatricians in our survey (mainly pediatric intensivists as primary specialty), compared with the anesthesiologists in the study of Funcke *et al.* (7), performed CO/CI/LVEF/SV/VTI monitoring more often, or that the answers given by the pediatricians in our survey (that was not based on individual patient data) overestimate the actual proportion of patients undergoing CO monitoring.

Less than 5% of the respondents reported using advanced hemodynamic variables of microcirculation, such as PtO_2 and $PtCO_2$, which was similar to the study of Funcke *et al.* (7). Whether the low frequency of use was caused by a lack of confidence in monitoring accuracy or by other reasons (for example cognitive, economic) was beyond the scope of the survey.

In our survey CVP was used for preload monitoring in almost half of the respondents and the use of volumetric or dynamic parameters of preload was infrequent (25% of the respondents), which was similar with earlier data from Funcke *et al.*, Cecconi *et al.* and Preau *et al.* (7,11,14). However, the poor use of these predictive indices observed in our survey was in contrast with their frequent use (49.7%) in the clinical case vignette, with the major limitation inherent to studies collecting declarative data. In addition, the significant use limitation of some parameters such as PLR in children may also account for the low frequency of use. This also illustrated the gap among theoretical, physiological knowledge and routine practice (15).

The most frequent invasive extended hemodynamic technology was transpulmonary thermodilution (21), however, the actual use of this monitoring modality for fluid therapy in the clinical case vignette with septic shock was comparably low (6.3% of respondents) in our study. In contrast, non-invasive HM devices were frequently used (61.1% of respondents reported using in their hospitals and 49.7% of respondents reported using in the clinical case vignettes), which was similar to the earlier data from Italian (9). Bedside transthoracic echocardiography led by intensivists was the most commonly used device in the survey. Our study suggests that there may be an increasing awareness and acceptance of non-invasive HM in pediatric intensive care medicine (outside cardiac surgery) in China. However, several studies have reported the gap between the high availability (7,11,15) or the strong recommendations (22,23) of noninvasive HM and their actual low clinical use in patients, which were out of our declarative data description. Of note, there were obviously differences between staff of ICU training centers and sepsis numbers per year regarding utilization of these noninvasive technologies in this survey. Our survey may suggest that professional training platform and the number of septic shock admission per year were major factors in the introduction and use of new technologies. Boulain *et al.* (15) also had reported the between-center heterogeneity in HM in 19 French ICU.

Clinical case vignettes were designed to indirectly assess the practical application of advanced HM in the respondents. The survey found that FR-VS assessment was not related to the volume expansion decision, although staff in training centers and highly educated individuals tended to assess the hemodynamics. Cecconi *et al.* (11) reported that patients in the FENICE Study received further fluids despite no response to the initial fluid challenge. Preau *et al.* (14) reported that dynamic parameters were often incorrectly used in the presence of contraindications in six French ICU. Those findings highlight the great variability in fluid management in critically ill patients, the gap in integrating different hemodynamic variables into management decisions, and the importance of continuing education and training of advanced HM at different levels and in different ways (13,16).

Our study has several strengths. We received responses from multiple different regions in China, ranging from high-income to lower middle-income regions. Respondents were PICU specialists at different professional title and academic qualification, and mainly working in tertiary hospitals.

Our survey has the limitations of being addressed only to the members of Association of Pediatric Intensivists who responded in a limited number. Therefore, it may only mirror the attitude and practice of Chinese pediatric intensivists in using HM to a certain extent. It is also possible that there was a selection bias, as pediatricians interested in hemodynamics may have greater tendency to being willing to answer the questionnaire. We were unable to determine causality or potential direction of effect for the associations observed through an email-based survey. Second, even if we consider that our survey results represent the actual practice of HM in critically ill children in China three years ago, but the knowledge and education of advanced HM, especially non-invasive HM, have been greatly improved in pediatrics in recent years. Third, to describe the degree of the simulated management of HM, a simple method (case vignette) was used to assess the consensus on clinicians' practices. Finally, given the inherent flaws in self-reported survey research, the gap between perception of practice and the real-life practice at the bedside may be significant. A multicenter study either prospective or retrospective data review would be a stronger study to find out an actual prevalence of these monitoring in real practice scenarios.

In conclusion, there was a large variability in use advanced HM parameters. Almost half of the respondents reported to use advanced HM such as CVP, cardiac output indicators (CO/CI/LVEF/SV/VTI) and $ScvO_2$, but the use of volumetric or dynamic indices of preload and microcirculation was infrequent in our study. There was a growing awareness and acceptance of non-invasive HM, but FR-VS assessment was not related to volume expansion decision. There was a potential need for hemodynamic education and training in pediatric intensive care medicine (outside cardiac surgery) in China.

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