Comparison Between Swan-Ganz Catheter and Minimally Invasive Hemodynamic Monitoring During Liver Transplantation: Report of a Monocentric Case Series

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ABSTRACT

Introduction. The aim of the present investigation was to retrospectively evaluate the utilization of Swan-Ganz catheter during orthotopic liver transplantation as opposed to FloTrac/Vigileo in selected cases, comparing a number of clinical outcomes across postoperative hospitalization.

Materials and methods. Before 2015 all recipients received pulmonary artery catheter (Swan-Ganz group, n = 109). After 2015 Swan-Ganz was used only if coronary artery disease or high-grade portal hypertension or Child-Pugh C were present; the remaining recipients were assigned to FloTrac/Vigileo monitoring (Mini group, n =100). A number of clinical outcomes were considered.

Results. Donor's Risk Index was similar between groups (median value 1.7, $P = .27$). Anthropometric characteristics of the recipients were similar in the 2 groups. There were no significant differences in the proportion of patients with Child-Pugh C ($P = .873$), coronary artery disease ($P = .18$), and grade of portal hypertension ($P = .733$). The Model for End-Stage Liver Disease score was slightly higher in the Mini group: (9 [7-11] vs 9 [8-12], Swan-Ganz vs Mini, respectively, $P < .035$). Swan-Ganz utilization decreased over time (92% vs 26%, Swan-Ganz vs Mini, $P < .001$). Upon admission to the intensive care unit, patients of the Mini group presented a higher SAPS II score with similar values of Sequential Organ Failure Assessment score. Days on mechanical ventilation were similar between groups. The incidence of graft failure was similar between groups (2% vs 5%, Swan-Ganz and Mini group respectively, $P = .376$). Recipients' hospital length of stay was similar (13 days [11-19] vs 14 [11-20], $P < .083$).

Conclusions. Our data suggest that the intraoperative utilization of FloTrac/Vigileo for oncologic patients with low grade end stage liver disease is reasonably safe.

THE intraoperative course of orthotopic liver transplantation (OLTX) is often characterized by significant hemodynamic derangements. During hepatectomy, meaningful fluid shifts occur from both drainage of ascites and bleeding; moreover, manipulation of the liver and retraction of the inferior vena cava intermittently obstruct venous return causing sudden changes in preload. During the anhepatic stage of the procedure, cardiac output often decreases with cross clamping of the portal vein and inferior vena cava. Finally, at reperfusion of the graft the heart is challenged with a volume load of blood often acidic,

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hyperkalemic, and loaded with a variety of inflammatory and vasodilatatory mediators. For these reasons hemodynamic measurements during OLTX have been traditionally performed by pulmonary artery catheter (PAC). However, less invasive monitoring systems and transesophageal echocardiography (TEE) are taking place during OLTX in many institutions [1].

The aim of the present investigation was to describe the hemodynamic monitoring workout during OLTX at our Institution, retrospectively evaluating the utilization of Swan-Ganz catheter as opposed to FloTrac/Vigileo (uncalibrated system which measures cardiac output from arterial pressure wave, Edwards Lifesciences, Irvine, CA United States) in selected cases, comparing a number of clinical main outcomes across postoperative hospitalization.

MATERIALS AND METHODS

Study Design

This retrospective monocentric study was performed after approval by the Ethics Committee of the Fondazione IRCCS Istituto Nazionale dei Tumori on February 2019 (protocol number n. 9/19).

All consecutive OLTXs performed between January 2012 and December 2017 were considered. Subjects were stratified according to the implementation of a clinical hemodynamic monitoring protocol that started from January 2015. The protocol (Fig 1) assigned patients with coronary artery disease, high grade portal hypertension, or Child-Pugh C to an intraoperative monitoring with PAC (Swan-Ganz group); the remaining recipients were assigned to FloTrac/Vigileo monitoring (Mini group), provided the final decision on intraoperative monitoring was based on the clinical judgement of the anesthesiologist implicated with the single transplant procedure. High grade of portal hypertension was defined considering the presence and severity of cirrhosis, thrombocytopenia, splenomegaly and esophageal varices with associated collateral vessels.

Donors and Recipients

Donors' data collected included the following variables: age, sex, race, body mass index, cause of death, length of stay in intensive care unit (ICU), positivity for viral hepatitis, and split liver execution. Donor Risk Index was also calculated [2].

Recipients' data included the following: anthropometric characteristics, American Society of Anesthesia physiological status classification, presence of CAD, indication to OLTX, and severity of the liver disease. This was assessed by the Model for End-Stage Liver Disease (MELD) and Child-Pugh score, and the grade, if present, of portal hypertension. The latter was graded on the basis of the presence of esophageal varices and splenomegaly in a numerical scale from 0 to 3.

Perioperative Data

The amount of crystalloids, synthetic colloids, human albumin, and any transfusion of components such as red blood cells, fresh frozen plasma, or platelet units infused during the procedure and vasopressor utilization were collected, together with frequency of utilization of thromboelastography. Adverse events in the operating room were reported.

After surgery, at the admission in ICU, Simplified Acute Physiology Score II (SAPS II) and the Sequential Organ Failure Assessment (SOFA) score were calculated. Utilization of vasoactive drugs started after ICU admission, transfusion of blood products, and time on mechanical ventilation were noted. Presence of acute kidney injury defined according to the KDIGO criteria [3] was assessed on day 1, 3, and 5 after surgery, together with need of continuous renal replacement therapy. Primary nonfunction of the liver, defined as graft failure and/or re-transplantation within 7 days [4] were recorded. Duration of ICU stay or readmissions to ICU, hospital length of stay, and in-hospital mortality were quantified.

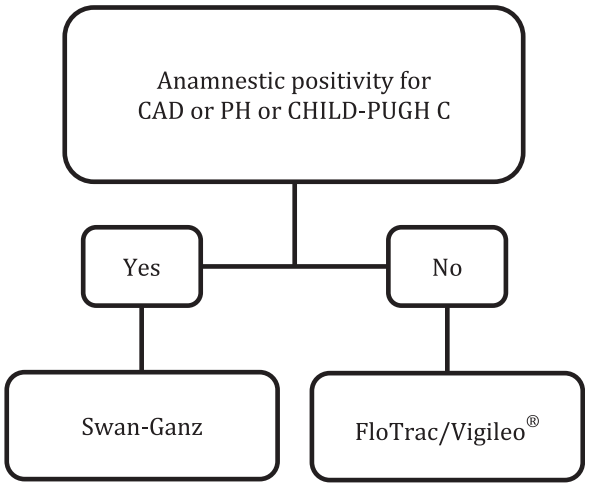

Fig 1. Protocol flow chart of the study.

Statistical Analysis

Data are presented as mean ± standard deviation if normally distributed, or as median and interquartile range. Absolute values and relative frequencies are utilized for categorical variables.

Comparison among study groups for continuous variables was performed using ANOVA, Student t test or with Mann-Whitney rank sum test as appropriate. Chi-square was utilized for discrete variables.

A P value $< .05$ was considered statistically significant. Analyses were performed with SigmaPlot version 12.0 (Systat Software, San Jose, CA).

RESULTS

A total of 209 OLTX were performed from January 2012 to December 2017. Of these, 109 were performed before 2015 (Swan-Ganz group) and 100 after (Mini group).

Donors and Recipients

Characteristics of the multiorgan donors are listed in Table 1. The causes of death differed significantly for the 2 groups, with head trauma and anoxia more frequently represented in the Mini group. There were no other differences between study groups.

As shown in Table 2, the baseline anthropometric characteristics of the recipients were similar in the 2 groups. There were no significant differences in the proportion of patients with Child-Pugh C ($P = .873$), coronary artery disease ($P = .180$), and in grade of portal hypertension ($P = .733$). The MELD

Table1. Donor Characteristics

	No.	OLTX 2012-2017 N=209	No.	Swan-Ganz 2012-2014 N=109	No.	Mini 2015-2017 N=100	P
Age, y	206	65 5273(-)	109	65 5372(-)	97	64 5174(-)	.723
Sex F, n (%)	206	80 (39)	109	48 (44)	97	32 (33)	.139
BMI	206	26 2428(-)	109	26 2428(-)	97	26 2429(-)	.505
Caucasian race, n (%)	206	202 (98)	109	106 (97)	97	96 (99)	.567
ICU stay, days	206	2 (1-4)	109	2 (1-4)	97	2 (1-4)	.982
Viral hepatitis, n (%)	206	54 (26)	109	27 (25)	97	27 (28)	.733
Split liver, n (%)	206	6 (3)	109	4 (4)	97	2 (2)	.787
Cause of death, n (%)	206		109		97		.016
Cerebrovascular accident		143 (69)		85 (78)		58 (60)	
Head trauma		34 (17)		14 (13)		20 (21)	
Anoxia		29 (14)		10 (9)		19 (20)	
Donor Risk Index	209	1.7 (1.4-1.9)	109	1.7 (1.5-1.9)	100	1.7 (1.4-1.9)	.25

BMI, body mass index; ICU, intensive care unit; OLTX, liver transplantation.

score was slightly higher in the Mini group: (9[7-11] vs 9 [8-12], Swan-Ganz vs Mini, respectively, $P < .035$).

INTRAOPERATIVE DATA

The utilization of the Swan-Ganz catheter decreased over time (92% vs 26%, Swan-Ganz vs Mini, $P < .001$), as shown in Table 3. Utilization of venovenous bypass was similar: 22% in the Swan-Ganz group and 13% in the Mini group ($P = .229$). The frequency of TEG monitoring was similar (96% vs 93%, Swan-Ganz vs Mini, $P = .419$).

Both groups underwent a similar rate of crystalloids infusion intraoperatively, with a median value of 9 mL/kg/h; the use of synthetic colloids decreased over time (1.5 mL/kg/h [0.7-7.4] vs 0.8 [0.4-1.3], Swan-Ganz vs Mini respectively, $P < .001$), whereas the consumption of albumin increased (0 g [0- 0] vs 12 [0-31], $P < .001$). Red blood cell (1 unit [0-3] both groups) and platelet (0 pool [0-0] both groups) transfusions were similar between study groups. The amount of fresh frozen plasma administered during OLTX was lower in the Mini group (1.2 mL/kg/h [0.6-1.8] vs 0.6 [0-1.2], $P < .001$). Diuresis (1.8 mL/kg/h [1.3-2.5] vs 1.7 [1.1-2.4], Swan-Ganz vs Mini respectively, $P = .236$) and use of vasopressors ($P = .488$), were similar between groups.

Time requested since induction of anesthesia until skin incision was higher in the Mini group (79 min [37-90] vs 85 [75-96], Swan-Ganz vs Mini, respectively, $P < .001$), and the whole transplant procedure had less duration (682 min [610-740] vs 606 [540-673], Swan-Ganz vs Mini, respectively, $P < .001$).

There were no incidences of adverse events leading to death.

ICU OUTCOMES

Data regarding the course of ICU stay are shown in Table 4. Upon admission, patients of the Mini group presented a higher SAPS II score with similar values of SOFA score. Days on mechanical ventilation were similar between groups (less than 24 hours as a median value).

Both groups had the same rate of red blood cell units and platelet pools transfusion, with 0 as median value, and the consumption of fresh frozen plasma was lower in the Mini group (500 mL [0-860] vs 0 [0-0], $P < .001$). There was no difference of vasopressor utilization ($P = .425$), acute

Table 2. Recipients Preoperative Characteristics

	No.	OLTX 2012-2017 N = 209	No.	Swan-Ganz 2012-2014 N = 109	No.	Mini 2015-2017 N = 100	P
Age, y	209	57 5261 (-)	109	57 5160(-)	100	58 5262(-)	.161
Sex F, n (%)	209	27 (1)	109	16 (15)	100	11 (11)	.558
BMI	209	25 2427 (-)	109	26 2428 (-)	100	25 2328 (-)	.935
ASA	206	2 (2-3)	107	2 (2-2)	99	2 (2-3)	.16
Indication for OLTX, n (%)	206		109		97		.379
HCC		188 (91)		99 (91)		89 (92)	
NET		10 (5)		7 (6)		3 (3)	
Other		8 (4)		3 (3)		5 (6)	
Child-Pugh C, n (%)	192	9 (5)	101	4 (4)	91	5 (6)	.873
MELD	209	9 (7-11)	109	9 (7-11)	100	9 (8-12)	.035
CAD, n (%)	208	6 (3)	108	1 (1)	100	5 (5)	.18
PH, 0-3	183	1 (0-2)	97	1 (0-2)	86	1 (0-2)	.733

ASA, American Society of Anesthesia; BMI, body mass index; CAD, coronary artery disease; HCC, hepatocellular carcinoma; NET, neuroendocrine tumor; MELD, Model for End-stage Liver Disease; OLTX, liver transplantation; PH, portal hypertension.

Table 3. Recipients Intraoperative Characteristics

	No.	OLTX 2012-2017 N = 209	No.	Swan-Ganz 2012-2014 N = 109	No.	Mini 2015-2017 N = 100	*P*
Swan-Ganz, n (%)	209	126 (60)	109	100 (92)	100	26 (26)	<.001
VVBP, n (%)	209	35 (17)	109	22 (20)	100	13 (13)	.229
TEG, n (%)	201	190 (95)	106	102 (96)	95	88 (93)	.419
Crystalloid, ml/kg/h	198	9 (7-11)	99	9 (7-11)	99	9 (7-11)	.249
Colloid, mL/kg/h	198	1.1 (0.5-1.9)	99	1.5 (0.7-7.4)	99	0.8 (0.4-13)	<.001
FFP, mL/kg/h	209	0.9 (0.3-1.5)	109	1.2 (0.6-1.8)	100	0.6 (0.0-1.2)	<.001
RBC, unit	209	1 (0-3)	109	1 (0-3)	100	1 (0-3)	.466
PLT, pool	209	0 (0-0)	109	0 (0-0)	100	0 (0-0)	.303
Albumin, g	199	0 (0-20)	102	0 (0-0)	97	12 (0-31)	<.001
Diuresis, mL/kg/h	197	1.7 (1.3-2.4)	102	1.8 (1.3-2.5)	95	1.7 (1.1-2.4)	.236
Vasopressors, n (%)	206	158 (77)	109	81 (74)	97	77 (79)	.488
Preparation time, min	209	83 (72-93)	109	79 (37-90)	100	85 (75-96)	<.001
Intraoperative time, min	209	636 (571-712)	109	682 (610-740)	100	606 (540-673)	<.001

FFP, fresh frozen plasma; PLT, platelet; RBC, red blood cell; TEG, thromboelastography; VVBP, venovenous bypass.

kidney injury (15%, $P = .857$), or use of continuous renal replacement therapy (2%, $P = .56$). Recipients of the Mini group had a significant shorter time of ICU stay (2 days [1-2] vs 1 [1-2], $P = .011$).

Post-ICU Outcomes

The incidence of graft failure was similar between groups (2% vs 5%, Swan-Ganz and Mini group, respectively, $P = .376$). The patients of the Mini group registered a higher frequency of readmission in ICU (4% vs 12%, $P = .045$). Recipients' hospital length of stay did not differ between Swan-Ganz and Mini group (13 days [11-19] vs 14 [11-20], $P < .083$). One patient died after transplantation, after several months of recovery (Mini group). Data are shown in Table 5.

DISCUSSION

Aim of the present investigation was to describe the hemodynamic monitoring workout during OLTX at our Institution, retrospectively evaluating the utilization of Swan-Ganz catheter as opposed to FloTrac/Vigileo in selected cases, comparing a number of clinical main outcomes across postoperative hospitalization. Analysis revealed that there were no major differences among recipient's outcomes when the mini-invasive hemodynamic measurement strategy was selectively applied.

Hemodynamic monitoring during OLTX varies among centers according to preferences matured over time and largely depending on recipient's selection. The cohort of subjects who underwent OLTX in our investigation included oncologic patients with low grade of end stage liver disease, most of which were Child-Pugh A, with a low average MELD score, low grade of portal hypertension, and minimal incidence of ischemic coronary disease. This made it possible to safely introduce the mini-invasive strategy. Severely cirrhotic recipients often characterized by systemic vascular resistance and cardiac output impairment would have been at greater risk with the mini-invasive strategy, given the low reliability of these systems at high or low extremes of pressure and cardiac output [5].

Nevertheless, it was interesting to find that the introduction of the internal protocol led to a reduction of PAC utilization without significant effects on subject's outcome.

Table 4. Postoperative ICU Data

	No.	OLTX 2012-2017 N = 209	No.	Swan-Ganz 2012-2014 N = 109	No.	Mini 2015-2017 N = 100	*P*
SAPS II	205	25 (21-30)	106	23 (18-28)	99	26 (24-31)	<.001
SOFA	205	5 (3-7)	106	5 (3-6)	99	5 (3-7)	.155
MV, d	208	0 (0-1)	108	0 (0-1)	100	0 (0-1)	.518
Vasopressors, n (%)	208	44 (21)	108	20 (19)	100	24 (24)	.425
AKI 1 POD, n (%)	209	26 (12)	109	10 (9)	100	16 (16)	.199
CRRT, n (%)	208	4 (2)	108	1 (1)	100	3 (3)	.56
ICU stay, d	209	1 (1-2)	109	2 (1-2)	100	1 (1-2)	.011
RBC, unit	205	0 (0-0)	107	0 (0-0)	98	0 (0-0)	.737
FFP, mL	205	0 (0-746)	107	500 (0-860)	98	0 (0-0)	<.001
PLT, pool	205	0 (0-0)	107	0 (0-0)	98	0 (0-0)	.414

AKI, acute kidney injury; CRRT, continuous renal replacement therapy; FFP, fresh frozen plasma; ICU, intensive care unit; MV, mechanical ventilation; OLTX, liver transplantation; PLT, platelet; POD, postoperative day; RBC, red blood cell; SAPS, Simplified Acute Physiology Score; SOFA, Sequential Organ Failure Assessment score.

Table 5. Post-ICU Stay Outcomes

	No.	OLTX 2012-2017 N = 209	No.	Swan-Ganz 2012-2014 N=109	No.	Mini 2015-2017 N = 100	*P*
ICU readmission, n (%)	209	16 (8)	109	4 (4)	100	12 (12)	.045
Graft failure, n (%)	209	7 (3)	109	2 (2)	100	5 (5)	.376
AKI 3 POD, n (%)	208	42 (20)	109	22 (20)	99	20 (20)	.865
AKI 5 POD, n (%)	202	31 (15)	104	16 (15)	98	15 (15)	.857
Hospitalization, d	209	13 (11-20)	109	13 (11-19)	100	14 (11-20)	.083
In-hospital mortality, n (%)	209	1 (0.5)	109	0 (0)	100	1 (1)	.966

AKI, acute kidney injury; ICU, intensive care unit; OLTX, liver transplantation; POD, postoperative day.

The design of the study, retrospective in nature, cannot account for improvement of surgical skill, as suggested by the reduction of the intraoperative time over the years. Similarly, improvements in the anesthesia conduct of OLTX likely occurred, as suggested by the fact that patients in the Mini group experienced shorter length of ICU stay despite higher SAPS II score at ICU admission, similar incidence of AKI and need of continuous renal replacement therapy, as well as similar rate of graft failure, mortality, and duration of hospitalization.

The fact that the strategies were not randomized and groups were time-stratified is a major flaw of the investigation. Moreover, the decisional algorithm applied is characterized by a major weakness: the lack of consideration of donor's liver characteristics. In fact, as shown in Table 1, even if donors did not differ significantly between groups, donor risk index scores were relatively low, and no donor after cardiac arrest was included in the analysis. Particularly when extended donor's criteria and livers from donation after cardiac death (DCD) donors are used, the Swan-Ganz catheter may be a better choice than mini-invasive monitoring given its reliability of cardiac output measurement and the possibility of measuring pulmonary artery pressures beat to beat, particularly during reperfusion of the graft. The absence of systematic use of TEE monitoring also adds to the limits of our investigation. Nevertheless, our data suggest that the intraoperative utilization of FloTrac/Vigileo for oncologic patients with low-grade end stage liver disease is reasonably safe. The decision to which patient reserves the mini-invasive hemodynamic monitoring strategy remains open to further investigation.

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