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Radial to femoral arterial blood pressure differences during liver transplantation

D. Arnal, I. Garutti, J. Perez-Peña, L. Olmedilla and I. G. Tzenkov

Consultants, Department of Anaesthesia and Reanimation, Hospital General Universitario, Gregorio Marañón, Madrid, Spain

Summary

This observational study compared femoral and radial arterial blood pressure in 72 patients undergoing liver transplant surgery. Simultaneous femoral and radial arterial blood pressures, cardiac index, core temperature and vasoconstrictor therapy were recorded at seven time points during the operation. No significant differences between radial and femoral pressures were found at the start of surgery. Femoral and radial systolic arterial blood pressures were statistically significantly different during liver reperfusion (mean (SD) arterial pressure = 92 (22) mmHg vs. 76 (22) mmHg, $p < 0.01$). Mean arterial blood pressures showed no statistically significant differences throughout the study. Vasoconstrictor drug administration was associated with a larger systolic pressure difference between femoral and radial arteries (28 (24) mmHg in patients being given vasoconstrictor drugs vs. 9 (19) mmHg in patients not needing vasoconstrictors during reperfusion, $p < 0.001$). In conclusion, differences in systolic arterial blood pressure occur between femoral and radial arterial monitoring sites during liver reperfusion, and in particular in patients being given vasoconstrictor therapy. Thus, if femoral arterial monitoring is not available, clinicians should rely on mean rather than systolic arterial pressure measurements from a radial artery catheter during liver transplantation.

Correspondence to: D. Arnal
E-mail: darnal@gmail.com
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The radial artery is the most common site for arterial blood pressure monitoring because of its ease of cannulation and the low incidence of complications [1]. Many therapeutic decisions rely on blood pressure values in everyday clinical practice, in particular during major surgical procedures such as liver transplantation. Systolic arterial pressure (SAP) measured in the radial artery is usually higher than aortic SAP, whereas mean arterial pressure (MAP) remains the same throughout the arterial tree [2]. A reverse central-to-radial difference has been documented after cardiopulmonary bypass [3–5] and in other clinical situations, including septic patients being given vasoconstrictor drugs [6]. Although similar blood pressure differences have been described during liver transplant surgery [7], these differences have not been confirmed [8]. The aim of this study was to determine the extent and timing of femoral to radial blood pressure differences during liver transplant surgery and the relationship between these differences and other haemodynamic variables.

Methods

After Local Research Ethics Committee approval and written, informed patient consent, we studied 72 consecutive patients undergoing liver transplantation for end-stage liver disease or acute liver failure. Liver surgery was performed with standard techniques, with the piggyback method and without the use of venovenous bypass. Standard monitoring included ECG, S_pO_2, F_ECO_2 and non-invasive blood pressure. We induced general anaesthesia with intravenous etomidate 0.2 $mg.kg^{-1}$, fentanyl 3 $\mu g.kg^{-1}$ and rocuronium 1 $mg.kg^{-1}$. After orotracheal intubation, the patient's lungs were ventilated to maintain S_pO_2 and F_ECO_2 within normal ranges. Anaesthesia was maintained with remifentanil 0.1–0.4 $\mu g.kg^{-1}.min^{-1}$, rocuronium 0.5 $mg.kg^{-1}.h^{-1}$ and midazolam 2–3 $\mu g.kg^{-1}.min^{-1}$.

After induction of anaesthesia, both right radial and right femoral arteries were cannulated with 20-G 4.5-cm-long Teflon cannulae (Arrow International Inc., Reading,

PA, USA). Both catheters were connected to 100-cm saline-filled, rigid manometer lines that were connected to identical continuous flush transducer systems (Gabarith PMSET 1DT-XX, Becton Dickinson, Franklin Lakes, NJ, USA), which were positioned at the patient's mid-axillary line. Pressure waveforms were displayed and systolic, mean and diastolic femoral and radial blood pressures were recorded (7250 Kontron Instruments™, Watford, UK) and analysed at the end of the surgery. Frequency responses and damping coefficients of the systems were obtained by the flush method of Gardner [9]. The systems were zeroed to atmospheric pressure. When necessary, further line flushing and transducer repositioning were performed. We introduced a pulmonary artery catheter (OptiQ, Abbott Laboratories, Abbott Park, IL, USA) via an 8.5 FG introducer in the right internal jugular vein and advanced it to a wedged position under continuous pressure monitoring. Cardiac index and derived haemodynamic variables were measured using cold thermodilution (Thermoset®, Abbott Laboratories), computed through a cardiac output computer (Oximetrix®, Abbott Laboratories). Body temperature was measured with the thermistor in the pulmonary artery catheter.

We obtained recordings of blood pressure, blood temperature and cardiac index at the following time points:

- baseline: immediately after radial and femoral arterial cannulation;
- 10 min before inferior vena cava clamping;
- 10 min after inferior vena cava clamping;
- 10 min before liver reperfusion;
- within 3 min of liver reperfusion;
- 10 min after liver reperfusion;
- at the end of biliary reconstruction.

We recorded the lowest radial SAP and MAP and its corresponding femoral SAP and MAP within 3 min of reperfusion and termed it the *reperfusion* time point. Neither cardiac index nor body temperature was determined at this time point because of the rapid temperature and haemodynamic changes that occur at this stage of the operation. According to our standard practice, we initiated and titrated vasoconstrictor drug therapy (epinephrine, norepinephrine or dopamine) when radial MAP decreased to < 65 mmHg for > 1 min.

Statistical analyses were performed with SPSS 11.5.0 (SPSS Inc., Chicago, IL). Clinically significant differences were defined as SAP differences > 10 mmHg and MAP differences > 5 mmHg [10]. Analysis of variance, paired *t*-tests with two-tailed probabilities and Bland-Altman analyses [11] were performed to test whether the femoral and radial blood pressures were statistically different. Linear regression was used to determine the relationships between the demographic and haemodynamic factors and the magnitude of the blood pressure differences at the different measurement time points. Independent variables included age, body mass index, cardiac index, core temperature and administration of significant doses of vasoconstrictor drugs (epinephrine > 100 μg, norepinephrine > 0.1 $\mu g.kg^{-1}.min^{-1}$ or dopamine > 10 $\mu g.kg^{-1}.min^{-1}$). Dependent variables included differences in SAP and MAP at the various time points. Cross-tables and Fisher's Exact tests were used to determine whether gender, obesity (body mass index > 30 $kg.m^{-2}$), type of transplant (transplant or redo transplant), extent of inferior vena cava clamping (partial or total), hyperdynamic state at the start of the surgery and after reperfusion (cardiac index > 5 $l.s^{-1}.m^{-2}$), advanced liver disease (Child-Pugh classification for liver disease class C [12, 13]) or administration of vasoconstrictor drugs was associated with clinically significant differences in blood pressure. Data are expressed as mean (SD).

Results

In all, 504 sets of blood pressure recordings were obtained in the 72 patients enrolled in the study. Patient characteristics are shown in Table 1. Of the patients with cirrhosis, 12% were assessed as Child-Pugh Class A, 47% as Class B and 41% as Class C. The inferior vena cava had

Table 1 Patient characteristics. Data are number or mean (SD).

Total number	72
Age; years	50 (10)
Sex ratio; M : F	50 : 22
Body mass index; $kg.m^{-2}$	24.0 (4.2)
Alcoholic or viral cirrhosis	54
Cirrhosis and tumour	8
Hepatic acute failure	2
Redo transplant	8

Table 2 Radial and femoral systolic and mean blood arterial pressures. Values are mean (SD).

	Systolic arterial blood pressure; mmHg		Mean arterial blood pressure; mmHg	
	Radial	Femoral	Radial	Femoral
Baseline	111 (19)	109 (17)	77 (15)	78 (15)
10 min before caval clamp	108 (21)	113 (22)	76 (15)	77 (17)
10 min after caval clamp	106 (19)	112 (20)	75 (13)	77 (14)
10 min before reperfusion	111 (17)	114 (17)	77 (13)	79 (12)
Reperfusion	76 (22)*	92 (22)	53 (15)	56 (14)
10 min after reperfusion	110 (20)	112 (24)	71 (14)	71 (15)
End of biliary reconstruction	108 (18)	110 (19)	72 (12)	72 (11)

*Significantly different to femoral systolic arterial pressure, $p < 0.01$.

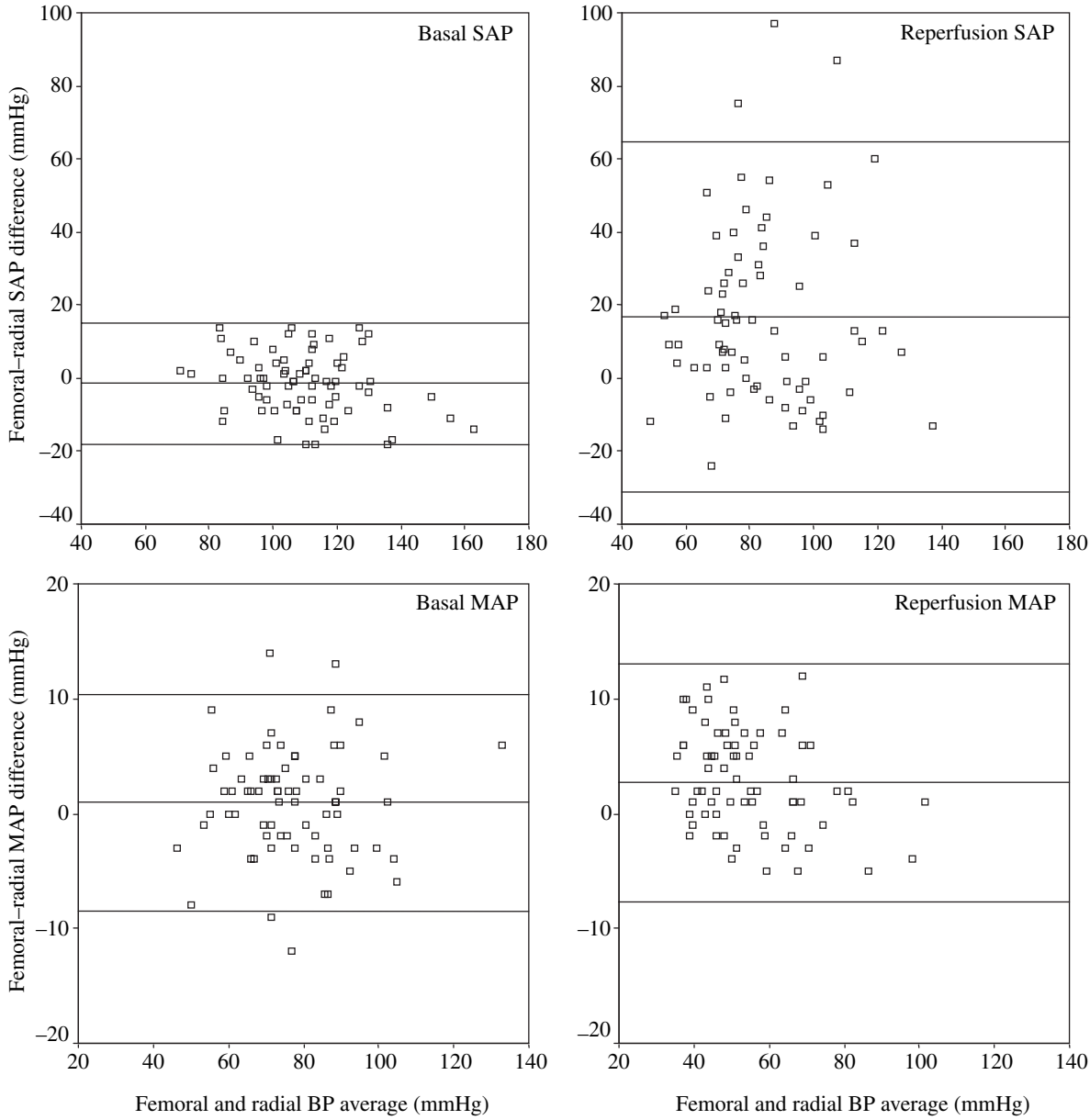

Figure 1 Femoral-to-radial blood pressure differences against mean blood pressure values for systolic arterial pressure (SAP) and mean arterial pressure (MAP) at basal and reperfusion measurement time points. Horizontal lines represent mean and 1.96 × SD.

to be totally clamped during surgery in 10 patients; in the rest of patients, liver transplantation could be performed with a partial caval clamp.

Frequency responses and damping coefficients were similar in both the radial and femoral systems. Systolic and mean arterial blood pressure data obtained from the radial and femoral artery cannulae are presented in Table 2. Femoral SAP was significantly higher than radial SAP at reperfusion but at no other measurement point. Femoral and radial MAPs did not differ throughout the study. Bland-Altman graphs for baseline and *reperfusion* time points are shown in Fig. 1. There were no significant differences between diastolic blood pressures throughout the study.

The following factors did not affect the magnitude of the differences in blood pressure between radial and femoral arteries: age, gender, body mass index, Child-Pugh Class, first transplant or redo transplant, partial or total caval clamping, cardiac index or core temperature. The 27 patients who required epinephrine, norepineph-

Table 3 Mean (SD) differences (femoral – radial) in systolic and mean arterial pressure in patients given vasoconstrictor drug therapy and those not given vasoconstrictor therapy.

	Systolic arterial blood pressure differences			Mean arterial blood pressure differences		
	No vasoconstrictor (n = 45)	Vasoconstrictor (n = 27)	p	No vasoconstrictor (n = 45)	Vasoconstrictor (n = 27)	p
Baseline	–1 (9)	–1 (7)	0.393	1 (5)	3 (2)	0.436
10 min before caval clamp	4 (15)	8 (17)	0.434	1 (10)	3 (4)	0.062
10 min after caval clamp	4 (16)	15 (29)	0.251	2 (5)	–1 (6)	0.454
10 min before reperfusion	2 (14)	12 (27)	0.414	2 (5)	5 (3)	0.104
Reperfusion	9 (22)*	28 (24)	0.001	2 (6)	4 (4)	0.054
10 min after reperfusion	–2 (19)	15 (28)	0.071	1 (8)	–1 (10)	0.436
End of biliary reconstruction	0 (14)	13 (23)	0.510	0 (4)	1 (5)	0.250

*Significantly different to value in patients given vasoconstrictor drugs.

rine or dopamine in significant doses showed statistically significantly greater femoral-to-radial SAP differences at the reperfusion time point (Table 3).

Discussion

Two interesting results can be derived from this observational study: the significant differences in radial and femoral SAP during reperfusion and the apparent association of vasoconstrictor drugs with greater differences in femoral and radial SAPs during reperfusion. Although femoral MAPs were slightly higher than radial MAPs during surgery, the differences were not significant. To our knowledge, this is the first publication specifically investigating this phenomenon in liver transplant surgery.

The Bland-Altman analysis shows a bias of 16 mmHg and limits of agreement of −18 mmHg to 15 mmHg for SAP at reperfusion (Fig. 1). We interpret this result as indicating that SAP at reperfusion may be misleading, depending on the site of monitoring. In normal conditions, compared with central aortic pressure, peripheral arterial waveforms show higher systolic and lower diastolic pressures, and thus wider pulse pressures [14]. Substantial femoral-to-radial artery differences have been described at the end of cardiopulmonary bypass [3–5], deep hypothermic circulatory arrest [10], cardiopulmonary resuscitation [15], isoflurane anaesthesia [16], in human volunteers during thermoregulatory vasodilation [17] and in patients with presumed sepsis treated with high dose vasoconstrictors [6]. Authors conclude that under these circumstances, peripheral (radial artery) pressure underestimates central (femoral artery) pressure. Although a number of mechanisms have been proposed to explain this phenomenon, the aetiology has not been completely elucidated.

A proposed mechanism is related to pulse wave reflection, which is the predominant factor that influences the shape of the blood pressure waveform as it travels peripherally [18]. In terms of retrograde transmission, the aorta behaves differently from the periphery [19]. The waveform and blood pressure of a small arterial branch, e.g. the radial or dorsalis pedis artery, may depend on regional vascular resistance. The upper extremity circulation is unique, being characterised by long, relatively narrow conduit vessels and distal arteriovenous shunts in the palmar surface of the hand and fingertips [20]. Vasoconstriction is the normal state of the vascular bed of the hand [16]. Most of the circumstances referred to above are characterised by decreased vasomotor tone or impedance. Under these conditions, wave reflection would be diminished [15].

We made no attempt to determine the reasons for the differences, which might include assessment of hand temperature, microcirculation characteristics, radial artery diameter, pressure waveform morphology and levels of inflammatory mediators [10]. Nevertheless, there are some similarities between liver transplant patients and those described as having large radial-to-central blood pressure differences. End-stage liver disease produces circulatory changes that include decreased arterial blood pressure secondary to marked arteriolar vasodilation and arteriovenous shunting [21]. Furthermore, the circulatory changes that occur during reperfusion include a decrease in blood pressure, heart rate and, in particular, systemic vascular resistance [7].

We could not demonstrate an association between femoral–radial SAP differences during reperfusion and the cardiac index at the beginning of the procedure nor with more advanced liver disease (Child-Pugh Class C). We expected to find that patients in a more hyperdynamic state at the beginning of the procedure would have larger differences. Other authors have also failed to prove a relationship between systemic vascular resistance and arterial pressure differences [10]. Local redistribution of blood flow may not be reflected in the systemic haemodynamic state. Unfortunately, we could not meas-

ure the cardiac index during reperfusion, and blood pressure differences during the rest of the liver transplant might not have been large enough to detect a correlation between these variables.

Of all the factors studied, only vasoconstrictor drug administration was associated with larger differences in blood pressure between radial and femoral monitoring sites. Dorman *et al.* observed that patients with septic shock who were being given vasoconstrictors showed higher femoral blood pressures, allowing decreases in drug dosage without a change in systemic haemodynamics [6]. Although we expected this because of the similarities between the haemodynamic conditions of the septic patient and the liver transplant patient, we have no clear explanation for this phenomenon. If we take a close look at the Bland-Altman plot (Fig. 1) there is no clear trend towards higher SAP or MAP differences in the patients with large decreases in blood pressure – those who might have a greater need for vasoconstrictor drugs. Therefore, we believe that the larger differences may be a direct effect of the vasoconstrictor rather than a reflection of a blood pressure differences being larger when the decrease in blood pressure is greater. Impaired peripheral vascular smooth muscle reactivity to sympathetic agonists [22, 23] or changes in vascular compliance [24] in the patient with cirrhosis might be factors involved in this phenomenon. We titrated the doses of vasoconstrictor drugs against radial blood pressure, so we cannot predict the theoretical effect of decreasing their dosage in our patients. Furthermore, in our study, the differences in MAP were clinically insignificant, even in patients receiving vasoconstrictors, so even if we had managed the patients according to femoral blood pressure, no differences in the doses of vasoconstrictor drugs given would have occurred. On the contrary, as 13 of the 27 patients receiving vasoconstrictor drugs had a femoral SAP > 90 mmHg, whereas none had a radial SAP at this level, decision-making based on the femoral SAP might have resulted in the decreased use and decreased doses of vasoconstrictor drugs in almost 50% of these patients. This would be clinically useful, as splanchnic and intrahepatic α-adrenoceptor mediated vasoconstriction should be avoided as far as possible at reperfusion to maximise liver perfusion.

The differences in SAP at reperfusion show a wide interindividual variation. Vasoconstrictor drug administration may not be the only factor in this, and the mechanism remains unclear. Even though fluid administration and vasoconstrictor therapy should be guided by MAP, SAP can be an additional source of information that may be unreliable depending on the monitoring site. Therefore, central arterial pressure monitoring is recommended for liver transplant surgery. If central monitoring is not available, clinicians should rely on MAP rather than SAP measurements from a radial artery catheter.

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