Fluid loading responsiveness

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Chapter 6

Comprehensive review: Is it better to use Trendelenburg or passive leg raising in the initial treatment of hypovolaemia?

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Hypovolaemia is a common problem in many clinical situations. The mortality of hypovolaemic shock is directly related to the severity and duration of organ hypoperfusion, which means that prompt volume replacement is the hallmark of success for managing the hypovolaemic patient [1] However, since fluid resuscitation will require some time to accomplish, manoeuvres like Trendelenburg position or passive leg raising (PLR) are commonly used as the initial treatment of shock and hypotension [2].

Trendelenburg position is the elevation of the pelvis above horizontal plane in the supine position. This position was originated by Bardenhauer of Cologne but a surgeon named Friedrich Trendelenburg popularized the position in the 19th century for facilitating surgery on the pelvic organs [3]. In World War I, the position was used as an anti-shock manoeuvre. In a survey by Ostrow and co-workers in 1997 99% of surveyed American nurses used the Trendelenburg position and approximately 80% had used PLR [4]. The Trendelenburg position is probably one of the most often used treatments in medicine.

Passive leg raising is straight passive elevation of both legs above cardiac level with the patient in a supine position. PLR is not only used to treat hypvolaemia but it is also used for its hemodynamic response to augment the murmur of heart valves and, to facilitate gynaecological and urological surgery.

Both manoeuvres are used either as a diagnostic tool to assess fluid loading response or as a therapeutic manoeuvre pending fluid resuscitation. It is the assumption that body inversion produces shifting of blood from the legs (and with Trendelenburg position also from the abdomen) towards the heart by gravitational displacement leading to an ‘auto-transfusion’ thereby increasing venous return to the heart and promoting cardiac output (CO) and ultimately increase perfusion of the vital organs [5,6]. With the advantage of auto-transfusion readily available both PLR and the Trendelenburg position are used for their expected instantaneous effect on cardiovascular performance.

The aim of the review is to evaluate whether PLR and Trendelenburg position supports the mechanism of auto-transfusion and to assess the effect of these manoeuvres on cardiac output.

Methods

This review was performed using the Cochrane Handbook for Systemic Reviews of Interventions [7]. We included prospective observational studies in normo- or hypovolaemic humans investigating the effects of hemodynamic parameters within 10 minutes after change from supine position.

The MEDLINE, EMBASE and CENTRAL databases were searched for relevant articles from 1960 up to 2010. We used (combinations of) the following search terms; passive leg raising, leg raising test, lower extremities elevation and passive leg elevation; Trendelenburg,

Trendelenburg position, head tilt-down, head-down; cardiac output and cardiac index (CI). Articles were collected by one reviewer and were crosschecked by another. This was supplemented by hand searching the reference lists for relevant articles.
Total-body head-down tilt of 5° to 60° was used as a definition for the Trendelenburg position and straight passive elevation of both legs of 10° to 90° in a supine position for PLR. Full text copies were obtained for all studies that were selected after reading title and abstract. Disputed articles or abstracts were included after arbitration by a third reviewer.

For all included studies the degree of tilt or elevation, number of patients, demographics, population pathology, CO or CI values, the CO measurement techniques and trends for mean arterial pressure (MAP), central venous pressure (CVP), heart rate (HR), systemic vascular resistance (SVR), pulmonary artery pressure (PAP) and pulmonary artery occlusion pressure (PAOP) were tabulated.
Studies were excluded when fluid administration exceeded urinary loss or baseline measurement of CO or CI were missing. Other exclusion criteria were the presence of pregnancy, pneumoperitoneum, and epidural or spinal anaesthesia.

Statistical analysis into the effect of the different manoeuvres on cardiac output was performed. For all other hemodynamic data descriptive statistics were used. To enable comparative analysis cardiac output was calculated from cardiac index using a body surface area of 1.8 m^2 as an average converting factor. Mean change and standard deviation (SD) of CO after PLR and Trendelenburg was described in only a few studies. Also P-value of changes in CO or correlations with the baseline CO were scarcely reported. Therefore the standard error of the change from baseline was not available for the majority of the groups. Consequently a meta-analysis using traditional statistical techniques was not possible. Therefore we decided to perform an unweighted random effects meta-analysis. Under the usual random effects meta-analysis this is a valid approach, although not statistically optimal [8]. A paired t-test was used to calculate the overall mean changes and associated standard errors for both manoeuvres from baseline, up to one minute and between two and ten minutes. Due to the absence of most standard errors, forest and funnel plots could not be made, and random effect variance could not be determined. SPSS 17.0 was used for the analyses. All values are given as mean (SD). A p value < 0.05 was considered statistically significant.

Results

In total 624 articles were found after the first query in the three databases. For the Trendelenburg 500 hits were found after the first query and 47 were selected based on their abstract. Thirteen articles met the inclusion criteria and were included into the review. Three articles were reviewed by arbitrage. 124 articles were found for PLR. 37 articles were selected after reading the abstract of which 21 remained after reading the full articles. An overview of all included studies and their characteristics are shown in Table 1 and 2.

Table 1 Characteristics of "Trendelenburg"-studies.

Authors	Population	N	Age	Hypo-volaemia	Tilt
van Lieshout, *et al.* [28]	Healthy	9	29	No	20°
Terai, *et al.* [5]	Healthy	8	19-26	No	10°
Reuter, *et al.* [29]	Cardiothoracic surgery	12	-	Yes	30°
Terai, *et al.* [30]	Healthy	10	21	No	20°
Ostrow, *et al.* [31]	Cardiothoracic surgery	18	55	No	10°
Sing, *et al.* [22]	Cardiothoracic surgery	8	60	Yes	15°
Dirschedl, *et al.* [32]	Coronary artery disease	10	-	No	6°
Reich, *et al.* [33]	Cardiothoracic surgery, EF >40%	18	62	No	20°
Gentili, *et al.* [34]	Mixed surgical	22	68	No	12°
Pricolo, *et al.* [35]	Cardiothoracic surgery, EF>50%	5	-	No	10°
Pricolo, *et al.* [35]	Cardiothoracic surgery, EF>50%	8	-	No	10°
Jennings, *et al.* [36]	Healthy	8	26	No	10°
Jennings, *et al.* [36]	Healthy	8	26	No	30°
Jennings, *et al.* [36]	Healthy	8	26	No	60°
Jennings, *et al.* [36]	Healthy	8	26	No	90°
Sibbald, *et al.* [9]	Mixed ICU	61	-	No	15-20°
Hong, *et al.* [37]	Gynaecological surgery	25	44	No	15°

Trendelenburg position

Thirteen studies were included that assessed the effects of the Trendelenburg position on cardiac output. In these studies 246 patients were studied (n ranged between 5 – 61 with an average of 14 subjects per study with an age of 40 ± 18 years). Sixty percent of the studied populations was male.

Overall, Trendelenburg position increased MAP and PAOP. CVP increased in three studies and did not change in four studies. Heart rate remained unchanged in the majority of studies during head-down tilt. Sibbald and Taylor looked into the difference in hemodynamic reactions between normo- and hypovolaemic subjects after Trendelenburg position [9,10]. This was defined either by kissing papillary muscles on echography or a PAOP smaller than 6 mmHg. Sibbald described a marked increase in CVP, MAP and PAP in normovolaemics [9]. In the hypovolaemic subjects there was no change in these parameters. However, the number of subjects in normovolaemic groups was three times larger than in the hypovolaemic groups (15 vs. 51 subjects).

Table 2 Characteristics of “passive leg raising” studies.

Authors	Population	N	Age	Hypo-volaemia	Tilt
Boulain, *et al.* [6]	Circulatory failure	15	65	Yes	45°
Tempe, *et al.* [38]	Cardiothoracic surgery, LVEF>50	10	57	No	45°
Tempe, *et al.* [38]	Cardiothoracic surgery, LVEF<35	10	52	No	45°
Reich, *et al.* [33]	Cardiothoracic surgery	18	62	No	60°
Reich, *et al.* [33]	Cardiothoracic surgery	20	36	No	-
Nelson, *et al.* [39]	Coronary artery disease	22	56	No	45°
Nelson, *et al.* [39]	Coronary artery disease	22	56	No	45°
Gaffney, *et al.* [40]	Healthy	10	30	No	60°
Paelinck, *et al.* [41]	Healthy	24	41	No	45°
Terai, *et al.* [5]	Healthy	8	19-26	No	60°
Bertolissi, *et al.* [42]	Cardiothoracic surgery, RVEF>45	10	56	No	60°
Bertolissi, *et al.* [42]	Cardiothoracic surgery, RVEF<40	6	67	No	60°
Schrijen, *et al.* [43]	Emphysema	16	53	No	30°
Schrijen, *et al.* [43]	Emphysema	13	56	No	30°
Carrère-Debat, *et al.* [44]	Respiratory failure	10	60	-	-
Schreuder, *et al.* [45]	Cardiothoracic surgery	6	-	No	45°
Schreuder, *et al.* [45]	Cardiothoracic surgery	6	-	No	45°
Dirschedl, *et al.* [32]	Coronary artery disease	10	-	No	45°
Ostrow, *et al.* [31]	Cardiothoracic surgery	18	55	No	30°
Lafanechere, *et al.* [12]	Circulatory failure	10	69	Yes	45°
Lafanechere, *et al.* [12]	Circulatory failure	10	69	Yes	45°
Albert, *et al.* [46]	Emphysema	30	52	No	35°
Maizel, *et al.* [11]	Circulatory failure	17	64	Yes	30°
Maizel, *et al.* [11]	Circulatory failure	17	58	Yes	30°
Jörgenson, *et al.* [47]	Emphysema	10	67	No	60-90°
Jörgenson, *et al.* [47]	Lung carcinoma	10	64	No	60-90°
de Wilde, *et al.* [48]	Cardiothoracic surgery	13	-	No	30°
de Wilde, *et al.* [49]	Cardiothoracic surgery	15	66	No	30°
Jabot, *et al.* [13]	General ICU	35	63	Yes	45°

Cardiac output showed a significant change in the overall population. Within one minute after head-down tilt: 9% or 0.35 $L \cdot min^{-1}$. The increase in CO declined to 4% or 0.14 $L \cdot min^{-1}$ after two to ten minutes of Trendelenburg application (see Table 3). The same trend was seen in the normo- and hypovolaemic subpopulations. However, only two studies focused on hypovolaemic patients. The degree of head tilt-down does not influence the occurrence of a significant change in CO except for a transient increase after one minute of 10° tilt-down.

Table 3 Meta-analysis of changes in cardiac output (CO) after Trendelenburg (after 1 and after 2-10 minutes) and after passive leg raising (PLR) (after 1 and after 2-10 minutes).

Authors	**Studies** (n subjects)	**Baseline CO** $L \cdot min^{-1}$	**CO after manoeuvre** $L \cdot min^{-1}$	**Change in CO** $L \cdot min^{-1}$ (%)	**P-value**
Trendelenburg, at 1 min [5,29,30,36]	4 (46)	2.81 ± 1.59	3.17 ± 1.97	0.35 ± 0.38 (9%)	0.111
Trendelenburg, at 2-10 mins [5,9,22,28-35]	11 (181)	3.04 ± 0.97	3.18 ± 1.04	0.14 ± 0.12 (4%)	0.004
PLR, at 1 min [6,32,33,38,40,42,43,45]	9 (140)	2.86 ± 0.39	3.05 ± 0.55	0.19 ± 0.23 (6%)	0.017
PLR, at 2-10 mins [5,11,12,31,33,38-41, 43,44,46,47,50,51]	15 (347)	2.91 ± 0.90	3.08 ± 1.01	0.17 ± 0.23 (6%)	0.005

CO is cardiac output; PLR is passive leg raising; $p < 0.05$ for change from baseline is considered significant

Passive leg raising

Twenty one studies were included that evaluated the hemodynamic effects of passive leg raising. In total 431 patients were studied with an average of 14 patients per study. In general, volume status was not clearly defined; four studies used hypovolaemic patients in their assessment. In these studies hypovolaemia was defined either as systolic pressure <90 mmHg, a drop in systolic blood pressure >50 mmHg, an increase in CO >12% after volume therapy [6,11-13]. The legs were raised with an average of 46° (ranging between 30° and 75°). Passive leg raising did not provide a general or unambiguous change in heart rate. Mean arterial pressure increased in 9 of 20 studies. CVP and PAP increased in all studies (n=8). Degree of PLR, volume status or pathological characteristics of the studied subjects did not influence the changes in either HR, MAP, CVP or PAP as a result of leg elevation.

CO increased significantly one minute after application of PLR with 6% or 0.19 $L \cdot min^{-1}$. (see Table 3). In hypovolaemic populations CO is raised after one minute of leg elevation by 11% or 0.6 $L \cdot min^{-1}$. This effect persists between two and ten minutes of application; 6% or 0.17 $L \cdot min^{-1}$.

Table 4 Effects of PLR and Trendelenburg on cardiac output (CO in $L \cdot min^{-1}$) in directly comparing studies.

		Trendelenburg				**Passive leg raising**			
Authors	**N**	**Tilt**	**CO** Base	**CO** 1–4 min	**CO** 5–10 min	**Tilt**	**CO** Base	**CO** 1–4 min	**CO** 5–10 min
Terai, *et al.* [5]	8	10°	3.0 ± 0.2	3.4 ± 0.3 *	3.1 ± 0.3	60°	2.8 ± 0.2	3.2 ± 0.2 *	3.1 ± 0.3
Ostrow, *et al.* [31]	18	10°	3.33 ± 0.77		3.63 ± 0.73	45°	2.6 ± 0.7	2.9 ± 0.9	
Dirschedl, *et al.* [32]	10	6°	2.6 ± 0.7		2.7 ± 0.7	30°	3.33 ± 0.77		3.61 ± 0.81
Reich, *et al.* [33]	18	20°	2.36 ± 0.79	2.52 ± 0.93 *		60°	2.36 ± 0.79	2.37 ± 0.73	

PLR is passive leg raising. All subjects are reported to be normovolaemic. * $p < 0.05$ for change from baseline

Direct comparison

Four studies directly compared the hemodynamic effects of Trendelenburg and PLR. Results of these studies are shown in Table 4. Although CO increases after both PLR and Trendelenburg within one minute after application with approximately 10% little can be said about the effect after 10 minutes. PLR seems to sustain this effect. However the amount of studies is low and the population sizes are small. More direct comparing studies are needed.

Discussion

The objective of this review was to compare the hemodynamic effects of the Trendelenburg position versus passive leg raising. We found that the Trendelenburg position and PLR increased cardiac output up to almost 10%. However, after several minutes Trendelenburg did not seem able to sustain this effect where PLR was still successful to maintain an increased CO. The reviewed studies nearly unanimously support the mechanism of autotransfusion as a way passive leg raising and Trendelenburg alters haemodynamics. Through elevation of the lower part of the body blood is translocated to the central circulation increasing cardiac output. The hypothesis of autotransfusion is supported by a nearly integral increase in reported central venous pressure and pulmonary artery occlusion pressure.

Trendelenburg vs. PLR

Cardiac output seems likely to be redirected to central parts of the circulation away from parts with increased resistance. Blood volume is shifted from the legs to the more central part of the circulation. The effect of PLR can be readily explained by auto-transfusion. Morgan and co-workers estimated that PLR of a single leg (30° angle) transfuses approximately 150 ml of blood to the central circulation [14]. This is confirmed by Boulain and colleagues who calculated, based on the results of radio-isotopic scans by Rutlen and co-workers, that PLR of both legs shifted 300 ml of blood from the legs toward the central compartment and subsequently confirmed this by showing no difference between changes in stroke volume after PLR and rapid fluid loading with 300 ml [6,15].

However, there is a discrepancy in the duration of this effect between PLR and the Trendelenburg manoeuvre. A first explanation can be found in the lower position of the baroreceptors in reference to the heart [10,16,17]. In the Trendelenburg position the baroreceptors are located below the level of the heart. The extra gravitational force or hydrostatic pressure is expected to cause a decrease in the baro-activity, leading to general vasodilatation, decreased heart rate and heart contractility. This is counterproductive to the desired effect. However, in the majority of studies heart rate did not change. Gravity and suppression of the baroreflex (or Bainbridge effect) during the Trendelenburg position will cause blood to dam in the veins, atria and pulmonary circulation which will decrease venous return and cardiac output subsequently [18-21]. This is supported by Sibbald and co-workers who reported a rise in central venous pressure [9]. Additionally, Sing and co-workers found that the Trendelenburg position did not improve systemic tissue oxygenation in hypovolaemic subjects [22]. This can be explained by the cephalad movement of abdominal organs against the diaphragm, resulting in a higher thoracic pressure and central venous pressure thus decreasing venous return [19-21].

Considerations

Several issues need to be taken into consideration. The standard error of the mean change is underreported in PLR and Trendelenburg literature. Also the standard errors could not be indirectly extracted from other data given in the articles, such as P-values or correlations. Henceforth, the data was not suited for traditional meta-analysis. Therefore we did a straightforward unweighted meta-analysis, which is statistically valid but some power is lost. The quality of the results of this meta-analysis would improve if more data was available and direct comparison was performed in the same groups.

110) We have to realize that hemodynamic parameters were monitored with different techniques. For instance, arterial blood pressure was measured with the Riva-Rocci method in some studies or with invasive techniques in either aorta or radial artery. Cardiac output was measured with variety of techniques with accuracies between 8 and 15% [23,24]. Thermodilution is the most often used technique and can be considered the “gold standard”. Only the techniques that show a high correlation or good agreement with the gold standard allowing to combine and to compare the results of the different studies [25]. The amplitude of the effect of CO with both maneouvers is well accepted in fluid loading responsiveness research and considered clinically significant [24,26].

The results of this review do not show a difference between normovolaemic and hypovolaemic patients in their response in CO after PLR or Trendelenburg. The amount of autotransfusion is likely to be less in a hypovolaemic state. However, this difference is likely compensated by the relative larger increase to a volume challenge in hypovolaemia compared to normovolaemia, i.e. when one is on a steeper slope of the Frank-Starling curve. A fluid loading challenge does not have to increase CO only in hypovolaemic patients but this will also occur during normovolaemia. In hypervolaemia, however, this is less likely since the heart will function on the flat part of the Frank Starling curve.

In this review differences exist between the studies such as mechanical ventilation or spontaneous breathing, level of sedation, beta blockade (i.e. cardiac surgery patients) and types of surgery. All these factors can influence the endogenous adrenergic response to positional change and the magnitude of the effect on CO. Identification and consequent analysis of the influence of these confounders would be very complex and not in the scope of the present review.

We also have to consider the practical applicability of both manoeuvres. Trendelenburg can be performed in nearly every situation in a medical setting. Although PLR can be easy to perform it can be impossible during certain types of surgery. Trendelenburg will be relatively contraindicated in most head-trauma patients.

Finally, in hypovolaemia guarantee of sufficient cerebral blood flow is vital. Shenkin and co-workers observed cerebral flow velocity to decrease in normal humans during Trendelenburg position although carotid blood flow increased [27]. We cannot rule out that Trendelenburg position changes perfusion of the vital organs with or without coinciding changes in cardiac output. The absence of studies into the effects on regional blood flow or local oxygen delivery by these manoeuvres is a major limitation to hemodynamic assessment in clinical studies as a whole.

Conclusions

We compared the hemodynamic effects of the Trendelenburg and passive leg raising and found that both manoeuvres increased cardiac output by 6-9% within one minute. However, after several minutes PLR seemed more able to sustain this effect than Trendelenburg. This is possibly explained by the position of the baroreceptors and a cephalad movement of abdominal organs during Trendelenburg. Since fluid resuscitation during hypovolaemia is not achieved within minutes, we advocate the use of autotransfusion with PLR in the initial treatment of hypovolaemia if possible.

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