Does fluid responsiveness imply fluid need?

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Fluid status and fluid responsiveness
Sheldon Magder

Current Opinion in Critical Care 2010, 16:289–296
What is the importance of fluid for
What is the importance of fluid for

• Water is the primary solvent for all the bodies chemicals:
What is the importance of fluid for

- Water is the primary solvent for all the bodies chemicals:
  - Allows convective and diffusional transport
What is the importance of fluid for

• Water is the primary solvent for all the bodies chemicals:
  – Allows convective and diffusional transport
  – Allows proteins to form their tertiary structures that are essential for their function
Water is 60% of total weight
Water is 60% of total weight

Extra-cellular Water 18%
Water is 60% of total weight

Plasma water 5%

Extra-cellular Water 18%
General Schema

Plasma -> Interstitial

40% 60%

IC

EC
Plasma vol \( \approx 3.5 \) l

General Schema

Plasma

Interstitial

EC

IC

40\%

60\%
General Schema

Plasma vol ~ 3.5 l

40%

Interstitial ~ 12 l

EC

60%

IC
When “volume resuscitating” consider-----

- Hydration
- Extracellular volume
- Intravascular volume
What is hydration?
What is hydration?

• The state of hydration refers to the amount of water relative to the amount of solute particles
  – Dehydration -- not enough water for the solute (ie osmolality is above normal)
  – Excess hydration -- too much water for the solute (ie osmolality is below normal)

• Hydration is assessed by examining the solutes
  – Primarily Na⁺
  – Also glucose, urea, alcohol, ketones etc
Assessment of extracellular
Assessment of extracellular

• Excess volume
Assessment of extracellular

• Excess volume
  – Peripheral edema
Assessment of extracellular

- Excess volume
  - Peripheral edema
  - Acites
Assessment of extracellular

- Excess volume
  - Peripheral edema
  - Acites
  - Pulmonary edema and pleural effusions
Assessment of extracellular

• Excess volume
  – Peripheral edema
  – Acites
  – Pulmonary edema and pleural effusions

• Decreased volume
Assessment of extracellular

- Excess volume
  - Peripheral edema
  - Acites
  - Pulmonary edema and pleural effusions
- Decreased volume
  - Loss of skin turgor
Assessment of extracellular

- Excess volume
  - Peripheral edema
  - Acites
  - Pulmonary edema and pleural effusions

- Decreased volume
  - Loss of skin turgor
  - Loss of sweat
Fluid status is not really about water balance but rather “salt solution balance”
Assessment of vascular volume
Assessment of vascular volume

- Excess volume
Assessment of vascular volume

- Excess volume
  - Elevated jugular veins
Assessment of vascular volume

- Excess volume
  - Elevated jugular veins
  - S3
Assessment of vascular volume

- Excess volume
  - Elevated jugular veins
  - S3
  - Pulmonary venous congestion
Assessment of vascular volume

• Excess volume
  – Elevated jugular veins
  – S3
  – Pulmonary venous congestion

• Decreased volume
Assessment of vascular volume

• Excess volume
  – Elevated jugular veins
  – S3
  – Pulmonary venous congestion

• Decreased volume
  – Postural hypotension
Assessment of vascular volume

- Excess volume
  - Elevated jugular veins
  - S3
  - Pulmonary venous congestion

- Decreased volume
  - Postural hypotension
  - Flat neck veins
Assessment of vascular volume

• Excess volume
  – Elevated jugular veins
  – S3
  – Pulmonary venous congestion

• Decreased volume
  – Postural hypotension
  – Flat neck veins
  – Tachycardia (not a strong sign)
Increasing evidence of harmful effects of excess fluid

Increasing evidence of harmful effects of excess fluid

- Durairaj L & Schmidt. Chest 2008;133:252-263

- therefore try to avoid excess volume
- Key is to identify likelihood of lack of volume responsiveness
- tests are useful in the negative
Patient has low urine output and is thought to be “pre-renal”
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How does volume increase the flow of urine?
Patient has low urine output and is thought to be “pre-renal”

How does volume increase the flow of urine?

1. Increase renal blood flow
Patient has low urine output and is thought to be “pre-renal”

How does volume increase the flow of urine?

1. Increase renal blood flow
2. By increasing blood pressure
Patient has low urine output and is thought to be “pre-renal”

How does volume increase the flow of urine?

1. Increase renal blood flow
2. By increasing blood pressure
3. By increasing cardiac output
What determines flow?
What determines flow?

Review of cardiovascular basics
Volume stretches the veins and creates the “recoil” pressure that drives flow back to the heart.
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Determinants of flow

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\[ Q = \frac{\text{Stressed Volume}}{C_v \times R_v} \]

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Determinants of flow
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Determinants of flow

\[ Q = \frac{\text{Stressed Volume}}{C_v \times R_v} \]

Heart has a “permissive” function. It lowers the outflow pressure and allows veins to empty.
Heart has a "restorative" function which refills the veins.

Heart has a "permissive" function. It lowers the outflow pressure and allows veins to empty.

Determinants of flow

\[ Q = \frac{\text{Stressed Volume}}{C_v \times R_v} \]
MCFP

Stressed volume

Unstressed volume

$Q$

$Q$

$Q$

Stressed volume

Unstressed volume
Frank-Starling’s Law
“the greater the preload the greater the Q--
Frank-Starling’s Law
“the greater the preload the greater the Q--
Frank-Starling’s Law
“the greater the preload the greater the Q--
Frank-Starling’s Law
“the greater the preload the greater the Q---"
Frank-Starling’s Law
“the greater the preload the greater the Q--
Frank-Starling’s Law
“the greater the preload the greater the Q--
Frank-Starling’s Law

“the greater the preload the greater the Q—

\[ P_r (\text{mmHg}) \]

\[ Q (\text{l/min}) \]

0

5

plateau

up to a maximum
MCFP
Stressed volume
Unstressed volume
Cardiac function
Rv

Stressed volume
Unstressed volume
MCFP

Stressed volume
Unstressed volume

Pra

Cardiac function

Return Function

Rv
Cardiac Preload

Pra/CVP

Cardiac output
Cardiac Preload

Pra/CVP Gradient for VR

Cardiac output
Cardiac limited "Wasted preload" Pra/CVP Gradient for VR Cardiac output
If cardiac function becomes limited the volume infusion will not increase cardiac output
If cardiac function becomes limited the volume infusion will not increase cardiac output

Q

“Plateau”

Pra
If cardiac function becomes limited the volume infusion will not increase cardiac output.
If cardiac function becomes limited, the volume infusion will not increase cardiac output. This is often referred to as a "plateau" or "wasted preload."
Maximal return

"Cardiac independent"
Lowering \( \text{Pra} \) further will not increase \( Q \)
Lowering $P_{ra}$ further will not increase $Q$.

Formula:

$$VR = \frac{MCFP - P_{ra}}{R_v}$$
Lowering Pra further will not increase Q

\[ VR \max = \frac{MCFP - Pra}{Rv} \]
Lowering Pra further will not increase Q

\[
VR_{\text{max}} = \frac{MCFP}{R_v}
\]
Lowering Pra further will not increase Q

\[ VR_{max} = \frac{MCFP}{R_v} \]
Lowering Pra further will not increase Q

\[ \text{VR max} = \frac{\text{MCFP}}{R_v} \]

Stressed volume must increase to increase Q

Diagram showing the relationship between Pra and Q.
Version 1

1. Is this pt volume responsive?
1. Is this pt volume responsive?
2. Does this pt need volume?
Version 1
1. Is this pt volume responsive?
2. Does this pt need volume?

Version 2
Version 1
1. Is this pt volume responsive?
2. Does this pt need volume?

Version 2
1. Does this pt need volume?
2. Is this pt volume responsive?
Version 2

1. Does this pt need volume?
2. Is this pt volume responsive?
Version 1
1. Is this pt volume responsive?
2. Does this pt need volume?

Version 2
1. Does this pt need volume?
2. Is this pt volume responsive?

*ie is the patient on the flat part of the cardiac function curve?*
Fluids after cardiac surgery: A pilot study of the use of colloids versus crystalloids*

Sheldon Magder, MD; Brian J. Potter, MD; Benoit De Varennes, MD; Steve Doucette, Msc; Dean Fergusson, PhD; for the Canadian Critical Care Trials Group

Crit Care Med 2010 Vol. 38, No. 11
CI < 4 and CVP < 12?

Chest tube drainage ≥ 200mL/hr or Hb < 80 mg/dL?

PRBC’s ± Platelets ± FFP

Bleeding Corrected?

Yes

No

Exclude bleeders

CI < 4 and CVP ≤ 12?

No

Yes

Protocol Fluid Bolus

Limit Q & CVP

CVP incr. < 2 and CI incr. < 0.3

CVP incr. < 2 and CI incr. ≥ 0.3

CVP incr. ≥ 2 and CI incr. ≥ 0.3

CVP incr. ≥ 2 and CI incr. < 0.3

Inadequate challenge

Cardiac response ok

Cardiac response ok

Pt not volume responsive

Total Protocol Fluid >1L/24hr?

Yes

No

250 mL NS Bolus until 24 hrs

Weaning Protocol

Catecholamine Protocol

Observe

Exclude

Patient on Catecholamines?

No

Yes

Weaning Protocol

Observe

Catecholamine Protocol

CI < 2.2 or MAP < Target or SBP < Target or CVP < 3

CI < 2.2 or MAP < 70 or SBP < Target or CVP < 3

Weaning Protocol

Observe

Catecholamine Protocol
Triggers for considering fluids

- Decreased Q
- Decreased BP
- Decreased urine output
- Decreased CVP
- ? Increased lactate
- ? Decreased ScVO$_2$
Estimate of CVP is readily available from Jugular Venous Pressure.
Estimate of CVP is readily available from Jugular Venous Pressure. Sternal Angle 5 cm
Estimate of CVP is readily available from Jugular Venous Pressure.

- Sternal Angle: 5 cm
- 8 cm
- 5 cm

Sternal Angle
Estimate of CVP is readily available from Jugular Venous Pressure
It is often argued that CVP is of no value
It is often argued that CVP is of no value

It is true!!
It is often argued that CVP is of no value

It is true!!

• CVP must be used in the context of the hemodynamics (especially Q) and the changes over time
It is often argued that CVP is of no value

It is true!!

- CVP must be used in the context of the hemodynamics (especially $Q$) and the changes over time.
It is often argued that CVP is of no value

It is true!!

• CVP must be used in the context of the hemodynamics (especially Q) and the changes over time

• Think of use of PCO$_2$ – it must always be in the context of the pH
Consider the following:
Consider the following:

In the sitting position the CVP of a normal person is $< 0 \text{ mmHg}$,
Consider the following:

In the sitting position the CVP of a normal person is $< 0$ mmHg, yet cardiac output ($Q$) and blood volume are normal.
Consider the following:

In the sitting position the CVP of a normal person is < 0 mmHg, yet cardiac output (Q) and blood volume are normal
Consider the following:

In the sitting position the CVP of a normal person is $< 0$ mmHg, yet cardiac output (Q) and blood volume are normal

&

*There is no need for fluid infusion*
What does CVP tell you?
What does CVP tell you?

• Is the CVP high and therefore it is unlikely that volume loading will help?
  – There is no “optimal” CVP
  – Concept should be “high” vs “low” CVP

• What happened to the CVP in relation to a change in hemodynamics (especially cardiac output)
Approach
Approach

• Although not perfect, CVP is a reasonable start
Approach

• Although not perfect, CVP is a reasonable start
  – Should be used in the “negative”
Approach

- Although not perfect, CVP is a reasonable start
  - Should be used in the “negative”
  - a “high” CVP means that fluids are unlikely to help
Approach

• Although not perfect, CVP is a reasonable start
  – Should be used in the “negative”
  – a “high” CVP means that fluids are unlikely to help
  – The pattern helps, especially relationship of CVP to Q
    • fall in Q with rise in CVP indicates “pump problem” - give inotropes
    • Fall in Q with a fall in CVP indicates return function - give fluid
Large overlap between responders and non responders
Large overlap between responders and non-responders

CVP (mmHg)
Large overlap between responders and non-responders

CVP (mmHg)
Large overlap between responders and non-responders
Large overlap between responders and non-responders
Large overlap between responders and non-responders

Bafaqeeh & Magder JICM 2007
Some Patients at all values of CVP fail to respond to fluids

Bafaqeeh & Magder JICM 2007
Some Patients at all values of CVP fail to respond to fluids

<table>
<thead>
<tr>
<th>CVP</th>
<th>0-5</th>
<th>6-10</th>
<th>11-15</th>
<th>16-20</th>
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Bafaqeeh & Magder JICM 2007
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Bafaqeeh & Magder JICM 2007
Some Patients at all values of CVP fail to respond to fluids
Some Patients at all values of CVP fail to respond to fluids

![Graph showing response to fluids at different CVP values]

- Total
- Res
- Non Res

Number of Pt:
- 25%
- 45%
- 82%
- 100%

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Fluids in pt with high CVP
Fluids in pt with high CVP

- Systemic capillaries are upstream from the CVP
Fluids in pt with high CVP

- Systemic capillaries are upstream from the CVP
- Therefore – if CVP is high, capillary pressure must be even higher
Fluids in pt with high CVP

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- The consequence is that raising the cap pressure further will increase capillary leak
Fluids in pt with high CVP

- Systemic capillaries are upstream from the CVP
- Therefore – if CVP is high, capillary pressure must be even higher
- The consequence is that raising the cap pressure further will increase capillary leak
- This could further compress the heart and create the need for even higher levels of CVP
Gold standard of responsiveness is a volume challenge
Gold standard of responsiveness is a volume challenge

• To test Starling’s law the fluid needs to be given quickly – the faster it is given the less that is needed
  – It makes no sense to test “preload” responses over long periods of time (eg Kumar et al 2004)
• The type of fluid is not critical if given quickly enough
Gold standard of responsiveness is a volume challenge

- To test Starling’s law the fluid needs to be given quickly – the faster it is given the less that is needed
  - It makes no sense to test “preload” responses over long periods of time (eg Kumar et al 2004)
- The type of fluid is not critical if given quickly enough
- There needs to be a change in CVP to know that Starling’s Law has been tested
Fluid Challenge with Q measurement
1 Assess the value of Pra (NOT the wedge).
1 Assess the value of Pra (NOT the wedge).
2 Give sufficient fluid to raise Pra by ~2mmHg and observe Q.
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2 Give sufficient fluid to raise Pra by ~2mmHg and observe Q.
Fluid Challenge with Q measurement

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Change in CVP of even 1 mmHg should be sufficient to test the Starling response
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Inspiratory fall in Pra
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Inspiratory fall in Pra
Inspiratory fall in Pra
Inspiratory fall in Pra
Inspiratory fall in Pra

No Inspiratory fall in Pra
Inspiratory fall in Pra

No Inspiratory fall in Pra
Inspiratory fall in Pra

No Inspiratory fall in Pra
Inspiratory fall in Pra

No Inspiratory fall in Pra
Inspiratory fall in Pra

No Inspiratory fall in Pra
Inspiratory fall in Pra

No Inspiratory fall in Pra
Unlikely to respond to fluids when ‘y’ ≥ 4 mmHg
Systolic or Pulse Pressure Variation

mmHg
150-

75-

0-

E1
Systolic or Pulse Pressure Variation

mmHg

150-

75-

PAP

CVP

0-

ART  CVP  PA

Insp  Insp  Insp
Systolic or Pulse Pressure Variation

Baseline ("apnea")

mmHg
150-
75-
PAP
CVP

E1
Insp
Insp
Insp
Systolic or Pulse Pressure Variation

Baseline ("apnea")

mmHg

Baseline

Art, CVP, PA

dUP

E1

Insp

Insp

Insp
Systolic or Pulse Pressure Variation

Baseline ("apnea")

mmHg
150-
75-
PAP
CVP
E1

Insp
Insp
Insp
Systolic or Pulse Pressure Variation

Baseline ("apnea")

dUP

dDown

SPV

mmHg

PAP

CVP

Insp

Insp

Insp
Systolic or Pulse Pressure Variation

Baseline ("apnea")

dDown

dUp

SPV

mmHg

Baseline

("apnea")

PAP

CVP

Insp

Insp

Insp

E1
Raising the pressure with fluids vs NE
Raising the pressure with fluids vs NE

Aorta → Ra
Raising the pressure with fluids vs NE
Raising the pressure with fluids vs NE
Raising the pressure with fluids vs NE

Aorta → Baseline → Fluid → Norepinephrine → Ra
Raising the pressure with fluids vs NE

- Baseline
- Norepinephrine
- Fluid

Aorta → Capillaries → Ra
Raising the pressure with fluids vs NE

Baseline

Norepinephrine

Fluid

Aorta

Capillaries

Ra
Raising the pressure with fluids vs NE

Baseline

Norepinephrine

Fluid

Aorta

Capillaries

Ra
Raising the pressure with fluids vs NE

- Aorta
- Baseline
- Fluid
- Norepinephrine
- Capillaries
- Ra
Use fluids judiciously
Avoid the Michelin Man syndrome

Use fluids judiciously
Avoid the Michelin Man syndrome

Use fluids judiciously
Plasma → IC

Plasma in Patient with Large Extra-cellular Volume
Normal Saline in Patient with Large Extracellular Volume
Plasma → IC → Interstitial → Normal Saline in Patient with Large Extracellular Volume
Plasma

IC

Interstitial Plasma

Normal Saline in Patient with Large Extra-cellular Volume
Normal Saline in Patient with Large Extracellular Volume
Normal Saline in Patient with Large Extra-cellular Volume

The rule that saline distribution is 1/3 vascular 2/3 interstitial is no longer true.
Determinants of Fluid Filtration (Starling Forces)

\[ J_v = K_{f,c} [(P_c - P_t) - \sigma_d (\pi_c - \pi_t)] \]

where: 
- \( J_v \) = vol flow across the wall
- \( K_{f,c} \) = filtration coefficient
- \( P_c \) = Capillary pressure
- \( P_t \) = tissue pressure
- \( \pi_c \) = capillary oncotic pressure
- \( \pi_t \) = tissue oncotic pressure
- \( \sigma_d \) = reflection coefficient
Determinants of Fluid Filtration (Starling Forces)

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- \( P_t \) = tissue pressure 
- \( \pi_c \) = capillary oncotic pressure 
- \( \pi_t \) = tissue oncotic pressure 
- \( \sigma_d \) = reflection coefficient
Effect of Normal Saline

Plasma & Interstitial spaces are expanded
Effect of Normal Saline

Plasma & Interstitial spaces are expanded
Effect of Normal Saline

Plasma & Interstitial spaces are expanded
Effect of Normal Saline

Plasma & Interstitial spaces are expanded
Effect of Normal Saline

Plasma & Interstitial spaces are expanded
Normal Saline in Patient with Large Extra-cellular Volume
Normal Saline in Patient with Large Extra-cellular Volume
Normal Saline in Patient with Large Extra-cellular Volume
Normal Saline in Patient with Large Extra-cellular Volume
Normal Saline in Patient with Large Extra-cellular Volume
Normal Saline in Patient with Large Extra-cellular Volume

The rule that saline distribution is 1/3 vascular 2/3 interstitial is no longer true
General Schema

Plasma 35% Interstitial 65%

EC IC
Vascular Capacitance
Vascular Capacitance

- Cannot be measured clinically
Vascular Capacitance

- Cannot be measured clinically
- Increased by vasodilators, $\alpha$-adrenergic blockers, and sedation
Vascular Capacitance

- Cannot be measured clinically
- Increased by vasodilators, α-adrenergic blockers, and sedation
- Reserves can be determined from the “volume history of the patient”
Vascular Capacitance

• Cannot be measured clinically
• Increased by vasodilators, $\alpha$-adrenergic blockers, and sedation
• Reserves can be determined from the “volume history of the patient”

Beware of narcotics or vasodilators in patients with increased sympathetic tone
Change in Volume
Change in Volume

\[ P \quad V \quad Q \quad Pra \]

MCFP
Change in Volume

P vs V

MCFP ↑

Q vs Pra

MCFP
Change in Volume

P

MCFP ↑

V

Q

MCFP

Pra
Change in Volume
Cardiac preload

Maximal return

Pra/CVP Gradient for VR

Cardiac output
Distinguish fluid challenge and fluid infusion

- “Challenge” is a small amount of fluid given rapidly while you observe a clinical effect
- Infusion of fluids are to maintain normal physiological status
Importance of volume
Importance of volume
Importance of volume

Increase the initial volume
Importance of volume

Increase the initial volume
Importance of volume

Increase the initial volume
Increase the initial volume

Importance of volume
Importance of volume

Increase the initial volume

Stressed volume
Importance of volume

Increase the initial volume

Greater flow

Stressed volume
Importance of volume

Greater flow

Stressed volume
Importance of volume

Determinants of flow

\[ Q = \frac{\text{Stressed Volume}}{C_v \times R_v} \]

Greater flow

Stressed volume
The equation for flow is:

\[ Q = \frac{\text{Stressed Volume}}{C_v \times R_v} \]

Determinants of flow:

- Stressed volume
- Greater flow
- Importance of volume
- Determinants of flow
- \( C_v \)
Importance of volume

Determinants of flow

\[ Q = \frac{\text{Stressed Volume}}{C_v \times R_v} \]

Greater flow

Stressed volume

C_v

R_v
What CVP is a “high CVP”? i.e. at what value does Q plateau?
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Bafaqeeh & Magder JCCM 2007
What CVP is a “high CVP”? i.e. at what value does Q plateau?

- 66 ICU patients – variety of disorders

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• 66 ICU patients – variety of disorders
• 135 measurements

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- Fluid challenges ordered by treating clinician based on presumed clinical need

Bafaqeeh & Magder JCCM 2007
What CVP is a “high CVP”? i.e. at what value does Q plateau?

- 66 ICU patients – variety of disorders
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- Fluid challenges ordered by treating clinician based on presumed clinical need
- “Successful” fluid challenge = increase in CVP $\geq 2$ mmHg ($n = 118$)

Bafaqeeh & Magder JCCM 2007
What CVP is a “high CVP”? i.e. at what value does Q plateau?

- 66 ICU patients – variety of disorders
- 135 measurements
- Fluid challenges ordered by treating clinician based on presumed clinical need
- “Successful” fluid challenge = increase in CVP $\geq 2$ mmHg ($n = 118$)
- Increase in CI $\geq 0.3$ L/min/m$^2$ considered “responders” & < 0.3 “non-responders”

Bafaqeeh & Magder JCCM 2007
Cardiac 
Preload 

Maximal return 
"Cardiac independent" 
Pra/CVP 
Cardiac output
Non-flow indications for fluids

• Correct hydration (ie high Na\textsuperscript{+})
• Replete interstitial reserves
• Replete unstressed volume reserves
Change in Capacitance
(can change by 10-15 ml /kg)
Change in Capacitance
(can change by 10-15 ml /kg)
Change in Capacitance
(can change by 10-15 ml /kg)
Change in Capacitance
(can change by 10-15 ml /kg)
What about a low CVP?