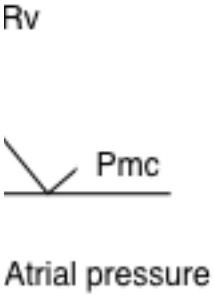
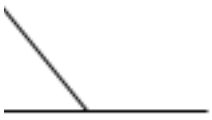
cellular level is inadequate oxygen consumption by the cell for its metabolic needs. The negative
debt with eventual cellular dvsfunction and death.
sult from the following: (1) inadequate oxygen content of the blood; (2) inadequate circulation of the
irculated blood tu the cell (ruicroperfusion); and (4) failure uf the cell to utilize the delivered oxygen

circulation (cardiac output) as the limiting factor in oxygen consumption (shock). Traditioually,
terminant of cardiac output. This function has been divided into preload, inotropy, afterload, and
ncreasing preload and inotropy, decreasing afterload, and optimizing heart rate.
ardiac output is determined by the interaction be
tate, the heart cannot eject more blood than it receives from the vasculature and the vasculature
ne heart. Cardiac output must equal venous return.
best be understood graphically. A family of Starling curves shows the regulation of cardiac output by
s adequate preload (indirectly measured as atrial pressure) and inotropy and minimal afterload

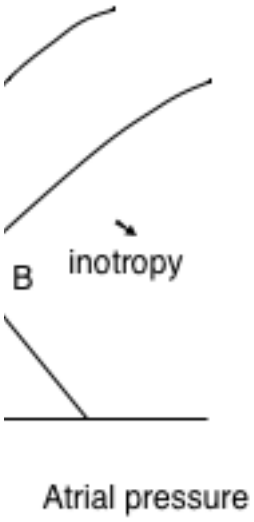


Atrial pressure

Atrial pressure



Atrial pressure



rating the pressun flow relationship of the venous system. The pressure-axis intercept equals mean
pe equals resistance to venous return (Rv), The plateau in the curve due to the great veins
raphs refer to atrial pressure in general. it should be noted right atria] pressure has a much greater

sentation of
on of cardiac output by the vasculature (Fig 2). This utilizes the concepts of mean circulatory:
(Rv). If, as a reasonable approximation, we approach the circulation as a single circuit (Fig 3), the
scular resistance (arterial resistance is seven to ten times venous resistance") and distribution of
travascular reservoir (small veins/venules) (venous compliance is 20 to 60 times arterial
is return (large veins). this conceptual model is an ovcrsimplification.since all types of veins have

culature dominates the physiology of vcnous return because its capacitancc is seven to tcn times

circuit (Fig 4), the venous return (equivalent to cardiac output in a closed system) equals

e, Pa is atrial pressure, and Rv is resistance to venous return (primarily venous resistance since the
les). The Pmc is the intravascular pressure measured when the heart has been stopped and the
that pressures everywhere in the circulation are exactly equal. I During active circulation, Pmc is
nd is the upstream driving pressure for venous return; atrial pressure (Pa) is the downstream
ood volume and the elastic properties of the circulation;

voir) blood volume, Vo the unstressed vascular volume (the volume contained within the vascular
atmospheric), and C the vascular (reservoir) compliance (Fig 4); Vo and C characterize vascular

urve intercepts the pressure axis at a Pa which is equal to mean circulatory pressure (Pmc) and the
s resistance to venous return (Rv). Although our graphs refer to atrial pressure (Pa), right atrial
eturn than left atrial pressure because the systemic compliance is so much larger than pulmonary
curve is due to the fact that the great veins entering the chest function as Starling resistors,
nes subatmospheric. A family of venous return curves can be constructed showing the effects of
r resistance to venous return. Venous return can be impaired by a decrease in mean circulatory
nce to venous return (Rv) (Fig 6). The Pmc decreases due to the loss of intravascular blood volume
d Vo, C). Decreased vascular elasticity is caused by dilatation/relaxation (an active process due to
anges, or a passive relaxation due to increased flow) of the reservoir vessels (small veins/ venules).
tance to venous return include central large veins such as the vena cavae, which are passively
d veins which can bepassively affected or responsive to circulatory vasoactive mediators and

due to active vasoconstriction of the peripheral large- and medium sized veins, passive narrowing of
traabdominal pleural pressure or passive elastic recoil due to low flow), or to hyperviscosity

an be greatly affected hy the distribution of blood flow (flow distribution is determined by
ure can be divided into vascular bedl with short time constants (striated muscle, kidney) and long
n
s will decrease resistance and therefore, improve venous rcturn while
stants will increase resistance and therefore interfere with venous

return must equal cardiac output in a closed system, the same graphic parameters could be used

superimposed curves demonstrate the interaction of the two systems in determining cardiac output

ne the cardiac output and atrial pressure based on the momentary pumping ability of the heart
ristics of the circulation (V, C, Vo, Rv). Both the heart and the circulation may be abnormal.
in blood flow (decreased inotropy or increased after,
associated with an increased atrial pressure (Fig 8, point B), On the other hand, if venous return is
culatory pressure or in.
here will be a low cardiac output associated with a decreased atrial pressure (Fig 9, point B, C),

k as hypo.volemic, cardiogenic, distributive, and obstructive. In cardiogenic and obstructive
k, the primary abnormality in cardiac function; cardiac output is decreased in association with an
e exact shape of the cardiac function curve will depend on the specific disorder). Although there can
nous return curve, cardiac function curve abnormalities limit the cardiac output.
normality is the loss of intravascular volume (V); although secondary changes in vascular and cardiac
decreased due to a low mean circulatory pressure (Pmc)6 (Fig 9, point A to (I. Cardiac output is
pressure.
e shock are much more complex and less understood; moreover, this form of shock is
nd neurogenic shock. Focusing on only septic shock, we clinicaJly find patients with a high, normal,
any of these findings are probably related to the age of the patient, the specific bacteria involved,
ugh arterial tone determines total vascular resistance, perfusion pressure, and distribution of blood

tic shock has dealt primarily with the arteries and not the veins. If the sepsis involves active
large veins) and elasticity (small veins/venules) will both be increased. The effect on venous return
nt (Pmc or Rv) dominates; increased Rv would decrease venous return while increased Pmc would
ınd endotoxin') and piglets (group B streptococci") have shown a decrease in venous return (cardiac
reased resistance to venous return (Fig 10, point A to B). The Rv is further increased by
ed by a low cardiac output) and by the blockage of small veins/ venules (microvascular agglutination

h significant arterioconstriction (elevated afterload), the cardiac output could be further harmed by a
arterioconstriction
capacitance of proximal arteries.
osis,9 resistance to venous return and elasticity will be decreased.

rdiac output) will depend on the balance between a low Rv and Pmc;
nt A to C) would increase venous return (the increased cardiac output could further decrease Rv by

mc (Fig 11, point A to B) would decrease venous return, If the venodilatation is associated with

ut could also be benefited by an improved cardiac function curve.
normal or increased in septic shock, the patient can still deteriorate due to abnormalities in

ion. 7,10
and septic shock, as the heart becomes injured because of an increasing oxygen debt within the
r abnormalities of venous
ction curve rather than the venous return curve limit cardiac output. However, there are also
curve. Due to changes in
l cellular permeability, intravascular fluid moves into the interstitial and cellular spaces, decreasing

lition, more than two decades ago, Lillelhei et al found evidence for increased resistance to venous

the interaction between venous return and cardiac function in shock is to be able to approach

tive shock are principally due to cardiac function abnormalities, we must focus our therapy on
t rate.
ypovolemic and septic shock, we must focus our therapy on abnormalities in the venous return
unction.
ach is to replace the intravascular volume loss. Physiologically, this correction of a decreased
ean circulatory pressure (Pmc),
int A). The controversy over whether to use crystalloid or colloid
e as long as enough fluid is retained intravascularly. Difficulties arise when intravenous fluid is not

rease in the microvascular hydrostatic pressure due to a rise in venous resistance, or fluid shifts into

epinephrine, can increase venous return in hypovolemic shock by
ore mean circulatory pressure (Pm *c).* 1.14,15 This can occur at a dosage that does not significantly

with hypo.volemic shock by mobilizing blood from the body~

used in hypovolemic shock (trauma) is the pneumatic anti.
be by compres sion of the systemic venules/small veins (increased
ıe upstream
c). However. when the garment is applied to the abdomen, ib inflation can distort and narrow large
sing Rv. Holcroft et
baboons, these
ıteract each other.
small amount
(2400 *mosm/L* may be beneficial in hemorrhagic shock by increasing
ut changing the blood volume;17 presumably, vascular elasticity is increased (Vo, C are decreased).
ıloride must be infused through the pulmonary circulation and the cervical vagus nerve must be
ry origin.
, treatment for septic shock should depend on the specific abnormal determinants of venous return.
e in resistance to
return (cardiac output) (Fig 10, point B) can be treated by elevation of pmc with enough intravenous
ease the upstream driving
nt A) or by normalization of the increased resistance to venous return. The increased resistance
atation with agents such nitroglycerin, calcium channel blockers, or beta-2 catecholamines. The
return are confusing and unresolved
elasticity (Vo, C), resistance to venous return (Rv), and the distribution of blood flow through

, small *veins/ven*ules tend to be the site of the intravascular reservoir, while large veins are the
). Ideally, a therapeutic agent would improve venous return by decreasing venous resistance without
Unfortunately, researchers have so far
that will clearly separate venous resistance and capacitance functions; this may partially be due to

ave components
tive agents may also affect venous return by altering arteriolar tone; increased perfusion of vascular
ıus return while perfusion of vascular beds with long time constants will decrease vcnous return.
e quite important for selecting vasoactive therapeutic agents. Finally, if the venoconstriction is
eased total vascular resistance), treatment of the elevated afterload may be important if cardiac
s venodilatation, and therefore, increased capacitance, maintaining an adequate mean circulatory
crucial to maintaining a normal or elevated cardiac output (Fig 11, point D); the dl'lTeased Rv will
catecholamines such as dopamine may benefit this form of septic shock by increasing venous
ly l1ll'ntioned, vasoactive agents can have unpredictable , effects on venous return because of
:e to venous return, and distribution of blood flow.
ajor cause of the distributive changes (venoconstriction or venodilatation) in septic shock. 7.9
reverse the abnormalities in
:r. Therapy for venous occlusion (caused by microvascular agglutination and/or clotting) may be
ınc.
shock, as cardiac decompensation becomes the dominant problem, therapy must focus on heart
on curve). However, as vascular and cellular permeability increase, a loss of intravascular fluid (V)
olaced with enough intravenous fluid to maintain an adequate mean circulatory pressure

nis becomes relevant as
crease at high levels of positive end-expiratory pressure. The venous return curve shows an
mpression of intrathoracic and
cardiac function curve is adversely affected by the increased afterload on the right ventricle and a
t any adverse cardiac effects, the cardiac function curve will be shifted to the right on the basis of the
in cardiac output during positive end-expiratory pressure (Fig 12, point A to B) can be explained by
cardiac function curves. W*e* have discussed the physiology of venous return and its importance in
liac output is regulated by the interaction between the vasculature and the heart. When approaching
cardiac output is being limited by the vasculature (venous return) or cardiac function; therapy will be
gy of shock will probably change over time. Therapy must be chosen based on an understanding of
n and cardiac function. In order to understand and improve our therapeutic options, there is a great
vasoactive agents on venous resistance, capacitance, and flow distribution. Adequate treatment for
malities in microperfusion and/or cellular oxygen utilization can still lead to cellular dysfunction and