The Interstitial Fluid Pressure Monitor: A Device To Aid In The Determination Of Patient Fluid Requirements

Richard D. Fisher, M.D., Paul M. Papoff, M.D., and Alan S. Fisher, Ph.D.

***Abstract*: Assessment of patient fluid requirements is often difficult. Previous basic as well as clinical studies have suggested that interstitial fluid pressure (IFP) correlates with interstitial fluid volume and can be measured with a catheter placed in the subcutaneous space. We constructed a simple device to monitor IFP. The mean IFP for 7 healthy volunteers was −1.19 mmHg. IFP was measured in 25 patients at presentation and as clinical status evolved. Patients were classified as hypervolemic, normovolemic, or hypovolemic on the basis of their clinical status, the evolution of their condition, and laboratory and radiographic data. IFP correlation with assigned classification was statistically significant. The results suggest IFP can be measured readily and reliably in humans and is sensitive for reflecting the hydration of the interstitial compartment. This measure can assist in the determination of patient fluid requirements. (J Am Bd Fam Pract 1990; 3:7-17.)**

The oliguric infant with sunken fontanelles, vomiting, and diarrhea for the past 24 hours clearly is hypovolemic and needs fluid repletion. Just as clearly, the acutely dyspneic 80-year-old with distended jugular veins, edematous lower extremities, cardiomegaly, and bilateral lung rales is volume overloaded and needs diuresis. All too often, however, a patient's fluid needs are not clear to the physician. Mitigating factors such as multiple organ system dysfunction, third-space losses, or subclinical presentations obfuscate the patient's fluid requirements.

When uncertain about the patient's fluid needs, the clinician often has little choice other than to instigate a therapeutic course of action and observe the patient's outcome. By monitoring blood pressure and heart rates, urine output, laboratory values, etc., treatment can be altered appropriately. When circumstances warrant, invasive hemodynamic monitoring can help guide clinical decision making.

Maintenance of adequate intravascular volume is crucial to vital organ perfusion; yet, a simple measure of intravascular volume does not exist. In this study, we turn our attention away from the intravascular space and measure the fluid pressure in a portion of the extracellular, extravascular space known as the interstitial space.

Approximately 56 percent of the body is fluid, and about one-third of this is extracellular. A major component of the extracellular space is the interstitial fluid space. This fluid lies between the cells and outside the vessels. In a 70-kg (154 lb) adult, it contains 12 liters (12.7 qts). The interstitial compartment is linked to the intravascular space through the dynamics expressed in the Starling equation at the capillary bed. It serves as a reservoir for fluid, which can be marshalled when intravascular volume is depleted, and is an overflow repository when this space is overloaded.

It has been shown by Guyton[1] and others[2-4] that interstitial fluid pressure (IFP) in both man and most other animals can be recorded and is subatmospheric. Additionally, IFP varies in a characteristic fashion with changes in interstitial fluid volume (Figure 1). IFP has been recorded in a number of human studies,[4,5] giving an indication that it could be a useful clinical measure in assessing patient fluid status. Because one-third of the interstitial space is subcutaneous, the compartment is readily accessible.

To study potential efficacy of IFP in patient care, a portable monitor was constructed, as were sterile wick catheters for subcutaneous insertion. Both healthy volunteers as well as acutely ill patients were tested. The aims of our investigation

From the Department of Family Practice and the Department of Surgery, Walter O. Boswell Memorial Hospital, Sun City, AZ, and the Department of Electrical Engineering, Stanford University, Stanford, CA. Address reprint requests to Richard D. Fisher, M.D., 13000 North 103rd Avenue, Suite 57, Sun City, AZ 85351.

were: (1) to verify that IFP could be recorded rapidly and reliably by our technique, and (2) that IFP correlates with the patient's assessed fluid status.

Materials and Methods

Clinical studies were conducted after obtaining informed patient consent. Patients were selected from a community-based general medical and surgical practice. Both hospital patients and ambulatory office patients were studied. Patients were classified into one of three groups: volume overloaded, volume depleted, and normovolemic.

A volume-overloaded or hypervolemic patient was one whose fluid homeostasis was altered so that an excessive amount of fluid had accumulated in the extravascular and intravascular compartments, causing discernible clinical signs and symptoms. Alternatively, a volume-depleted patient had lost enough fluid from either space to promulgate clearly recognizable clinical changes. Normovolemic patients were deemed to have normal fluid homeostasis. Classification criteria for each group of patients are listed in Table 1. Typically, the patients for this study were selected from the authors' private practices. In this population, critically ill patients requiring invasive hemodynamic monitoring were infrequent. Because of difficulty of obtaining informed consent from patients cared for by other attending physicians, adequate data from invasively monitored patients were not available for this study. At no time was IFP used in clinical management or patient grouping.

No restrictions were placed on the type of clinical problems or prior diagnosis in any patient considered for study. A patient was selected if it appeared that there was an acute change in clinical status, which was influenced by accumulation or depletion of fluids, thus yielding a situation in which ready measurement of such fluid status would assist patient management. IFP was recorded during the first visit and, whenever possible, on subsequent visits as the clinical picture evolved. In addition, a number of patients with complex medical problems who were believed likely to develop fluid difficulties were selected for baseline IFP recording at a time of stable clinical assessment. To date, 25 patients have been studied, yielding 48 IFP measurements.

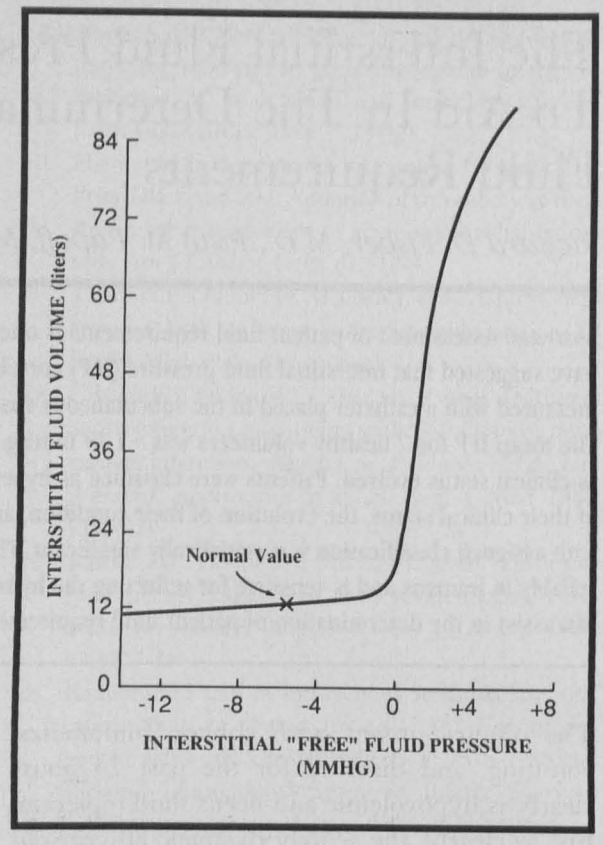

Figure 1. Pressure-volume curve of the interstitial spaces (data from dogs). Used with permission from Guyton AC. Interstitial fluid pressure:II. Pressure-volume curves of interstitial space. Circulation Research 1965; 16:452-60.

IFP was recorded in 7 healthy volunteers to help establish a normal measurement for our technique.

Monitoring Device

The monitor is a solid-state electronic device constructed by us. It converts the voltage produced by a pressure transducer into a numeric value (mmHg) seen on its liquid crystal display. Operating on two 9-volt batteries and housed in a small metal box (approximately 10 cm × 12 cm × 12 cm, weighing 0.25 kg), it is entirely portable. The monitor is attached by a cable to a Cobe CDX III, solid-state pressure transducer (cat. no. 042-502-503, Cobe Laboratories, Lakewood, CO). Our pre-investigational engineering studies indicate transducer accuracy to ± 0.2 mmHg. Measurements were displayed and recorded to 0.1 mmHg.

The transducer is connected at its other end to a 3-way stopcock, which in turn is connected to a

Table 1. Criteria for Classification of Patients According to Fluid Status.

Hypervolemic
1. Congestive Heart Failure
   A. Commonly accepted clinical signs and symptoms of left and right heart failure, such as exertional dyspnea, paroxysmal nocturnal dyspnea, orthopnea, cardiomegaly, gallop, elevated jugular venous pressure, peripheral edema
   B. Medical imaging evidence of congestive heart failure, i.e., chest radiograph, echocardiogram, angiography
   C. Clinical course – patient responds in an appropriate fashion to commonly accepted treatment for congestive heart failure, i.e., weight loss and improvement in dyspnea with diuresis, digitalization
2. Renal Insufficiency
   A. Commonly accepted clinical signs and symptoms of acute or chronic renal failure with volume overload, such as peripheral edema, rising blood pressure, symptoms of uremia
   B. Laboratory evidence of renal failure, i.e., elevated BUN, creatinine, decreased creatinine clearance
   C. Clinical course, i.e., patient improvement with established treatment for renal failure, such as dialysis, worsening of patient condition with increased hydration
3. Leaky capillaries
   A. Clinical condition predisposing to leaky capillary membranes, such as cirrhosis, endotoxemia, prolonged catabolism with subsequent hypoproteinemia
   B. Clinical signs and symptoms of leaky capillaries, such as edema, pleural effusions, greater intake than output, weight gain
   C. Laboratory evidence consistent with leaky capillaries, such as hypoproteinemia, low serum oncotic pressure
   D. Clinical course commensurate with leaky capillaries, i.e., improvement of intravascular oncotic pressure improves patient condition

Hypovolemic
4. History of abnormal fluid loss, such as whole blood; third space losses; substantial vomiting, diarrhea, or both; excessive diuresis; abnormal fluid intake
5. Clinical signs and symptoms consistent with substantial volume loss, such as hypotension, tachycardia, weight loss, dry mucous membranes, decreased skin turgor, decreased urine output
6. Clinical course – fluid replacement normalizes patient condition; further fluid loss worsens patient condition
7. Laboratory evidence consistent with hypovolemia, i.e., hypernatremia, rising BUN and hematocrit

Normovolemic
8. Clinical signs and symptoms consistent with normal volumes within fluid compartments
9. Clinical course does not substantiate the assignment into hypovolemic or hypervolemic categories or is consistent with already restored fluid status

30-cm length of pressure tubing (cat. no. 50-P112, American Edwards Laboratories, Irvine, CA). A second 3-way stopcock is attached to the distal end of the pressure tubing. The wick catheter is attached to the distal stopcock, completing the monitor-transducer assembly (Figure 2).

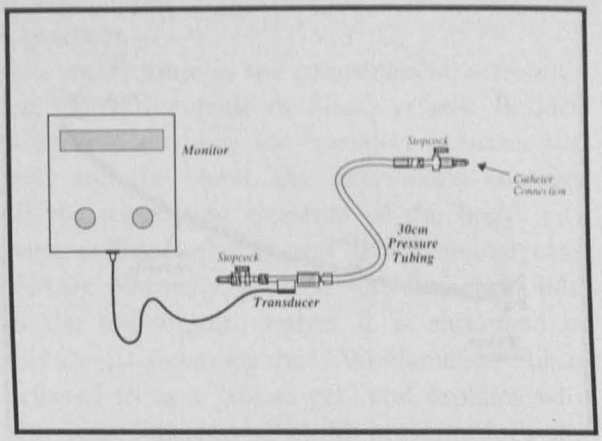

Figure 2. A simple representation of the portable interstitial fluid pressure monitor constructed by us for use in this study.

The Wick Catheter

Our catheters are made from 7 centimeters of PE90 tubing (cat. no. 144-7410, Clay Adams, Franklin Hills, NJ), with a 20-gauge adapter inserted into one end (cat. no. 144-7564, Clay Adams). Two 4-centimeter lengths of 4-0 braided polyglycolic acid suture are doubled over and fished through the distal end of the catheter with a loop of 6-0 nylon suture, which is knotted in the hub of the catheter. The braided polyglycolic acid suture forms a wick about 2 centimeters long at the distal end of the catheter (Figure 3).

Catheter Insertion and IFP Measurement

The transducer assembly was connected to the monitor and filled with sterile normal saline from a 5-mL syringe attached to one port of the proximal stopcock. The transducer was then calibrated before each insertion. A sterile wick catheter was attached to the distal end of the transducer assembly and filled with saline. The entire assembly was then brought to the patient's bedside.

The insertion site selected for the purpose of this study was either the right or left anterior chest wall with the patient supine. The site was prepped with poviiodine solution and anesthetized with 0.5 mL 2-percent lidocaine. A 16-gauge, 57-mm IV cannula was inserted through its entire length into the subcutaneous space, then backed off about 1 cm. After the trocar was removed, the catheter was inserted into the cannula and rezeroed. The transducer was carefully placed at the same vertical level as the distal tip of

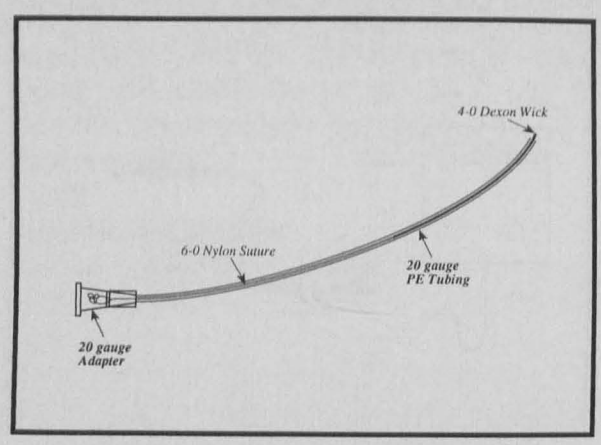

Figure 3. A representation of the wick catheter constructed by us for use in this study.

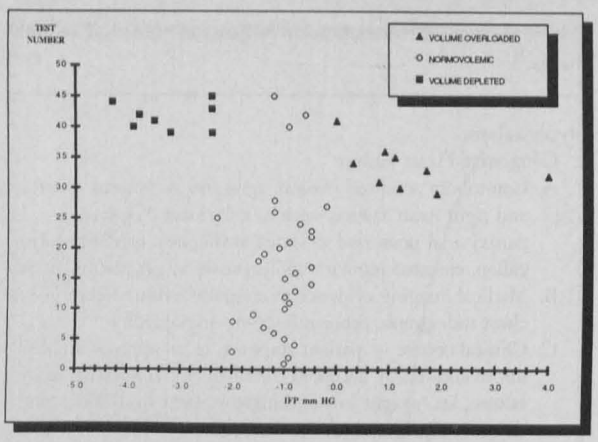

Figure 4. A scattergraph of all IFP measurements made during the study.

the catheter. The reading appearing on the monitor at this position was the IFP measurement that was recorded. The wick catheter and cannula were then removed, and the insertion site was dressed with an adhesive bandage.

Readings usually required approximately 10 minutes from monitor setup to IFP measurement and recording. Patients were questioned after the measurement was taken about any discomfort during the procedure. The insertion site was inspected for several days thereafter for the appearance of complications. No patient in the study admitted to any more than a mild discomfort from the insertion of the IFP catheter. There were no complications from insertion other than one small ecchymosis that resolved spontaneously.

Results

The results of our study are provided in Table 2 to show individual patient and case findings. A scattergraph is presented that shows a consistent correlation between the fluid status suggested by IFP measurement and the clinical classification (Figure 4). It also supports the normal range (−2.0 mmHg to −0.5 mmHg) for IFP.

The normal range was established by analyzing and comparing four different distribution means of 46 of the 48 independent readings on 25 patients. Each of the multiple readings on the same patient was treated as a single reading on separate patients in order to establish the initial statistical criteria. Then, to prove that the above-established range was optimal, four mean values of IFP were calculated from the following populations of data:

Distribution mean 1 (−1.19) was obtained from the 7 healthy volunteers. Distribution mean 2 (−1.04) was made through visual observation of the independent readings and manually setting a Gaussian cutoff range. This distribution mean included statistically normovolemic patients. Distribution mean 3 (−1.00) was derived by including the 7 healthy volunteers with the selective population of distribution mean 2. Distribution mean 4 (−0.79) included 46 hypervolemic, hypovolemic, and normovolemic readings.

In order to determine whether these four distribution means were acceptable for the study, the following disease versus disease-free readings were ranked from highest to lowest according to importance: true-positive results; true-negative results; false-positive results; and false-negative results. Table 3A shows the distribution within the ranking of importance for the four calculated means. Then, using the standard accepted formulae, the efficacy, sensitivity, and specificity of the 46 readings within the four distribution means were calculated. These results are shown in Table 3B.

Distribution mean 4 of combined population was eliminated by its low true-positive result (4), high false-negative result (16), low efficacy (0.65), and sensitivity (0.20). Distribution mean 3 was eliminated because distribution means 1 and 2 had higher sensitivity and efficacy. Even though its specificity was higher than 1 and 2, the lower true-positive results proved to be the deciding factor in eliminating 3. Distribution mean 1 had the highest sensitivity (0.95) with commensurate efficacy (0.91).

Mean 1 of −1.19 mmHg with the range of −2.0 mmHg to −0.5 mmHg was then tested for validity. Those cases in which multiple readings reflected a change from abnormal volume state to subsequent normalcy were reviewed (27 readings on 12 patients), and it was found that 89 percent of the time (24 readings) the abnormal IFP reading correctly reflected the clinical status of the patient. The remaining 3 readings were borderline and required clinical judgment. This correlates with the reported specificity (89 percent) and sensitivity (95 percent).

Case Report

We were fortunate to be able to study one of our patients during two acute illnesses. This 74-year-old man was known to have metastatic adenocarcinoma of the prostate controlled with orchiectomy, severe chronic obstructive lung disease, arteriosclerotic heart disease (often decompensating into congestive heart failure), and diabetes mellitus. The initial IFP reading of 1.7 mmHg was obtained during an episode marked by rapid increase of serum creatinine (rising from a resting level of 88.4 μmol/L [1 mg/dL] to 353 μmol/L [3.99 mg/dL] at presentation) and acute hyperkalemia (K = 6.8 mmol/L). At this point, the attending nephrologist, who was concerned that he might be volume depleted, gave the patient a fluid challenge. This brought no improvement in renal function and, in fact, increased the patient's dyspnea. Subsequently, the creatinine gradually fell to 132 μmol/L (1.49 mg/dL). It was concluded that this acute episode was best explained by aminoglycoside nephrotoxicity following aggressive antibiotic therapy administered 3 weeks earlier for prostatic abscess. In this case, the elevated IFP was consistent with the ultimate clinical interpretation and explains why the fluid challenge was ineffective. IFP done at the time of improvement was −0.5 mmHg after a significant weight loss, improved urine output, and restoration of normal biochemical values. This patient was then readmitted to the hospital approximately 5 months later with overt dehydration because of diarrhea and, once again, serum creatinine was 323 μmol/L (3.65 mg/dL). Severe volume depletion was reflected in the IFP reading (−4.3 mmHg). Volume replacement restored renal function in 48 hours (creatinine 176 μmol/L [1.99 mg/dL]) and the IFP rose to −2.4 mmHg.

Comment

The interstitium is the compartment surrounding all cells outside of blood vessels. Besides being the medium for transport between the cells and the blood, the interstitium contains all the supporting elements of the body, i.e., bone, collagen, elastin, and glycosaminoglycans (GAG). Normally, there is very little free fluid in the interstitium; rather, it is entrapped in minute spaces among the GAG filaments. This is referred to as a "tissue gel" and explains why the large volume of fluid present does not "flow" down the trunk and extremities when the body is erect.

Before 1960, it was believed that normal IFP was positive. However, Guyton implanted perforated hollow capsules in the tissues of laboratory test animals and showed that the cavity of the capsule was filled with interstitial fluid whose pressure consistently measured −5 mmHg to −7 mmHg.[1] This phenomenon has been verified by numerous studies using different research models with a variety of pressure-recording techniques.[6,7] The negative IFP represents the free fluid pressure of the interstitium; prior studies reporting positive pressure were measuring total tissue pressure, which is greatly influenced by solid tissue pressure. Guyton has shown that the concept of a negative IFP fits the explanation of Starling forces far more suitably than a positive IFP.[8]

The response of the interstitium to fluid changes is dependent on its compliance. It has been shown that, in the negative pressure range, the compliance is low; little free fluid is "accepted," the interstitial compartment serving as a buffer against edema. Once the IFP is in the positive range, compliance increases dramatically, and large volumes of fluid "overflow" into the interstitial "reservoir." Thus, from research in dogs, Guyton was able to derive a reproducible relation between interstitial fluid volume and IFP (Figure 1).[7] Also, he reported that interstitial fluid volume increased 30 percent before IFP became positive and edema became apparent.[8] This is consistent with the time-honored clinical adage that clinical edema is not detectable until the patient has accumulated 2 to 3 liters of fluid greater than normal total body water.

These findings are important. While derived mainly in dogs, they are likely true in man. Thus,

Table 2. Summary of Patients Studied.

Test	Patient	Age	Clinical Status	IFP (mmHg)	Clinical Classification of Fluid Status
1	A	75	12 days post aortocoronary bypass – acute congestive heart failure.	1.9	Hypervolemic – 1A, 1B, 1C
2	A	75	Start of treatment of congestive heart failure with diuretic.	1.2	Hypervolemic – 1A, 1B, 1C
3	A	75	3 weeks of continued use of high-dose diuretic.	−3.9	Hypovolemic – 4, 5
4	B	73	Renal insufficiency, hypertension, congestive heart failure well compensated.	−2.0	Normal – 8
5	B	73	Dose of diuretic decreased.	0.8	Hypervolemic – 1A, 1B
6	B	73	Dose of diuretic restored to normal.	−1.6	Normal – 8, 9
7	C	63	Chronic congestive heart failure – compensated.	−1.0	Normal – 8
8	C	63	Weight gain with slight dyspnea, no signs of heart failure.	−0.9	Normal – 1A, 9
9	D	67	Acute upper gastrointestinal hemorrhage with hemoglobin 70.6 gm/L and melena.	−2.4	Hypovolemic – 4, 5
10	E		Acute heart failure following myocardial infarction with dyspnea; bilateral rales. Chest radiograph, bilateral pleural effusions.	4.0	Hypervolemic – 1A, 1B
11	F	81	Idiopathic ascites, edema, hypotension. Hypoproteinemic. 1.5 kg weight gain.	−0.5	Hypervolemic – 3A, 3B, 3C
12	G	74	Essential hypertension.	−1.0	Normal – 8
13	G	74	Stopped diuretic. Feels bloated. Gains 2.7 kg, BP 170/70, no edema.	−0.8	Hypervolemic – 8, 9
14	H	78	Metastatic carcinoma of the prostate with acute renal failure.	1.7	Hypervolemic – 2B, 2C
15	H	78	Resolution of renal failure.	−0.5	Normal – 8, 9
44	H	78	Diarrhea, poor fluid intake, postural hypotension.	−4.3	Hypovolemic – 4, 5, 6, 7
48	H	78	Rehydration started, still postural hypotension.	−2.4	Hypovolemic – 4, 5, 6
16	I	76	End-stage renal disease, on chronic dialysis. Stable.	−1.0	Normal – 8, 9
17	J	78	Severe obstructive pulmonary disease, chronic congestive heart failure. Cardiac status stable.	−0.8	Normal – 8, 9
45	J	78	Blood loss from hematuria, poor oral intake.	−2.4	Hypovolemic – 4, 6, 7
46	J	78	Transfused 2 units packed cells; Hb 106 gm/L.	−1.2	Normal – 8
18	K	86	Chronic renal failure, bladder retention – stable.	−2.0	Normal – 8, 9
19	L	74	Chronic congestive heart failure. Acute chest pain.	−0.5	Normal – 8, 9
20	M	89	Acute congestive heart failure with dyspnea, pleural effusions, and edema.	0.5	Hypervolemic – 1A, 1B, 1C
21	M	89	After diuresis, effusions cleared.	−1.5	Normal – 8, 9

a normal, negative IFP, rising slowly while fluid volume gradually increases, presents a "window" through which normal status can be observed. Once IFP rises above zero, fluid should accumulate rapidly, so that small increases in IFP are associated with large volume changes. A reverse effect is observed in fluid depletion states and abnormally low IFP. In fact, numerous studies on animals have verified this as a valid concept.[9-11] Typically, under controlled laboratory conditions, animals were fluid depleted or overloaded, while IFP and other measurements, such as blood pressure, were recorded. IFP changes significantly mirrored known changes in volume and observed changes in blood pressure. Moreover, IFP changes were rapid, often responding within 20 to 30 minutes after a 10 percent hemorrhage.[10,11]

The use of implantable hollow spheres requiring 4 weeks for equilibration with interstitial free fluid is clearly impractical for clinical use. However, Scholander and others have found that IFP can be reliably measured with the wick cannula.[12,13] It is believed that the wick fibers displace solid interstitial tissue and communicate with free fluid spaces in the interstitium. Generally, wick-recorded pressures are somewhat less negative than capsule fluid pressures. Little tissue reaction has been detected in histologic studies at the wick tip[13]; thus, pressures recorded at the tip are not artifacts.

With this supportive theoretic basis, as well as confirmatory animal studies in mind, it is not surprising to find that other investigators have commented on potential application of wick-recorded IFP measurement to clinical medicine.

Table 2 (continued).

Test	Patient	Age	Clinical Status	IFP (mmHg)	Clinical Classification of Fluid Status
22	N	75	Severe cirrhosis with portal vein hypertension and ascites – severe diarrhea, hypotensive.	−3.5	Hypovolemic – 3A, 4, 5, 6
23	N	75	Rehydrated.	−1.4	Normal – 8, 9
24	O	75	Acute upper intestinal hemorrhage with Hb 70 gm/L; BP 140/70 – 2 days after bleed.	−1.1	Normal – 4, 8
25	P	72	Hypertension, renal insufficiency with increase in creatinine, hypotensive, inadequate fluid intake.	−3.8	Hypovolemic – 4, 6, 7
26	P	72	Rehydrated.	−0.9	Normal – 8, 9
27	Q	62	Renal insufficiency, Crohn disease – stable.	1.0	Normal – 8
28	R	74	Renal failure in acute pulmonary edema.	1.1	Hypervolemic – 1A, 1B, 1C
29	R	74	Diuresis – stable.	−0.5	Normal – 8, 9
30	R	74	Continued diuresis – stable.	−0.5	Normal – 8, 9
31	S	74	Congestive heart failure – stable.	−0.5	Normal – 8
32	T	72	Crohn disease 24 hours after surgical correction of small bowel obstruction – stable.	−0.7	Normal – 8, 9
33	U	81	Acute *Listeria* meningitis, febrile, comatose. Pleural effusion. Total protein 52 gm/L.	−0.2	Hypervolemic – 3A, 3B, 3C, 3D
34	U	81	Excessive, positive fluid balance. BUN 3 μmol/L; edema of arms.	0.9	Hypervolemic – 3A, 3B, 3C, 3D
35	U	81	Transfused with protein. Vigorous diuresis for 48 hours.	−2.3	Normal – 8
36	V	82	Chronic urinary retention due to prostatic obstruction, normal renal function. Vigorous diuresis after catheter drainage.	−1.2	Normal – 8
37	V	82	Immediately after prostatic resection; minimal blood loss; generous fluid replacement.	−0.2	Normal – 8, 9
38	W	82	Coronary artery disease, recent diarrhea but adequate intake and diuretics stopped.	−1.2	Normal – 8, 9
39	X	75	Aggressive colonic cleansing with poor fluid intake.	−3.2	Hypovolemic – 4, 6
40	X	75	48 hours after colon resection, with fluid replacement.	−0.9	Normal – 8, 9
41	M	90	Congestive heart failure, renal insufficiency, dyspneic; effusions on chest radiograph.	0.0	Hypervolemic – 1A, 1B, 1C 2A, 2B, 2C
42	M	90	Diuresis now stable; chest clear of rales.	−0.6	Normal – 8, 9
43	Y	85	Acute renal insufficiency due to obstruction of solitary kidney. Nausea; poor intake. Creatinine 398 μmol/L.	−2.4	Hypovolemic – 4, 6, 7
47	Y	85	Improved. Kidney drained with stent. Creatinine 272 μmol/L.	−1.1	Normal – 8, 9

Hargens, et al. has reported that IFP was −1.3 mmHg in 19 normal volunteers.[3] Noddeland, in a study on 28 healthy volunteers, found IFP to average −1.3 mmHg on the thorax[14] and, in another study, involving 20 healthy volunteers, recorded a mean IFP of −1.9 mmHg on the upper chest wall.[15] Stranden and Myhre reported 18 healthy controls with an average leg IFP of −7 mmHg.[16] These results corroborate our observation that normal human subcutaneous IFP is likely in the range of −2.0 mmHg to −0.5 mmHg.

Other studies in humans have also shown significant changes in IFP in disease states; such changes were consistent with predictions based on our understanding of Starling forces. Both Christenson, et al. in a report on 20 patients,[17] and Stranden, who described 46 patients,[16] found significant elevation of IFP with local edema in the leg. Menninger, et al. has reported on 12 patients who underwent coronary bypass surgery.[5] Such patients are known to gain fluid during the initial postoperative period. In these patients, IFP rose significantly above preoperative levels within 90 minutes and began to fall towards normal by 18 hours; this pattern was paralleled by an initial fall and subsequent rise in hematocrit. Noddeland, et al. measured IFP in 22 patients who had cardiac catheterization.[4] They contended that IFP was positively correlated to right atrial pressure and that rising IFP could be traced in patients with reduced cardiac pump function before the development of clinical edema.

Although in most instances IFP varies in a direct fashion with the intravascular volume, reflecting changes within this compartment, IFP is

Table 3. Statistical Analysis.

	1 (−1.19*)	2 (−1.04*)	3 (−1.00*)	4 (−0.79*)
A. Ranking of Importance				
True-positive result (no.)	(19)	(18)	(16)	(4)
True-negative result (no.)	(23)	(24)	(25)	(26)
False-positive result (no.)	(3)	(2)	(1)	(0)
False-negative result (no.)	(1)	(2)	(4)	(16)
B. Performance Characteristic Function				
Sensitivity	0.95	0.90	0.80	0.20
Specificity	0.89	0.92	0.96	1.00
Efficacy	0.91	0.91	0.89	0.65

*Distribution mean.

not a measure of the intravascular volume. In instances of hypoproteinemia or other causes of leaky capillaries, the interstitial fluid volume and, hence, the IFP can increase at the expense of decreasing intravascular volume. Therefore, IFP must be interpreted in light of all aspects of the patient's condition, which may influence the Starling forces and thereby affect fluid shifts.

For those who care for the sick and injured, the assessment of the interstitial volume is actually commonplace. Everyday clinical terms, such as "dehydrated," "overloaded," or "edematous," are really descriptions of the fluid content within the interstitial compartment. In fact, the IFP is merely a real time, numeric value quantifying our otherwise subjective impression of the hydration of the interstitial space. When we consider replenishing or diminishing a patient's body fluids, although we prioritize the intravascular volume in order to preserve vital organ perfusion, we really attempt to return all disturbed fluid compartments back to normal in order to maintain homeostasis.

This study, an initial one into the efficacy of the IFP in clinical medicine, allows us to draw some conclusions on the clinical utility of this measurement. With the monitor described, IFP can be measured quickly, easily, and with a minimum of discomfort to the patient. Our study supports previous investigators in suggesting that IFP reflects patient fluid status – more precisely, the degree of hydration of the interstitial space. When added to other clinical information, it can aid in the determination of patient fluid needs. Given the value of accurate knowledge of patient fluid status and the broad range of clinical conditions in which proper management of fluids is critical, a measure of fluid status that is so readily obtained merits further investigation.

References

1. Guyton AC, Armstrong GG, Crowell JW. Negative pressure in interstitial spaces. Physiologist 1960; 3:70.
2. Snashall PD, Lucas J, Guz A, Floyer MA. Measurement of interstitial "fluid" pressure by means of a cotton wick in man and animal: an analysis of the origin of the pressure. Clin Sci 1971; 41:35-53.
3. Hargens AR, Cologne JB, Menninger FJ, Hogan JS, Tucker BJ, Peters RM. Normal transcapillary pressure in human skeletal muscle and subcutaneous tissues. Microvasc Res 1981; 22:177-89.
4. Noddeland H, Omvik P, Lund-Johansen P, Ofstad J, Aukland K. Interstitial colloid osmotic and hydrostatic pressures in human subcutaneous tissue during early stages of heart failure. Clin Physiol 1984; 4:283-97.
5. Menninger FJ 3d, Rosenkranz ER, Utley JR, Dembitsky WP, Hargens AR, Peters RM. Interstitial hydrostatic pressures in patients undergoing CABG and valve replacement. J Thorac Cardiovasc Surg 1980; 79:181-7.
6. Aukland K, Nicolaysen G. Interstitial fluid volume: local regulatory mechanisms. Physiol Rev 1981; 61:556-643.
7. Guyton AC. Interstitial fluid pressure. II. Pressure-volume curves of interstitial space. Circ Res 1965; 16:452-60.
8. *Idem.* Capillary dynamics and exchange of fluid between the blood and interstitial fluid. In: Guyton AC. Textbook of medical physiology. Philadelphia: W.B. Saunders Company, 1986:348-73.
9. Guyton AC, Granger HJ, Taylor AE. Interstitial fluid pressure. Physiol Rev 1971; 51:527-63.
10. Hopkinson BR, Border JR, Heyden WC, Schenk WG Jr. Interstitial fluid pressure changes during hemorrhage and blood replacement with and without hypotension. Surgery 1968; 64:68-74.
11. Anas P, Neely WA, Hardy JD. Interstitial fluid pressure changes in endotoxin shock. Surgery 1968; 63:938-41.
12. Scholander PF, Hargens AR, Miller SL. Negative pressure in the interstitial fluid of animals. Fluid tensions are spectacular in plants; in animals they are elusively small, but just as vital. Science 1968; 161:321-28.
13. Prather JW, Bower DN, Warrell DA, Zweifach BW. Comparison of capsule and wick techniques for measurement of interstitial fluid pressure. J Appl Physiol 1971; 31:942-45.
14. Noddeland H. Influence of body posture on transca-

pillary pressures in human subcutaneous tissue. Scand J Clin Lab Invest 1982; 42:131-8.
15. Noddeland H, Riisnes SM, Fadnes HO. Interstitial fluid colloid osmotic and hydrostatic pressures in subcutaneous tissue of patients with nephrotic syndrome. Scand J Clin Lab Invest 1982; 42:139-46.
16. Stranden E, Myhre HO. Pressure – volume recordings of human subcutaneous tissue: a study in patients with edema following arterial reconstruction for lower limb arteriosclerosis. Microvasc Res 1982; 24:241-8.
17. Christenson JT, Shawa NJ, Hamad MM, et al. The relationship between subcutaneous tissue pressures and intramuscular pressure in normal and edematous legs. Microcirc Endothelium Lymphatics 1985; 2:367-84.

Editorial Comment

All too often, physicians seem to believe that hospitalized patients cannot recover unless there is a "bottle of fluid hanging over their heads." Intravenous fluids, in my opinion, are often underutilized, overutilized, and misutilized.

When one remembers that I.V. fluids are medications, it follows that they should be administered only for an indication. Not only should the physician be guided by specific indications, but also by expectations for a beneficial outcome, knowledge of potential toxic effects, and logical plans for correction of the signs and symptoms of toxicity should they occur. After all, we are guided by these principles when treating cardiac failure with I.V. cardiac glycosides. We always look at the vial and know its contents, but this is not always the case when ordering I.V. fluids. For example, how many milliequivalents of lactate are in lactated Ringer's solution? How is the lactate metabolized? Is it appropriate to administer lactate to a patient with an elevated serum lactate level from any cause? Orders for "routine I.V.s" or "keep the vein open" are not more rational than an order to administer "routine digoxin." One must always specify what fluid is to be given and at what rate.

It is axiomatic that proper replacement therapy depends upon both the absolute level of the fluid and electrolyte disorder *and* the clinical state of the patient at the time the disorder was observed. The total body sodium needs of a hypertensive patient on a low-sodium diet, or a patient on a natriuretic diuretic, can be totally and suddenly changed if either suffers a sudden myocardial infarction and is in cardiogenic shock. The initial sodium concentrations can be the same in both patients, but the sodium-depleted patient needs sodium, carefully administered and monitored, in order to allow an optimum response to elevated endogenous catecholamines and to enhance renal functions and oxygen consumption by means of sodium ATPase.

It is certain that the absolute value of the serum electrolyte is of much less importance than the direction of therapeutic change, a phenomenon I refer to as trajectory.

It is also axiomatic that the tolerance for error in the critically ill patient is much less than in the ordinary hospital patient, who is not critically ill.

The study reported in this issue is a well-conceived and well-executed contribution to knowledge in the field of fluid and electrolyte therapy. The authors, in the body of the manuscript, state:

> In instances of hypoproteinemia or other causes of leaky capillaries, the interstitial fluid volume and, hence, the IFP can increase at the expense of decreasing intravascular volume. Therefore, IFP must be interpreted in the light of all aspects of the patient's condition, which may influence the Starling forces and thereby affect fluid shifts. [p14]

The authors are warning us to heed the phenomenon of volume distribution, which is governed by the osmolality of its fluids. Osmolality is equitably distributed in all compartments, and living cells do not tolerate osmotic gradients across their membranous exteriors, except for cells lining the renal tubules, which are designed to resorb water in the face of osmotic gradients in order to deliver a concentrated urine when physiologic needs dictate. All other cells are in osmolar equilibrium. Drastic changes in osmolality result in either intracellular water excess and signs of water intoxication, or in intracellular water depletion, as is evident in nonketotic hyperosmolar states.

Further, we must always be cognizant, as implied by the authors, that while it is the total body osmolality that determines the total body water, and the "sodium osmolality" that predominantly determines the extracellular water, it is the intravascular oncotic (colloid osmotic) pressure that determines the distribution of water between the intra- and extravascular spaces. The