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Various Methods of Determining Irrigating Fluid Absorption during Transurethal Resection of the Prostate*

Theoretical and Practical Considerations

P. O. Madsen, H. Kuni, and K. G. Naber

Section of Urology, Veterans Administration Hospital and Department of Surgery, University of Wisconsin School of, Medicine, Madison, Wisconsin, USA, and the Departments of Nuclear Medicine and Urology, University of Marburg, Germany (FRG)

Summary. A review is presented of all methods, nonquantitative as well as quantitative, applied in the determination of absorption of irrigating fluids used during transurethral resection of the prostate. The nonquantitative methods are clinical observations of pulmonary edema, cerebral edema, cardiac failure, mental agitation, hypertension, hemolysis, large postoperative diuresis, unexplained decrease in hematocrit, transient bacteremia, osteomyelitis, hyperglycemia, and extravasation of contrast medium. To determine total absorption in clinical practice the volumetric or gravimetric methods are the most reliable. The use of radioindicators added to the irrigation fluid is recommended for discrimination between intravascular and extravascular absorption. For this purpose 131 I-macroaggregated human serum albumin has the most advantages: low radiation hazard with good sensitivity, possibility of quantitative external monitoring of intravascular absorption, short time delay of the activity accumulation, and additional quantitative measurement of extravascular absorption.

Key words: Irrigating fluid, absorption, transurethal prostatic resection.

Introduction

The importance of the absorption of irrigating fluids during transurethral resection of the prostate (TURP) has frequently been emphasized in the literature. Many ingenious methods, some practical some less practical in the determination of the amount of absorbed fluid, have been described. In the following all the methods described to date will be summarized and criticized concerning their practical and theoretical application.

Clinical Observations Indicating Irrigating Fluid Absorption

In the early years of development of transurethral resection of the prostate clinical observation of pulmonary or cerebral edema, cardiac failure, mental agitation, hypertension, hemolysis, large postoperative diuresis, unexplained decrease in hematocrit, transient bacteremia, and osteomyelitis suggested that occasionally large amounts of irrigating fluids were being absorbed (1-11). The observation of extravasation of contrast medium on a cystogram carried out immediately following TURP (12-14) indicated a possible route of absorption. Pelvic veins were seen filled following the cystogram and even an excretory urogram could be obtained following the cystogram.

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Table 1: Summary of methods used in determining absorption of irrigation fluid during TURP

Type of Indicator Used	Indicator Measured	Measuring Techniques Used	Absorption Type Measurable			Continuous Monitoring Possible		References
			Total	I. V.	Extra-vascular	Semi-quant.	Quant.	
Irrigating fluid itself	irrigating fluid volume	volumetric measurement of input and output	X					15-17
	body weight	pre- and postop. weight of patient	X					10, 16-20
	blood volume	pre- and postop. blood volume		X				17, 19, 20 23, 24
	Extracellular fluid space	pre- and postop. determination	X					23
	body fluid constituents	chemical analyses of blood specimens		X				18, 19, 24-27
Substances normally used in irrigating fluids	glucose	chemical anylyses pre- and postoperatively of blood and urine		X				1, 10, 26
	mannitol		X	X				28, 31, 32
	sorbitol			X				
	glycine			(X)				
	urea			X				
Other substances added to irrigating fluids a) unlabeled	salicylic acid	chemical analyses in blood specimens	X					4
b) radionuclide labeled	sodium chromate (^{51}Cr)	counting of blood specimens		X		(X)		33
	sodium iodine (^{131}I)	external counting over heart	(X)	X		X		15, 16
	iothalamate (^{125}I)	24 hour urinary excretion	X	(X)		(X)		17, 22, 34
	Xenon (^{133}Xe)	counting of expired air	X	X		X		37
	RISA (^{131}I)	counting of blood specimens and external counting over heart		X		X		15, 17, 22, 24, 25, 33, 34
	pertechnetate (^{99m}Tc)	counting of blood specimens and external counting over heart		X		X	X	22
	MAA (^{131}I)	external counting over lungs and urinary bladder region	X	X	X			26, 35, 37

(X) = method possible, but not used to date

Methods Determining Irrigating Fluid Absorption

Most of the clinical complications outlined above can be avoided by omitting unsuitable irrigation fluids such as plain water, by operating under optimal technical conditions and by monitoring the fluid absorption during the procedure. In Table 1 all the described methods of fluid absorption determination have been outlined and the most important references are listed.

I. Methods Using the Irrigating Fluid Itself as Indicator: The simplest and therefore the most popular methods of measuring fluid absorption have been the volumetric (15-17) and gravimetric (10, 16-20) methods.

The volumetric method consists of measuring accurately the entire amount of irrigating fluid used during the TURP. All the irrigating fluid is then again accurately collected in suitable containers and measured. Although fairly simple the volumetric method suffers from several inaccuracies: the volume of irrigating fluid in the commercially available containers often vary 1-2% from the indicated amount. Measurement of the collected irrigating fluid in 10 l buckets, although carefully graduated, suffers an inaccuracy of ± 1% (100 ml). The urinary output during surgery cannot be determined but only estimated and the spillage of irrigating fluid on drapes and floor must be measured by weighing the drapes before and after surgery. A certain evaporation of irrigating fluid from drapes and floor during surgery can only be estimated. We have seen a tendency to underestimate the amount of irrigating fluid spilled and thereby overestimating the amount of absorbed irrigating fluid occasionally as much as 500 ml. This figure was found by recording intake and output of irrigating fluid as usual in cases of only superficial fulguration of small bladder tumors. In these cases it must be assumed that practically no irrigating fluid is being absorbed. Fig. 1 supports this possible overestimation by the volumetric method. The blood loss during surgery must be taken into consideration and can easily be measured (21).

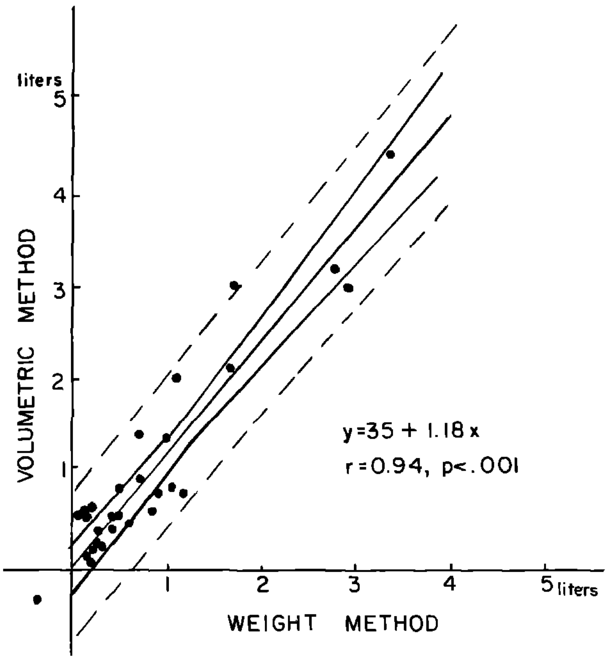

Fig. 1. Illustration of the correlation between the gravimetric and volumetric methods of determining irrigating fluid absorption during TURP.

The gravimetric method of determining irrigating fluid absorption requires accurate weighing of the patient before and after surgery. This method has a similar number of possible inaccuracies as the volumetric method. Although the scale is accurate within a few grams, factors such as insensitive loss and urine production during surgery can only be estimated. Although the blood loss during surgery can be measured and the amount of the intravenous fluids given also is accurately known, the weighing of the patient with or without clothing, with or without clamped or unclamped indwelling catheter (possible residual urine), all represent possible inaccuracies of this method. A major inconvenience concerning this method is the necessity of moving the patient to and from a scale pre- and postoperatively. This makes this method quite impractical unless electronic bed scales are used.

When the volumetric and gravimetric methods are carried out meticulously, however, it is our impression that for clinical purposes a fairly accurate estimate of the fluid absorption can be obtained. In Figure 1 the correlation between the gravimetric and volumetric methods is illustrated and the two methods are correlating well. The solid lines around the regression line indicate the 95% confidence limits and the stippled lines around the regression line, the 95% tolerance limits. The intercept of 35 ml is not significantly different from 0. The slope of 1.18 is significantly different from 1 ($t = 2.31$, $p < 0.05$), indicating that the irrigating fluid absorption is consistently being underestimated by the grav-

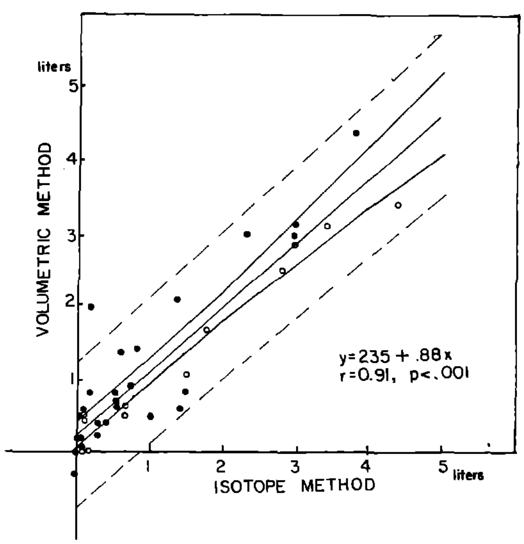

Fig. 2. Illustration of the correlation between irrigating fluid absorption determination by the isotope method and volumetric method.

imetric method or overestimated by the volumetric method.

Figure 2 illustrates the correlation between the volumetric method and a radionuclide determination method of the total absorption of irrigating fluid. Again the correlation is good but the radionuclide method as discussed below also suffers from considerable inaccuracies. The solid lines around the regression line indicate the 95 per cent confidence limits and the stippled lines around the regression line, the 95 per cent tolerance limits. The intercept of 235 ml is not significantly different from 0. The slope of 0.88 is significantly different from 1 ($t = 13.5$, $p < 0.001$) indicating that the irrigating fluid absorption is consistently being overestimated by the isotope method or underestimated by the volumetric method. The solid points and the open circles refer to results from two previous publications (17, 22).

Since it was assumed that intravascular absorption of irrigating fluids would result at least in a transient increase in the patient's blood volume, several authors (17, 19, 20, 23, 24) have determined blood volumes before and after TURP mainly by using iodinated serum albumin. All authors have agreed that there is no consistent change in the blood volume following TURP and that this determination, therefore, is of no value in the evaluation of irrigating fluid absorption during TURP.

The same limitations apply in the determination of changes in extracellular fluid space and changes in concentrations of constituents of body fluid (18, 19, 23-27).

II. Methods Using Substances Normally Contained in the Irrigating Fluids. The determination of substances normally used in irrigating fluids such as glucose in the patient's blood postoperatively would give only a rough estimate of the amount of the absorbed irrigating fluids (1, 10, 26, 28) since glucose is rapidly metabolized. This would also be the case for the analysis of sorbitol which is similarly rapidly metabolized (29, 30), whereas the determination of mannitol in the patient's blood postoperatively theoretically should be reliable. However, the irrigating fluids used in the patients where these determinations were carried out contained so little mannitol that an accurate measurement of fluid absorption could not be obtained by measuring postoperative serum mannitol levels (31). The postoperative analysis of serum glycine levels have not been carried out, but this method would suffer from the same inaccuracies as glucose and sorbitol determinations since glycine is also metabolized (10). Finally the addition of urea (32) and postoperative determination of the blood urea levels would give an estimation of the fluid absorption.

III. Methods Using Other Substances Added to the Irrigating Fluids:

A. Unlabeled Substances. Other substances that have been added to the irrigating fluid in order to determine the absorption have been salicylic acid (4). The addition of salicylic acid to the irrigating fluid actually represented the first attempt to quantitatively estimate the amount of irrigating fluid absorption.

B. Radiolabeled Substances. Many refined methods have been developed adding various radiolabeled substances to the irrigating fluids as tracers in an attempt to measure the intravascular, extravascular, as well as total absorption of the irrigating fluid during TURP.

1. Measurement of intravascular absorption. Since the intravascular absorption of irrigating fluid can be considered clinically most important, most methods have been limited to tracers remaining in the blood stream for a certain length of time. All the compounds labeled with γ-emitting radionuclides would theoretically allow external monitoring of irrigating fluid absorption as well as determination by measurement of radioactivity in blood samples.

Initially low molecular diffusible substances such as $Na_2\,^{51}CrO_4$ (33) and $Na^{131}I$ (15, 16) were used. Due to the rapid diffusion from and to the blood stream these substances have the same disadvantages as ^{125}Iothalamate, which therefore only was used for measurement of total fluid absorption (17, 22, 34).

The high molecular compound ^{131}I-human serum albumin (RISA) as well as ^{99m}Tc-pertechnetate, with a protein binding of about 80%, (36) remain in the blood stream at least for several hours and diffuse into the blood stream from extravascularly absorbed irrigating fluid only in small amounts during the

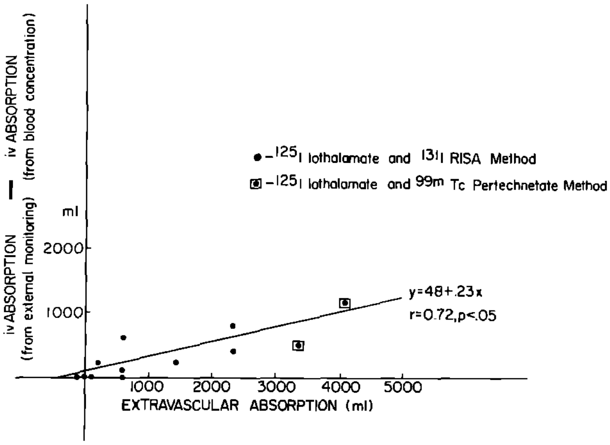

Fig. 3. Illustration of the correlation between two methods of estimating extravasular irrigating fluid absorption.

operation. Especially RISA has been used frequently in the determination of intravascular irrigating fluid absorption (15, 17, 22, 24, 25, 33, 34). The external monitoring however, of this compound is disturbed considerably if large amounts of irrigating fluids are being absorbed extravascularly (Fig. 3), since the tracer diffuses with the absorbed fluid proximally towards the diaphragm in the retroperitoneal space (Fig. 4). Fig. 3 illustrates absorbed irrigating fluid by counting blood samples as well as external monitoring, and the results seemed to follow the same pattern of irrigating fluid absorption determination as the ^{125}I-iothalamate method together with the ^{131}I-RISA method. The lack of an increase in the counts registered over the thorax after filling the urinary bladder with radioactivity suggests that this observation cannot be explained by Compton scattering.

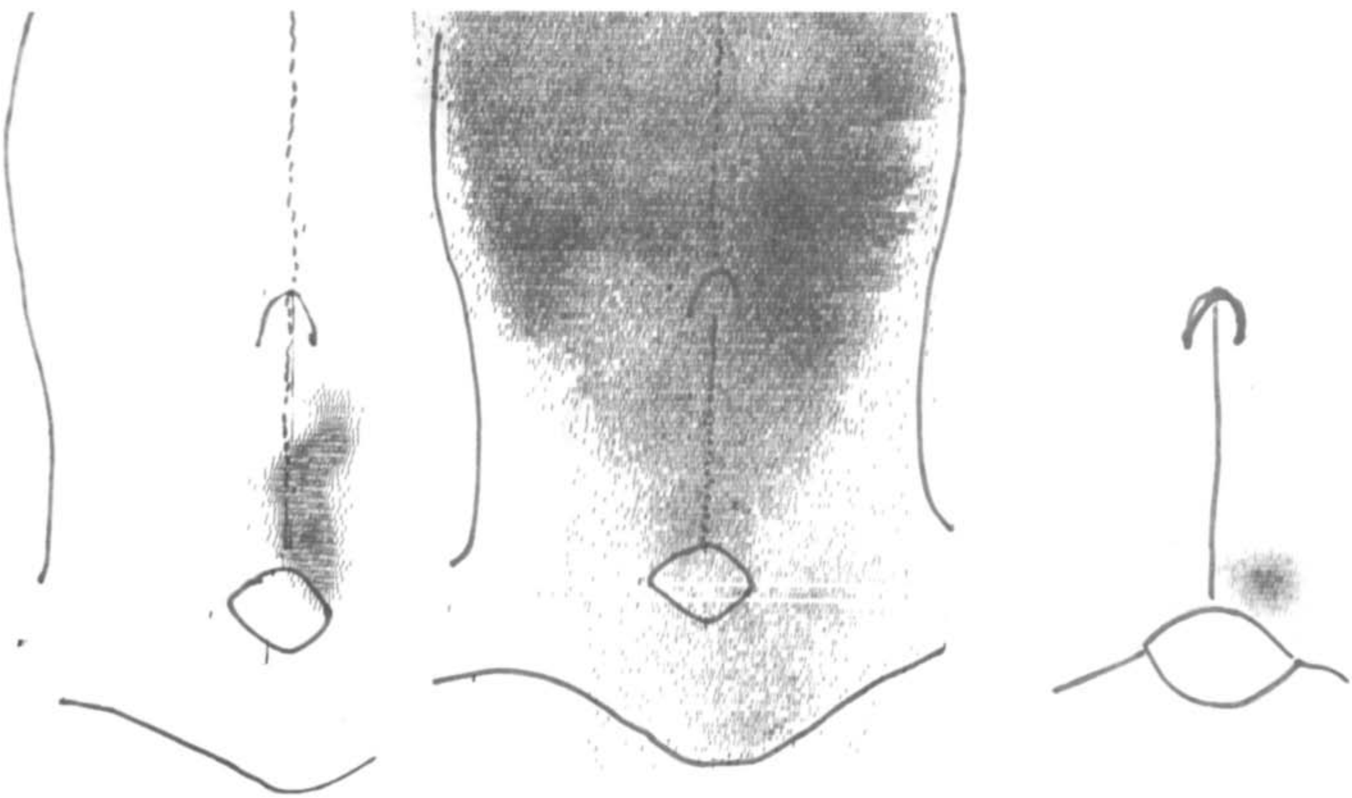

Fig. 4. Comparison of the activity distribution after paraprostatic infusion of 2 liters of normal saline containing ^{99m}Tc-albumin microspheres (A) and simultaneously ^{131}I-RISA (B) (dog 1) or ^{131}I-MAA (C) (dog 2).

the good correlation between extravascular absorption as calculated by deducting the intravascular absorption (as determined by ^{131}I RISA method) from the total absorption (as determined by ^{125}I-iothalamate method) and the difference in intravascular absorption as calculated by external monitoring and from the increase in plasma concentrations postoperatively. The presence of this correlation indicates that a part of the extravascularly (retroperitoneally) absorbed irrigating fluid is also registered by the scintillation counter over the patient's thorax and thus resulting in overestimation of intravascular absorption by this external monitoring technique. In two patients ^{99m}Tc pertechnetate was used both for the determination of the intravascularly

Figure 4 illustrates the activity distribution after paraprostatic infusion of 2 l of normal saline containing ^{99m}Tc-albumin microspheres (A) and simultaneously ^{131}I-RISA (B) (dog 1) or ^{131}I-MAA (C) (dog 2). In dog 2 the needle was kept at the same place throughout the infusion. In dog 1 the needle was retracted slightly after about 1/3 of the infusion. For purposes of simultaneous demonstration in dog 1 a dose of ^{99m}Tc-albumin microspheres sufficiently high to give a 64 times higher count rate than that of ^{131}I-RISA was chosen thus preventing disturbance by ^{131}I scatter. The low photon energy of ^{99m}Tc is not registered in the ^{131}I window. The results in this Fig. are also included in a previous publication (35).

The use of pertechnetate (^{99m}Tc) has been used in only two cases for the determination of intravascular absorption (22) and essentially reveals the same information as the radioiodinated serum albumin because of its binding to serum proteins (36).

The very rapid clearance of Xenon from the blood stream through the lungs allows the quantitative measurement of intravascularly absorbed irrigating fluid. However, the quantitative evaluation of radioactivity in the expired air is more difficult than the direct measurement of the activity accumulation using other tracers. Fig. 6A illustrates the registration of ^{133}Xe-activity in the expired air (heavy line, left scale) and the integral of activity (thin line, right scale) of patient B.S. The arrow indicates the time of the intravenous injection of a calibration dose of 100 ml irrigating fluid. Note the initially higher activity at the beginning of the irrigation as compared to the background activity after the TURP.

The use of ^{131}I-macroaggregated human serum albumin (MAA) (26, 35, 37) has certain advantages compared to the use of RISA and pertechnetate ^{99m}Tc. The continuous accumulation of the tracer in the lungs results in a marked increase in the measurement sensitivity (37). Thus the dosage of radioactive material can be reduced (Fig. 5). Furthermore, the radioactivity over the lungs can be detected within less than 20-30 seconds whereas it takes more than 2 min. before intravascular equilibration of RISA has taken place. This time factor, however, would only be of importance when certain acute changes in the fluid absorption are being investigated, for instance when correlating the pressure in the prostatic fossa with the amount of absorbed irrigating fluid (22). The MAA method also has the advantage that external monitoring of radioactivity over the patient's lung is not being disturbed even in cases of massive extravascular absorption of irrigating fluid, since the extravascular absorbed MAA remains at the place where it entered the body (Fig. 4) (35). The MAA method furthermore allows direct measurement of the extravascular absorption in addition to the intravascular absorption and thus the total absorption.

Fig. 6 (B & C) illustrate the typical registration of activity over the lungs during TURP with irrigating fluid labeled with ^{131}I-MAA. The scale on the right side of each curve gives the absolute quantity of intravascularly absorbed fluid calculated from the quantitative calibration. In B (Same patient as in A) the main intravascular absorption accurs at the end of the TURP. In C (Patient Z.W.) the intravascular absorption takes place continuously throughout the TURP. The operation was interrupted for several minutes for teaching purposes in the middle of the procedure resulting in a temporary lowering of the absorption.

The thyroid gland must be blocked in order to prevent unnecessary radiation, as is the

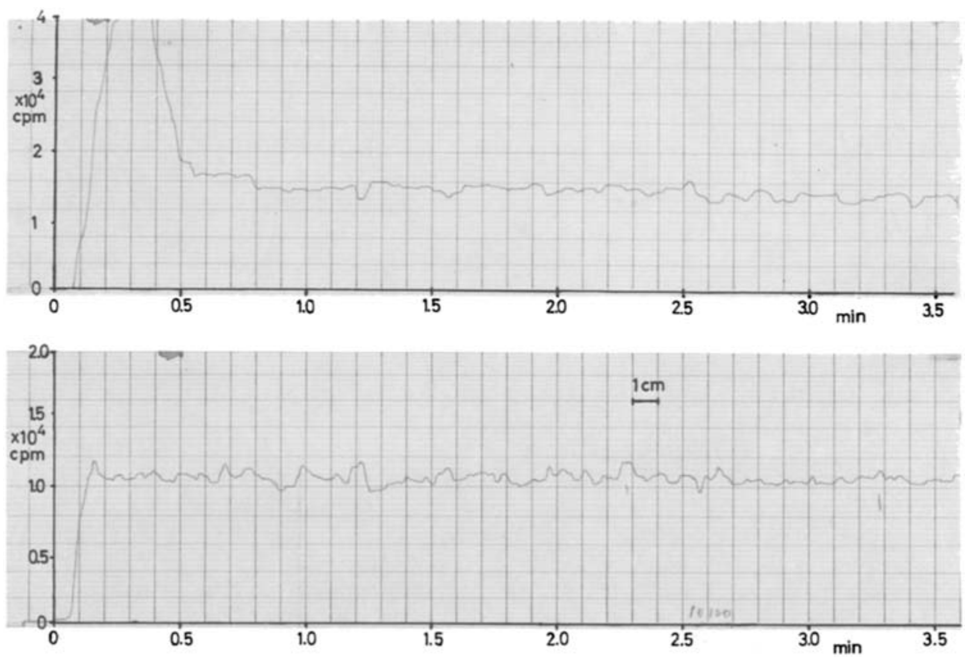

Fig. 5. Comparison of the sensitivity and stabilization time delay of the reading of activity following intravenous injection of ^{131}I-MAA (lower picture) and ^{131}I-RISA (upper picture) in the same patient.

case when other metabolized radioiodine labeled compounds are being used.

One definite disadvantage of the ^{131}I-MAA method is the necessity of continuous stirring of the labeled irrigating fluid in order to prevent uneven distribution of the tracer.

Using high molecular and easily diffusable radionuclides it has been found that only a fraction (usually less than one half) of the absorbed irrigating fluid during TURP is being absorbed directly intravascularly (15, 17, 22, 26, 34).

One important problem is whether the tracer is representative of the labeled fluid. The ideal tracer from this point of view would be ^{3}H-labeled water but this tracer is not suitable for simple continuous monitoring and could not be used for differentiation between extravascularly and intravascularly absorbed fluid, since it is easily diffusable. Small molecular substances such as Na^{131}I and ^{133}Xe may have the tendency to diffuse into the blood stream through opened vessels without effective concommitant fluid transport (15, 37). When using MAA it is also theoretically possible that irrigating fluid could enter the small vessels without allowing entry of the Maa particles. In clinical practice, however, it has been observed that rapid fluid absorption takes place through opened large veins and that a certain critical fluid pressure is necessary for significant intravascular absorption (16, 22, 26).

2. Measurement of extravascular absorption. The direct quantitative measurement of extravascular absorption of irrigating fluid is possible only with MAA added to the irrigating fluid. This compound is filtered by the tissue at the place of entering the body also when excessive amounts of irrigating fluid are being absorbed. This fact also may allow localization of a possible perforation responsible for massive extravascular fluid absorption (Fig. 4) (35). Soluble tracers however, moving with the absorbed irrigating fluid makes direct external measurement impossible.

Continuous monitoring of the extravascular

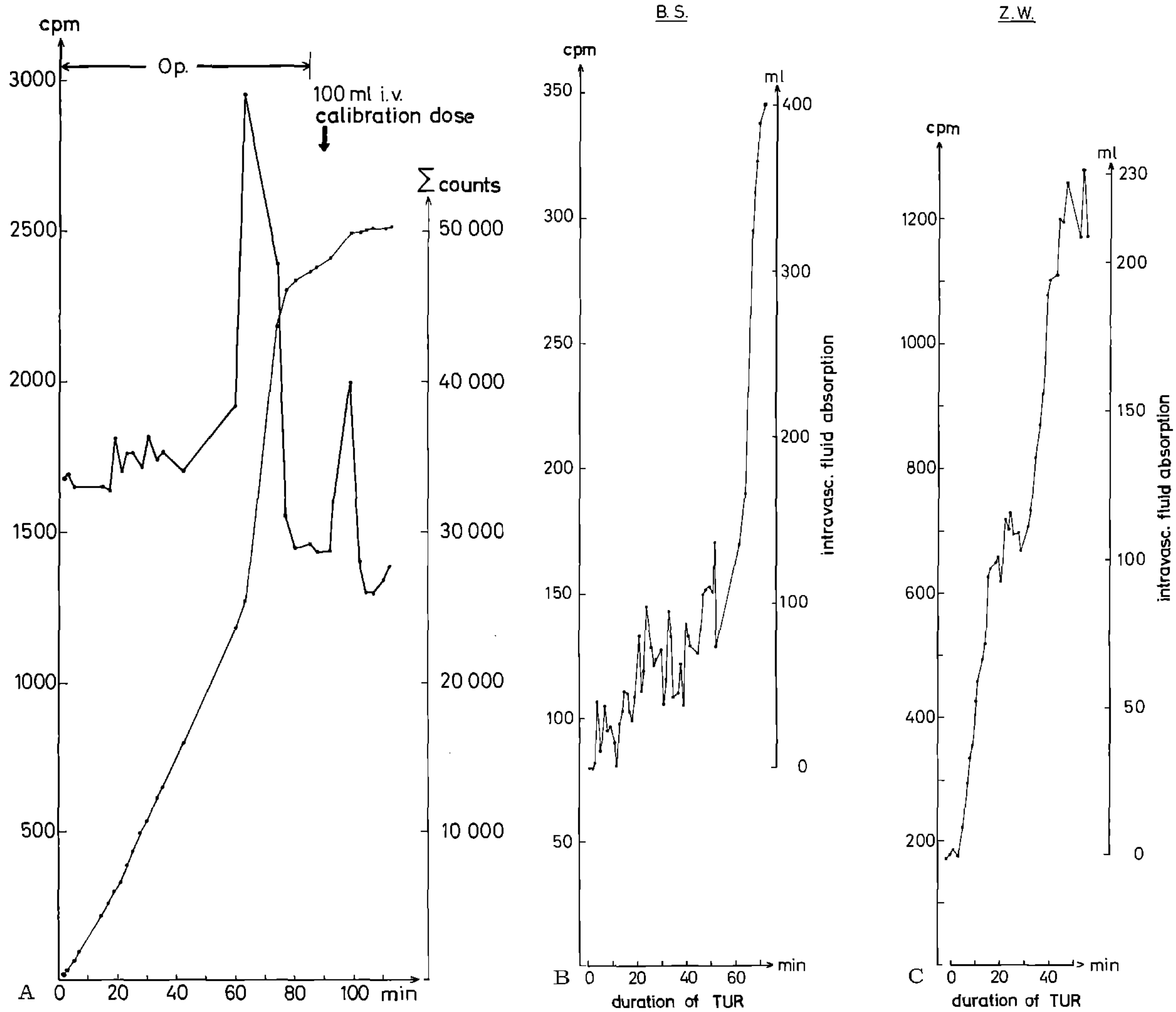

Fig. 6. A, Registration of ^{133}Xe-activity in the expired air. B & C, Typical registration of activity over the lungs during TURP with irrigating fluid labeled with ^{131}I-MAA.

absorption is not possible using MAA because of the interference by the radioactivity of the irrigating fluid in the urinary bladder during surgery.

^{133}Xe is cleared very rapidly from the blood stream by the lungs. Analysis of the exhaled air can detect extravascular fluid absorption as an increase of the activity between the spikes caused by intravascular absorption. Simultaneous direct measurement of intravascular absorption by means of MAA, however is necessary to detect the continuous intravascular absorption of small amounts of fluid (37). The relatively slow diffusion of the Xenon from the extravascular space and the technical difficulties of continued exhalation measurements make this method impractical for quantitative determination of extravascularly absorbed fluid. For the same reasons quantitative continuous monitoring is impossible.

3. Measurement of total irrigating fluid absorption.

Basically all γ-ray emitting tracers would be suitable for quantitative measurement of total irrigating fluid absorption by means of whole body counting, a method which has as yet not been applied. The method actually used has been measurement of total excretion of radionuclide postoperatively (17, 22, 34). Such methods, however, suffer from the loss of an unknown amount of radionuclides excreted during the last part of the operation, and also from the lack of complete excretion in the urine of the radionuclides postoperatively during a reasonable observation time. Approximately 90% of injected ^{125}I-iothalamate is excreted in the urine within 24 hours (22) and the determination of the ^{125}I-iothalamate excretion following TURP correlates well with the volumetric (and therefore also with the gravimetric) determination of fluid absorption (Fig. 2).

The renal clearance of Na^{131}I, even after blocking the thyroid gland, is lower than that of iothalamate (38, 39) making this substance less suitable. The very incomplete and irregular excretion of $Na_2{}^{51}CrO_4$ due to tissue binding also excludes the practical use of this substance (40). The use of Xenon is impractical due to the technical reasons mentioned above.

Using ^{131}I-MAA the total fluid absorption can simply be calculated by adding the intravascularly and extravascularly absorbed amounts.

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Paul O. Madsen, M.D.
Veterans Administration Hospital
2500 Overlook Terrace
Urology Research Laboratory
Madison, Wisconsin 53705
USA