EVALUATION OF THE ACCURACY OF DEVICES COMMONLY USED TO MEASURE FLUID VOLUMES FOR RECORDING INTAKE AND OUTPUT

by

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CHAPTER I

INTRODUCTION

Water balance, taken for granted in health, can become a serious maintenance problem during illness. Hospitalized patients are especially vulnerable because they frequently cannot control intake of water and may have a markedly reduced capability for regulating output. These individuals depend on hospital personnel to assist them in maintaining water balance.

Currently, professional nurses have major responsibility for helping patients maintain water balance. These responsibilities include administration of oral and intravenous fluid, measuring fluid output from all routes as well as estimating insensible losses. This information is recorded in the patient's chart. Changes in body weight are also recorded to assess changes in fluid balance. These data, fluid volume intake, fluid volume output and change in body weight are the major measurements used to assess fluid balance and plan nursing interventions.

Assessment is an integral part of the nursing process. Evaluation of fluid balance or imbalance is one of the important nursing assessments in the hospital setting. For example, when an individual with acute renal failure is admitted to the hospital, the nurse must recognize the severity of the condition. The weight and the hydration status of the individual is assessed by combining information gathered from the history and the physical examination.

Nurses gather further information from the results of analysis of blood specimens, insert intravenous catheters, and regulate the

delivery of fluid entering the patient's body. Nurses also provide hourly care and evaluation for the patient. Because of this unique position wherein nurses gather data and perform patient assessment, they can evaluate critical changes in patient status.

Continuing evaluation of patient status includes follow-up assessment of fluid balance. Changes in patients' fluid status may require new medications or treatments. Since intake and output records have the potential to provide early warning of dangerous fluid imbalances, they may provide information that signals significant fluid retention. In the case of the patient in acute renal failure, retention of body fluids may precipitate peripheral edema and congestive heart failure. Intake and output records are also beneficial because they constitute non-invasive techniques for obtaining vital information about fluid imbalances upon which to base decisions regarding fluid therapy.

If accurate fluid balance records are not maintained and used in assessment of patient fluid status, serious fluid overloads can easily occur. When critically ill patients are given large volumes of fluids over a period of several days, they may retain much of this fluid due to their compromised homeostatic mechanisms. Appropriate therapeutic measures can be taken to rid the body of excess fluid <u>if</u> the excess volume is detected. Accurate cumulative fluid balance records including evaluation of day by day fluid, electrolytes, and acid-base status may provide invaluable insight for altering fluid therapy. It should also be noted that these kinds of records require that an estimate of insensible or unmeasured losses be included as a portion

of fluid output.

Sometimes a patient's fluid status warrants investigation beyond intake and output records and calculations for change in patient weight. A sample of fluid taken from a body compartment may provide valuable additional information. Plasma, which is in equilibration with other body compartments, is a good fluid to sample. However, venipuncture, often considered the least invasive of other techniques to assess hydration status, still carries the risk of venous thrombosis. When venipuncture is indicated, laboratory data such as blood urea nitrogen, serum concentration of electrolytes, and serum osmolarity may be obtained. Physicians and surgeons frequently order blood analyses because they do not consider fluid balance records to be sufficiently accurate for decisions about fluid therapy. Maintenance of more accurate and specialized records could ultimately provide the appropriate information for more complex fluid therapy decisions. Patient discomfort and risks could also be decreased.

Clinically, it now stands that physicians and nurses base decisions for fluid therapy partially on a combination of fluid balance records and changes in patient weight. Nurses rely upon and assume accuracy of their methods and the equipment used. If either are inaccurate, serious mistakes could be made in fluid therapy provided for patients.

Two studies have indirectly evaluated the accuracy of fluid balance records. Pflaum (1979) and Oveson (1981) both evaluated intake and output records against change in patient weight. Pflaum found a significant discrepancy between change in weight and the

difference in intake and output in thirty patients. Oveson found a variable correlation between changes in daily weight and intake-output differences in the same patients over two consecutive days. Both authors questioned the accuracy of the measurements of fluid intake and output made by nurses in the clinical setting. If the measuring devices and procedures are reliable and accurate, the correlation between the change in weight and the difference between fluid intake and output should be high and consistent.

If one assumes that there were no other fluid losses, then the inconsistency of the values obtained by Oveson could be due to at least five factors. First, the scale or balance used to weigh patients may not have been sufficiently accurate. Second, volumes measured and recorded by nurses may have been inaccurate. Third, there may have been errors made during calculations. Fourth, the containers used to measure fluid volumes may have been inaccurate. Fifth, there might be great individual variation of unmeasured loss from day to day.

While conducting a pilot study, I found that I.V. infusion sets may be inaccurate by ten percent or more at low volumes (Bergstrom, Bracis, Robbins, 1980). While an adult who is not critically ill may be able to effectively adjust to this amount of error, a premature infant may become volume expanded by the same volume error. Infants and very young children tend to become dehydrated more easily than adults. This dehydration problem occurs as the result of several factors: childrens' higher metabolic rate, their higher surface area to mass ratio, and their dependence on others to supply their fluid needs (Winters, 1973). The margin for error is greatly reduced in the

normal infant especially in the perinatal period and can also be reduced in the critically ill adult.

Finally, it should be noted that the practice of maintenance of fluid balance records will be continued, because it provides information not otherwise available. Both composition of fluids lost (and/or source), as well as volumes of fluid gained are recorded in the fluid balance records. For example, knowledge of whether 800 ml recorded output volume was urine or gastric drainage is essential in consequent treatment. Of equal importance to determination of fluid composition is the accuracy of the volume measurements. This is a critical question in nursing practice for assessment of fluid status. We assume that the methods and the devices used are accurate. Considering the five factors mentioned above which might give poor correlation between change in patient weight and the difference between intake and output, the issue of accuracy of the measuring devices themselves is the area which concerns me the most. No studies have been found which document accuracy of these devices. However, this information is essential if fluid balance records are to be accurate. In order to evaluate the literature, the following theoretical framework identifies concepts necessary for critical review.

Theoretical Framework

The assessment component of the nursing process is based on the nurse's ability to understand the recognize basic principles of physiological fluid balance. Heath (1971) suggests that the mechanisms and manifestations of water-sodium balance and imbalance provide a conceptual framework for assessing body water status. She further

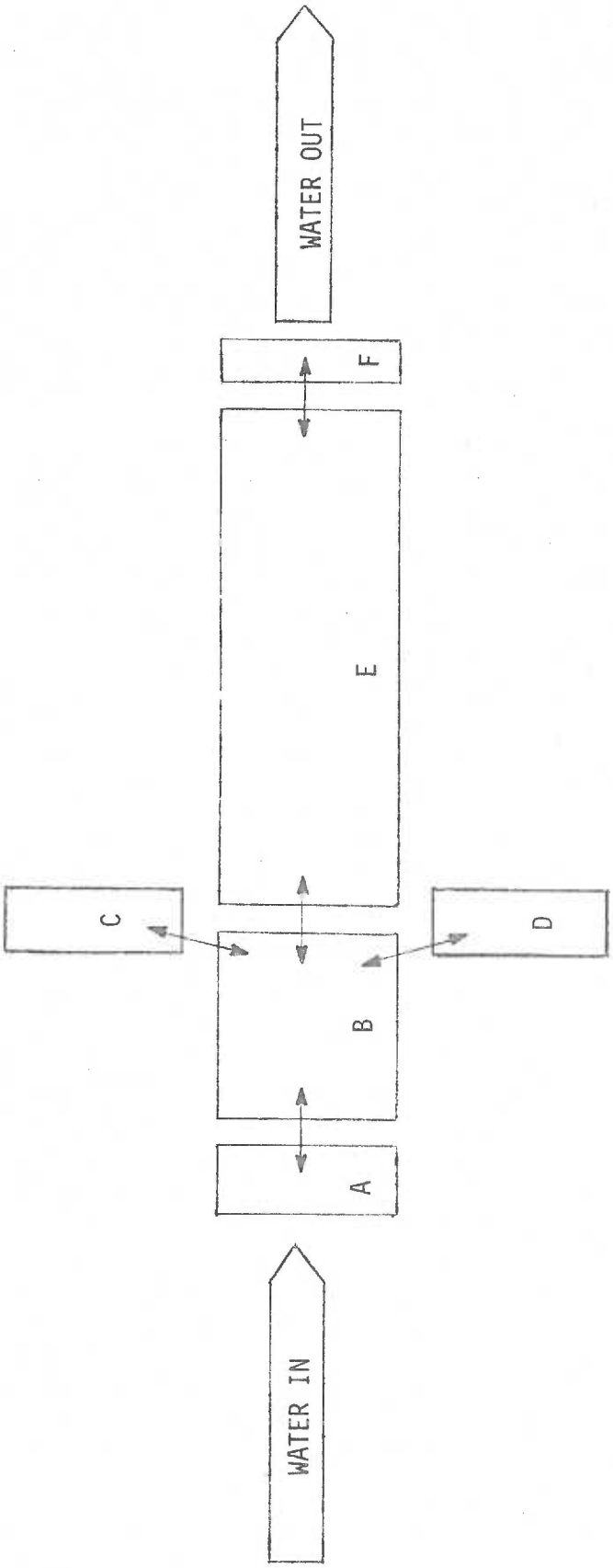
suggests that data specific to body water status can be identified through the development of such a conceptual framework. From her standpoint, the assessment of body water status includes the systematic collection and organization of specific data to evaluate an individual's state of body water balance or imbalance.

Gump, Kinney, Long, and Gelber (1968) suggest determining total body water balance in patients. These investigators considered that both external balance (total volume of water entering and leaving the body as a unit) and internal balance (shifts of fluid between body compartments and water of oxidation) were a part of total body water balance. This practice provides essential data for planning fluid replacement therapy. A model of total body water balance is shown diagrammatically in Figure I.

In order to determine total body water balance, water of oxidation and internal shifts of water must also be taken into account. Estimation of these two components is difficult and requires complicated diagnostic procedures. For clinical purposes fluid balance, rather than total body water balance, is used. Fluid balance is basically external balance. To determine fluid balance, volume of intake and output must be measured. Furthermore, an estimate of insensible loss must also be included. The difference between total intake and output must be equal to the change in weight (equation 1).

$$I - O = \Delta \text{ weight} \qquad (1)$$

where I = intake
O = output
Δ weight = change in weight


WATER OUT
F
E
C
D
B
A
WATER IN

Fluid intake is the sum of parenteral and oral intake while output is the sum of the volume of fluid lost normally via the skin, the respiratory tract, stool, and in the urine as well as abnormal losses, for example, via gastric or wound drainage. Since the volume lost through the skin and respiratory tract are not directly measureable nor sensed by the body, it is convenient to combine these under the heading of insensible losses (equation 2).

$$\text{volume lost (skin)} + \text{volume lost (repiratory tract)} = \text{insensible loss} \quad (2)$$

Sweat, a sensible loss, is very difficult to measure. When the volume of sweat is combined with insensible loss it is called unmeasured loss (UML) (equation 3).

$$\text{insensible} + \text{sweat} = \text{UML} \quad (3)$$

Thus, equation 1 may be expanded to include all of the intake and output variables as shown in equation 4:

$$PO + IV = Vu + UML + GI + WD = \Delta \text{ wt} \quad (4)$$

where:

PO = oral intake (per os)
IV = parenteral fluid intake
Vu = urine volume excreted
UML = unmeasured loss
GI = volume output from GI tract in all forms
WD = wound drainage

If an individual is in fluid homeostasis (i.e. fluid balance), then intake equals output and change in weight is zero. The assumption made in this last statement is that volume changes are measured over a relatively short period of time (24 hours) so that changes in tissue mass due to growth are not measurable as a change in weight. During illness, when an individual may not be in fluid homeostasis, the

assessment of fluid balance requires an accurate determination of the variables shown in equation 4. Currently there are several different devices used to measure fluid volumes. The volumes measured in these containers are currently accepted as being accurate for clinical purposes. However, none of the containers supplied by manufacturers include information about the accuracy of these measuring devices. To compound the picture, several different brands and kinds of devices may be used for measuring intake and output in the same patient even over a short period of time. For example, the McGaw Burets may be used for measuring intravenous (I.V.) fluids, an American Hospital Supply medicine cup for measuring volumes of fluid medications taken by mouth, and a Davol Uri-Meter for measuring urine output. Each device will have a certain amount of error associated with its proper use. Thus, intake and output records reflect instrument error in addition to human error. Therefore, it is appropriate and necessary to determine the accuracy of devices used clinically for measuring volumes of intake and output, due to the crucial nature of these measurements in the nursing assessment of patient fluid status.

Review of the Literature

Nurses monitor patient fluid status to protect the individual health of the patient. The importance of this practice, particularly for young children and critically ill patients, is generally accepted. Since medical and nursing practice base therapeutic regimens on information garnered from fluid balance records, the need for accuracy in these records is acute.

There is a paucity of information in periodicals and textbooks about the possibility of inaccuracies in measurements related to fluid balance. The need for accuracy in fluid balance records is mentioned in most commonly used nursing textbooks. However, most of these books also refer only to the nurse's responsibility to maintain accurate records; they do not consider potential sources of error in the records themselves.

These textbooks are read and the knowledge assimilated during nurses' education. This is the time when diligence in maintenance of accurate records is stressed. McGrath (1980) believes that nurses in the community frequently do not fully understand the reasons for devoting attention to a patient's intake and output. She attributes inaccuracies in fluid balance records to nurses' lack of motivation because of insufficient understanding. Scipien (1979) and Luckmann and Sorensen (1980) attribute inaccuracies to inadequate education. Even though most of the sources reviewed consider fluid balance records inaccurate, nursing literature recommends and clinical practice demands continuing the maintenance of these records.

Therefore, a primary nursing goal during illness is the accurate measurement of fluid loss so that correct fluid replacement can be administered (Aspinall & Tanner, 1981; Brunner & Suddarth, 1980; Grant & Kubo, 1975; Jones, Dunbar, & Jirovec, 1978; Luckmann & Sorensen, 1980; McGrath, 1980; Mitchell & Loustau, 1981; Roberts, S., 1979; Scipien, 1979; Shafer, Phipps, Long, & Woods, 1980). Recording and maintenance of fluid balance records are ultimately the responsibility of nursing personnel in clinical settings. Urrows (1980, p. 538)

suggests that unless excessive amounts of fluid are lost through abnormal routes, "measurement of fluid intake and urine output can be used to estimate water balance". A recommendation made by many current nursing textbooks and other sources is that accurate fluid balance records should be kept on all patients at risk (Brunner & Suddarth, 1980; Mitchell & Loustau, 1981; Roberts, A., 1978; Roberts, S., 1979; Shafer, et. al., 1980).

Despite the belief that recording fluid intake and output volumes is a necessary nursing responsibility, the accuracy of the records is in serious question (Abbey, 1968; Grant & Kubo, 1975; Heath, 1971; Luckmann & Sorensen, 1980; McGrath, 1980; Metheny & Snively, 1979; Mitchell & Loustau, 1981; Scipien, et. al., 1979; Valtin, 1973).

Mitchell and Loustau (1981, p. 474) and Grant and Kubo (1975, p. 1310) both agree that intake and output records are "notoriously inaccurate". Grant and Kubo, Valtin, and Shafer, et. al., believe that changes in patient weight are more accurate measurements for determination of a patient's fluid status. Valtin believes that intake and output records are completely useless and should not be used at all for assessing a patient's hydration status. Luckmann and Sorensen (1980, p. 213), who are more specific about the source of nursing error, include the following:

1. Intravenous solutions contained in bottles may contain more fluid than expected.
2. Blood components in bottles or packets may exceed the expected volume.

3. Patients who rinse their mouth frequently but do not drink the water may still actually still retain a significant amount of water.
4. Nurses may guess at volumes instead of actually measuring the fluid.
5. Nurses may fail to record fluid taken as ice chips.
6. Nurses may fail to record intake of solid foods (which may contain large amounts of fluid).
7. Nurses may fail to include sources of output such as perspiration.
8. Nurses may miss recording fluid from incontinence of urine, stool, or from wound exudate.
9. Fluid losses which occur with irrigation of body cavities may not be included in the records.
10. Weights taken on a daily basis may be done incorrectly, which could give an inaccurate weight.

They further state that intravenous (I.V.) fluid bottles contain more fluid than listed on the bottle label. They do not suggest that the markings on the bottle may also be inaccurate.

Metheny and Snively believe that failure to obtain an adequate measuring device for frequent checks of urinary output may contribute to significant inaccuracies in the fluid balance record. They state that an error of 10 ml volume would be significant when dealing with very small amounts of urine.

Several sources recommend the use of serial determinations of patient weight to serve as a check on fluid balance records (Gump,

et. al., 1968; Mitchell & Loustau, 1981; Oveson, 1981; Pflaum, 1979; Shafer, et. al., 1980).

Two studies in the literature are of particular interest (Pflaum, 1979 and Oveson, 1981). In both studies changes in patient weight were evaluated in conjunction with the difference between intake and output.

Pflaum attempted to determine the accuracy of the nursing practice of keeping intake and output records as a means of determining body fluid balance. Thirty adult patients from an acute care setting were weighed two consecutive days at approximately the same time in the morning. Their intake and output were calculated for the same twenty-four hour period. Change in weight was considered to be the more accurate estimate of fluid gain or loss. Pflaum took any difference between change in weight and intake and output totals to be error. Of particular note is the fact that nowhere does she take into consideration the normal insensible losses accumulated over a twenty-four hour period for the average adult patient. The insensible losses accrued can be as much as 700 to 1000 ml on an average day (Valtin, 1973). Pflaum (p. 497) reported a mean error of 733.30 ml. She also suggests that the data generated in her study invalidate the nursing practice of assessing fluid balance from intake and output records alone. However, if insensible losses were included in the calculations, the data could indicate agreement between the two values obtained.

Oveson (1981, pp. 18-20) included variables such as the relationship between body surface area, mean daily body temperature, and daily caloric intake in her study. Using twenty-six hospitalized patients

Oveson found a correlation coefficient (Pearson's r) between changes in daily weight and difference between intake and output for all subjects to be 0.76 for the first day and 0.74 for the second day. She also found that there was a large individual day to day variation in unmeasured loss. She further stated that this variation might have been due to errors in measuring and recording. She concluded that neither intake and output records nor daily assessment of changes in body weight are accurate enough for evaluation of fluid balance. However, she did recommend continuation of the practices and held that, with continued effort to maintain the accuracy of the techniques, clinicians may be able to detect early changes in the fluid balance of patients.

Metheny and Snively believe that the daily weighing of patients with potential or actual problems in fluid balance is of great clinical value because (1) accurate body weight measurements are easier to obtain than accurate intake and output measurements and (2) rapid changes in weight closely reflect change in total body fluid volume. However, neither procedure will identify internal body water shifts such as those which occur with the fluid pooling in acute intestinal obstruction.

Gump, et. al., (1968) also assert that weight changes roughly parallel cumulative water balance, and that it is possible to estimate water balance if the weight measurements are reliable. He suggests that water records and weight change serve as checks, comparing one against the other. Shafer, et. al., and Grant and Kubo believe that daily weight measurements are the best way to determine onset time for

fluid imbalances. Shafer also believes that the two procedures should be compared for better management of fluid imbalances.

It is evident from the studies cited above that fluid balance records can be used to evalaute small changes in fluid volume status. If would appear that if we can document the accuracy of the equipment and improve the methods nurses use, fluid balance records could be more accurate and useful. While both aspects are important factors in accuracy of the fluid balance record, this study evaluated only the first, that of accuracy of the devices used to measure fluid volumes.

Because of the lack of literature available to evaluate the devices themselves, letters were written to four of the companies who manufacture some of the measuring devices commonly used. The following questions were asked of these companies:

1. whether or not they evaluated their equipment
2. how they evaluated their equipment
3. what the percentage errors were.

Particularly requested was information on any research, published or unpublished, which evaluated the accuracy of the measuring devices. In general the companies did not know of specific literature of the nature requested, nor do they always use regular or systemmatic procedures for determining accuracy. Two out of three companies responding checked the accuracy of their equipment with certain procedures while one of the three used no means to check accuracy of the devices. Copies of the three letters which I received in response are found in Appendix A.

Problem Statement

Recently a nephrologist, Valtin (1973), questioned the practice of keeping intake and output records. He does not believe that these records are sufficiently accurate for clinical purposes. Valtin believes that nurses make errors when measuring, recording, and summing fluid volumes. While these kinds of errors do occur, another unrecognized source of error may be the measuring device itself. If what Valtin suggests is true, improved nursing techniques should reduce the errors in the intake and output records. However, if the devices themselves are inaccurate, changes in the nursing techniques will not change basic inaccuracies. A first step to reduce error in the intake and output records is to determine the accuracy of the containers used to measure fluid volumes.

Unpublished laboratory research revealed varying degrees of error in equipment used to measure volumes of fluid intake and output. (Bergstrom, Bracis, & Robbins, 1980). These findings stimulated my interest in determining the magnitude of error in such containers and whether the error was systematic or random. As a result I conducted this study to answer the following questions:

1. What is the magnitude of error of selected devices used to measure volumes of intake and output of fluid in clinical settings?
2. Does the magnitude of the error vary with the volume of liquid contained?

CHAPTER II

METHODS

In this study the actual volume of fluid contained in devices used for measuring intake and output was determined. The volumes contained in the devices using the scale provided by the manufacturer were compared by using two other independent methods for measuring volume. The two other methods used were (1) dye dilution and (2) gravimetric techniques. From the information obtained, the analysis involved determination of both magnitude of error and percent error. Mean magnitude and percent error ($\pm$ S.D.) for both gravimetric and dye dilution methods were then calculated. The mean values obtained from both gravimetric and dye dilution techniques were then averaged to determine mean magnitude of error. The same calculations were performed for the mean percent error. Variances from this last set of calculations were reported as the standard error of the mean (SEM). The devices tested were those most frequently used in pediatric wards located in two large hospitals in the Portland metropolitan area. Several of the devices are also used in adult wards and surgical intensive care units. The companies supplying these devices are large companies which supply many hospitals in the Northwest. All measuring devices were evaluated for accuracy at two or three different volumes. The actual values tested depended on the size of the container and are listed in Table 1. These volumes covered the usable range for the container. A complete list of the devices tested, the manufacturer, trademark, and synonyms are included in Appendix C.

Table 1

Devices and Volumes Tested

Devices	Volumes Tested (ml)		
Intake			
Abbot Solusets	20	60	100
McGaw Burets	20	60	100
Mead Johnson Grad-U-Feed	20	40	60
Ross Volu-Feed	20	40	
Enfamil Nursettes	60	120	
Medicine Cups	5	10	20
Output			
Davol Uri-Meters	20	60	100
Tomac Urinal	200	400	1000
American Urinal	200	400	1000
American Triangles	200	400	1000

A pilot study was conducted to develop appropriate techniques and reliable methods. Results from this study indicated that for reliability, the following methods had to be followed. The container to be tested was set upon a level surface. Those containers which would not readily balance on a flat surface (Davol Uri-Meters, intravenous sets) were balanced as carefully as possible with the use of vise clamps. To avoid parallax, the bottom of the fluid meniscus was read at eye level. A second observer confirmed the accuracy of this technique for obtaining the readings. Where necessary, a piece of paper was placed behind the containers to improve the visual contrast of the meniscus from the manufacturer-marked level. No gravimetric studies were done in the pilot study. However, during later gravimetric measurements,

the same visual methods were used. Vise clamps were not used because appropriate clamps were not available. Instead, measuring devices which could not be balanced alone were manually balanced and the level read prior to weighing.

The pilot study also served to determine appropriate ranges for concentrations of dye used in the study. The concentrations most appropriate at 370 nm ranged between 2 mg % and 6 mg %.

The dye dilution technique is based on the following principle:

$$\text{volume of fluid in container} = \frac{\text{amount of dye in the container}}{\text{concentration of dye in fluid}} \quad (5)$$

A volume of dye solution (stock standard) containing an exact amount of dye was transferred to the container to be tested. (See Appendix B for the method used to prepare the stock standard.) The container was next filled with diluent (0.05 N KOH) to a manufacturer-marked level. The diluent and dye solution were then mixed well. The optical density (read as absorbance) of samples taken from the diluted solution was measured at 370 nm using a spectrophotometer (Beckman, Model 25). The volumes of stock standard and diluent used for each container at each level tested are shown in Tables 2 and 3. All volumes of stock standard were transferred to the container using volumetric pipettes.

The relationship between absorbance and concentration were determined from a standard curve. The standard curve was obtained by preparing duplicate sets of solutions of known concentration of dye and measuring the absorbance of these solutions. The curves were linear and an equation was determined for calculating the concentration of solutions obtained from the intake and output devices. Tables 4 and 5 show the dye dilution and absorbance values obtained from

standards. Two different standard curves were needed to cover the wide range of volumes tested.

The second method used to determine accuracy of intake and output containers (gravimetric) required a top loading balance (Ohaus 1500). The dry container to be tested was placed on the balance and weighed. This tared weight was later subtracted from the combined weight of the container plus water. The same manufacturer-marked levels were used with this method as described for the dye dilution technique. As the container was filled, the water level was visually checked with the manufacturer's level. Corrections were made for water density using the temperature of the water at the time the measurements were made. Actual volumes of water in the containers at the specified levels were calculated for each container at each level tested.

In this study an attempt was made to control the variables of parallax and consistency of visual readings of fluid levels in the containers. The consistency of the laboratory data obtained was assured by having only one individual conducting the experiments. However, certain errors are inherent in methods used in the study. For example, the gravimetric technique has an inherent error of approximately 1% error, while the dye dilution technique is associated with approximately 3% error.*

* Keyes, J. L., personal communication, June 1980.

Table 2

Dye Dilution Tables for Measuring Devices at Levels Tested (using potassium chromate stock standard 100 mg %)

Equipment Levels	ml Stock Standard	ml 0.05N KOH
Abbot Solusets		
20 ml	1 ml (1 mg dye)	19 ml
60 ml	3 ml (3 mg dye)	57 ml
100 ml	5 ml (5 mg dye)	95 ml
McGaw Burets		
20 ml	1 ml (1 mg dye)	19 ml
60 ml	3 ml (3 mg dye)	57 ml
100 ml	5 ml (5 mg dye)	95 ml
Mead Johnson Grad-U-Feed		
20 ml	1 ml (1 mg dye)	19 ml
40 ml	2 ml (2 mg dye)	38 ml
60 ml	3 ml (3 mg dye)	57 ml
Ross Volu-Feed		
20 ml	1 ml (1 mg dye)	19 ml
40 ml	2 ml (2 mg dye)	38 ml
Enfamil Nursettes		
60 cc	3 ml (3 mg dye)	57 ml
120 cc	6 ml (6 mg dye)	114 ml
Davol Uri-Meters		
20 cc	1 ml (1 mg dye)	19 ml
60 cc	3 ml (3 mg dye)	57 ml
100 cc	5 ml (5 mg dye)	95 ml
Tomac Urinals		
200 cc	10 ml (10 mg dye)	190 ml
400 cc	20 ml (20 mg dye)	380 ml
1000 cc	50 ml (50 mg dye)	950 ml
American Urinals		
200 cc	10 ml (10 mg dye)	190 ml
400 cc	20 ml (20 mg dye)	380 ml
1000 cc	50 ml (50 mg dye)	950 ml
American Triangles		
200 cc	10 ml (10 mg dye)	190 ml
400 cc	20 ml (20 mg dye)	380 ml
1000 cc	50 ml (50 mg dye)	950 ml

* If the equipment tested had 0 % error, the volume of KOH added (column 3) would be exact.

Table 3

Dye Dilution Tables for Measuring Devices at Levels Tested (using potassium chromate stock standard 50 mg %)

Equipment Levels	ml Stock Standard	ml 0.05N KOH
American Medicine Cups		
5 ml	0.5 ml (0.25 mg dye)	4.5 ml
10 ml	1.0 ml (0.5 mg dye)	4 ml
20 ml	2.0 ml (1.0 mg dye)	3 ml

*If the equipment had 0 % error, the volume of KOH added (column 3) would be exact.

Table 4

Dilution Table for Standards, Potassium Chromate
Stock Standard 100 mg%

Standard Solution	mg dye	ml dye	ml KOH	total ml	$\bar{x}$ absorbance
2 mg %	2	2	98	100	0.491
4 mg %	4	4	96	100	0.988
6 mg %	6	6	94	100	1.477

Stock Standard prepared by dissolving 1.000 gm potassium chromate in 0.05N KOH and diluting to a final volume of 1.00 L.

Table 5

Dilution Table for Standards, Potassium Chromate
Stock Standard 50 mg%

Standard Solution	mg dye	ml dye	ml KOH	total ml	$\bar{x}$ absorbance
2 mg %	2	4	96	100	0.496
4 mg %	4	8	92	100	0.988
6 mg %	6	12	88	100	1.485

Stock Standard prepared by dissolving 0.500 gm potassium chromate in 0.05N KOH and diluting to a final volume of 1.00 L.

CHAPTER III

RESULTS

Volumes of fluid contained in ten different devices were measured using the scale provided by the manufacturer of the container. The accuracy of those volume measurements were then evaluated using two other independent methods for determining fluid volumes. The two methods used were the dye dilution and the gravimetric techniques. The results are presented according to the type of device tested. Intake devices included two brands of intravenous (I.V.) infusion sets, three brands of infant feeding bottles, and one brand of medicine cups. Output devices included three different kinds of urine collection receptacles and graduated triangles. Triangles are used for measuring both intake and output volumes.

A summary of the results is shown in Table 6. Mean percent errors ranged from 0.4% to 9.6%. The largest mean percent error ($\bar{x}$ % error) was found in the I.V. infusion sets. These devices are used in the clinical setting for very precise measurements. Other devices tested had smaller mean percent errors. However, the urinals can be seen to have a large standard error of the mean (S.E.M.). The medicine cups had a smaller variation about the mean. It should be noted that the actual range of percent error for medicine cups (Table 12) was 16%.

The I.V. infusion sets consistently contained a greater volume than expected (Tables 7 and 8). Other devices, such as the Ross bottles and the American Triangles had volumes consistently lower than predicted from visual measurements using the manufacturer-marked levels (Tables 10 and 16). The following section describes the

specific findings for the devices tested.

Input Devices

I.V. infusion set. Two brands of intravenous infusion sets (Abbot and McGaw) were checked for accuracy at 20 ml, 60 ml, and 100 ml levels. The McGaw Burets were more accurate than the Abbot Solusets. At 20 ml volume the Solusets averaged 9.6% error while the Burets averaged 6.9% error. At higher volumes there was less difference in the percent error (Tables 7 and 8).

Infant feeding bottles. Three brands of infant feeding bottles were tested. The Mead-Johnson and Ross bottles were tested at 20 and 40 ml levels. The larger of the two bottles was also tested at 60 ml. Enfamil Nursettes, the brand capable of holding the most fluid, were measured at 60 ml and 120 ml. Values obtained for the smaller capacity feeding bottles (Table 10) indicate that the manufacturers' scale usually reads higher than the actual volumes of fluid contained (Table 10). The Mead Johnson bottles were more inaccurate as the volumes increased (% error = -1.0 at 20 ml, % error = -2.0 at 60 ml level) (Table 9). In contrast, the Ross feeding bottles (Table 10) had a larger percent error at lower volumes (-3.2% error at 20 ml, -2.8% error at 40 ml). Enfamil Nursettes (Table 11) measured consistently higher volumes than indicated by the marked levels. These bottles were also more inaccurate at lower volumes (4.6% error at 60 ml, 2.6% error at 120 ml).

Medicine cups. The error found for medicine cups varied over the range of volumes tested. At 5 ml, the average percent error was -1.7, while the average percent errors at 10 ml and 20 ml were -1.3% and

-4.7%, respectively (Table 12).

Output Devices

Urine measuring devices: Davol Uri-Meters, Tomac and American Urinals, American Triangles. The Davol Uri-Meters had a mean percent error of -1.7 at the 20 ml level, -3.6% at the 60 ml level, and -2.8% at the 100 ml level. However, the range of percent errors can be seen to be quite large at all levels tested (Table 13). The urinals tested were surprisingly accurate for the volumes tested. Mean percent errors were quite close between the American and Tomac urinals, averaging -1.6% and 0.4% respectively at 200 cc. Neither urinal was significantly different from the other in mean percent error at the 400 cc or the 1000 cc levels (Tables 14 and 15). The American Triangle had a mean percent error at 200 cc, 400 cc, and 1000 cc which was consistently negative, again indicating an actual volume less than that indicated by the manufacturer-marked levels. These percent errors were -1.8%, -2.0%, and -1.0%, respectively (Table 16).

Summary of Results

Generally, the error found depended on both the type of container and the brand. The largest mean percent error was found in the I.V. infusion sets and the smallest mean percent errors were found in the larger measuring devices such as the Tomac urinal (Table 6). Mean percent errors as shown in Table 6 give a result that can be obtained on the average. However, a much wider range of variation may be expected from any given container.

Table 6

Mean Magnitude and Mean Percent Error of Estimated Volumes in Devices Tested

INTAKE

I.V. Infusion Sets	20 ml		60 ml		100 ml	
	magnitude (ml)	%	magnitude (ml)	%	magnitude (ml)	%
Abbot	1.9 (0.2)	9.6 (1.3)	1.8 (0.1)	3.0 (0.1)	2.1 (0.3)	2.1 (0.3)
McGaw	1.4 (0.0)	7.0 (0.1)	1.6 (0.4)	2.6 (0.7)	1.1 (0.3)	1.1 (0.3)

Infant Feeding Bottles	20 ml		40 ml		60 ml		120 ml	
	magnitude (ml)	%	magnitude (ml)	%	magnitude (ml)	%	magnitude (ml)	%
Mead Johnson Grad-U-Feed	-0.2 (0.0)	-1.0 (0.0)	-0.5 (0.2)	-1.4 (0.4)	-1.1 (0.3)	-2.1 (0.7)		
Ross Volu-Feed	-0.6 (0.3)	-3.3 (1.6)	-1.1 (0.5)	-2.3 (1.3)				
Enfamil Nursettes					2.7 (0.1)	4.6 (0.2)	3.2 (0.9)	2.6 (0.7)

Medicine Cups	5 ml		10 ml		20 ml	
	magnitude (ml)	%	magnitude (ml)	%	magnitude (ml)	%
American Hospital Supply	-0.1 (0.1)	-2.5 (2.3)	-0.1 (0.2)	-1.3 (1.9)	-0.9 (0.1)	-4.7 (0.5)

OUTPUT

Urine Collection Devices	20 ml		60 ml		100 ml	
	magnitude (ml)	%	magnitude (ml)	%	magnitude (ml)	%
Davol Uri-Meters	-0.5 (0.7)	-1.7 (2.4)	-2.2 (2.4)	-3.7 (4.1)	-2.8 (4.3)	-2.8 (4.3)

	200 ml		400 ml		1000 ml	
	magnitude (ml)	%	magnitude (ml)	%	magnitude (ml)	%
Tomac Urinals	-3.1 (10.3)	-1.6 (5.1)	-3.4 (8.9)	-0.9 (2.2)	6.6 (10.4)	0.7 (1.1)
American Urinals	0.7 (9.0)	0.4 (4.5)	8.5 (6.2)	1.6 (2.1)	-13.0 (3.1)	-1.3 (0.3)
American Triangles	3.7 (1.1)	-1.9 (0.5)	-8.1 (0.2)	-2.1 (0.0)	-9.4 (2.8)	-1.1 (0.4)

Numbers in parentheses represent Standard Error of the Mean (SEM).

Table 7

Actual Volume and Percent Error Obtained from Abbot Solusets

	20 ml level		60 ml level		100 ml level	
	Actual Volume	% Error	Actual Volume	% Error	Actual Volume	% Error
Container I						
Dye dilution						
Run A	21.3	6.5	61.2	2.0	102.2	2.0
Run B	21.3	6.5	61.2	2.0	102.2	2.0
Gravimetric						
Run A	21.3	6.5	61.2	2.0	101.5	1.5
Run B	22.0	11.0	61.4	2.3	101.1	1.1
Container II						
Dye dilution						
Run A	21.7	8.5	63.8	6.3	104.2	4.2
Run B	22.7	13.5	62.5	4.2	102.0	2.0
Gravimetric						
Run A	22.9	14.5	62.2	3.7	102.1	2.1
Run B	22.9	14.5	62.3	3.8	102.5	2.5
Container III						
Dye dilution						
Run A	21.3	6.5	61.2	2.0	102.0	2.0
Run B	21.7	8.5	61.2	2.0	102.0	2.0
Gravimetric						
Run A	21.8	9.0	61.5	2.5	101.6	1.6
Run B	21.9	9.5	61.6	2.7	101.2	1.2
DD[a] $\bar{x} \pm$ (SD)	21.7(0.5)	8.3(2.7)	61.9(1.1)	3.1(1.8)	102.4(0.9)	2.4(0.9)
GR[b] $\bar{x} \pm$ (SD)	22.1(0.6)	10.8(3.2)	61.7(0.4)	2.8(0.7)	101.7(0.5)	1.7(0.5)

[a] DD = Dye dilution studies

[b] GR = Gravimetric studies

Table 8

Actual Volume and Percent Error Obtained from McGaw Burets

	20 ml level		60 ml level		100 ml level	
	Actual Volume	% Error	Actual Volume	% Error	Actual Volume	% Error
Container I						
Dye dilution						
Run A	21.3	6.5	61.2	2.0	102.0	2.0
Run B	21.3	6.5	62.5	4.2	100.0	0
Gravimetric						
Run A	21.5	7.5	60.6	1.0	100.1	0.1
Run B	21.6	8.0	61.3	2.2	100.2	0.2
Container II						
Dye dilution						
Run A	21.3	6.5	62.5	4.2	102.0	2.0
Run B	21.3	6.5	62.5	4.2	102.0	2.0
Gravimetric						
Run A	21.5	7.5	61.5	2.5	100.9	0.9
Run B	21.9	9.5	61.3	2.2	101.0	1.0
Container III						
Dye dilution						
Run A	21.7	8.5	62.5	4.2	102.0	2.0
Run B	21.7	8.5	62.5	4.2	102.0	2.0
Gravimetric						
Run A	21.4	7.0	61.3	2.2	101.0	1.0
Run B	21.3	6.5	61.1	1.8	101.0	1.0
Container IV						
Dye dilution						
Run A	21.7	8.5	62.5	4.2	102.0	2.0
Run B	21.7	8.5	62.5	4.2	102.0	2.0
Gravimetric						
Run A	21.3	6.5	61.1	1.8	101.2	1.2
Run B	21.5	7.5	61.8	3.0	101.4	1.4
Container V						
Dye dilution						
Run A	20.8	4.0	60.0	0	100.0	0
Run B	21.3	6.5	61.2	2.0	100.0	0
Gravimetric						
Run A	20.8	4.0	60.5	0.8	99.8	-0.2
Run B	20.8	4.0	60.3	0.5	100.2	0.2
DD[a] $\bar{x} \pm$ (SD)	21.4(0.3)	7.1(1.5)	62.0(0.9)	3.3(1.5)	101.4(1.0)	1.4(1.0)
GR[b] $\bar{x} \pm$ (SD)	21.4(0.3)	6.8(1.7)	61.1(0.5)	1.8(0.8)	100.7(0.5)	0.7(0.5)

[a] DD = Dye dilution studies

[b] GR = Gravimetric studies

Table 9

Actual Volume and Percent Error Obtained from Mead-Johnson Grad-U-Feed Bottles

	20 ml level		40 ml level		60 ml level	
	Actual Volume	% Error	Actual Volume	% Error	Actual Volume	% Error
Container I						
Dye dilution						
Run A	19.6	-2.0	39.2	-2.0	58.8	-2.5
Run B	19.6	-2.0	39.2	-2.0	58.8	-2.5
Gravimetric						
Run A	20.0	0	39.5	-1.3	58.9	-1.8
Run B	19.7	-1.5	39.6	-1.0	59.1	-1.3
Container II						
Dye dilution						
Run A	20.0	0	39.2	-2.0	58.8	-2.5
Run B	20.0	0	39.2	-2.0	58.8	-2.5
Gravimetric						
Run A	20.2	1.0	40.0	0	59.3	-1.2
Run B	20.2	1.0	39.4	-1.5	59.2	-1.2
Container III						
Dye dilution						
Run A	19.6	-2.0	39.2	-2.0	58.8	-2.5
Run B	19.6	-2.0	40.0	0	58.8	-2.5
Gravimetric						
Run A	20.0	0	39.8	-0.5	59.4	-1.0
Run B	19.6	-2.0	39.8	-0.5	59.2	-1.3
Container IV						
Dye dilution						
Run A	19.6	-2.0	39.2	-2.0	57.7	-3.8
Run B	20.0	0	39.2	-2.0	57.7	-3.8
Gravimetric						
Run A	19.3	-3.5	39.3	-1.8	59.0	-1.7
Run B	19.6	-2.0	39.6	-1.0	58.8	-2.0
Container V						
Dye dilution						
Run A	20.0	0	39.2	-2.0	58.8	-2.5
Run B	20.0	0	39.2	-2.0	58.8	-2.5
Gravimetric						
Run A	19.9	-0.5	39.8	-0.5	59.6	-0.7
Run B	19.5	-2.5	39.8	-0.5	59.6	-0.7
DD[a] $\bar{x} \pm$ (SD)	19.8(0.2)	-0.9(1.2)	39.3(0.3)	-1.8(0.6)	58.6(0.5)	-2.8(0.5)
GR[b] $\bar{x} \pm$ (SD)	19.8(0.3)	-1.0(1.5)	39.7(0.2)	-0.9(0.6)	59.2(0.3)	-1.3(0.4)

[a] DD = Dye dilution studies

[b] GR = Gravimentric studies

Table 10

Actual Volume and Percent Error Obtained from Ross Volu-Feed Bottles

	20 ml level		40 ml level	
	Actual Volume	% Error	Actual Volume	% Error
Container I				
Dye dilution				
Run A	18.9	-5.5	38.5	-3.8
Run B	19.2	-4.0	38.5	-3.8
Gravimetric				
Run A	19.7	-1.5	39.6	-1.0
Run B	19.7	-1.5	39.2	-2.0
Container II				
Dye dilution				
Run A	19.2	-4.0	38.5	-3.8
Run B	18.9	-5.5	38.5	-3.8
Gravimetric				
Run A	19.7	-1.5	39.5	-1.3
Run B	19.8	-1.0	39.5	-1.3
Container III				
Dye dilution				
Run A	18.9	-5.5	38.5	-3.8
Run B	18.9	-5.5	38.5	-3.8
Gravimetric				
Run A	19.9	-0.5	39.6	-1.0
Run B	19.5	-2.5	39.3	-1.8
Container IV				
Dye dilution				
Run A	19.2	-4.0	38.5	-3.8
Run B	19.2	-4.0	37.7	-5.8
Gravimetric				
Run A	19.6	-2.0	39.4	-1.5
Run B	19.4	-3.0	39.2	-2.0
DD[a] $\bar{x}$ (SD)	19.1(0.2)	-4.8(0.8)	38.4(0.3)	-4.1(0.7)
GR[b] $\bar{x}$ (SD)	19.7(0.2)	-1.7(0.8)	39.4(0.2)	-1.5(0.4)

[a] DD = Dye dilution studies

[b] GR = Gravimetric studies

Table 11

Actual Volume and Percent Error Obtained from Enfamil Nursettes

	60 ml level		120 ml level	
	Actual Volume	% Error	Actual Volume	% Error
Container I				
Dye dilution				
Run A	60.0	0	122.4	2.0
Run B	61.2	2.0	122.4	2.0
Gravimetric				
Run A	61.6	2.7	120.7	0.6
Run B	61.0	1.7	121.0	0.8
Container II				
Dye dilution				
Run A	62.5	4.2	125.0	4.2
Run B	62.5	4.2	122.4	2.0
Gravimetric				
Run A	62.0	3.3	121.7	1.4
Run B	63.6	6.2	122.7	2.3
Container III				
Dye dilution				
Run A	62.5	4.2	125.0	4.2
Run B	63.8	6.3	125.0	4.2
Gravimetric				
Run A	63.9	6.5	123.5	2.9
Run B	62.9	5.0	124.1	3.4
Container IV				
Dye dilution				
Run A	62.5	4.2	125.0	4.2
Run B	63.8	6.3	122.4	2.0
Gravimetric				
Run A	63.2	5.3	122.2	1.8
Run B	61.9	3.2	120.4	0.4
Container V				
Dye dilution				
Run A	63.8	6.3	125.0	4.2
Run B	63.8	6.3	125.0	4.2
Gravimetric				
Run A	63.8	6.3	123.3	2.8
Run B	64.4	7.3	123.6	3.0
DD[a] $\bar{x}$ (SD)	62.6(1.3)	4.4(2.1)	124.0(1.3)	3.3(1.1)
GR[b] $\bar{x}$ (SD)	62.8(1.1)	4.8(1.9)	122.3(1.3)	1.9(1.1)

[a] DD = Dye dilution studies

[b] GR = Gravimetric studies

Table 12

Actual Volume and Percent Error Obtained from American Medicine Cups

	5 ml level		10 ml level		20 ml level	
	Actual Volume	% Error	Actual Volume	% Error	Actual Volume	% Error
Container I						
Dye dilution						
Run A	4.5	-10.0	9.6	-4.0	18.9	-5.5
Run B	5.0	0	10.0	0	18.9	-5.5
Gravimetric						
Run A	4.3	-14.0	9.4	-6.0	18.6	-7.0
Run B	(no second run)		9.2	-8.0	18.4	-8.0
Container II						
Dye dilution						
Run A	5.0	0	10.0	0	19.6	-2.0
Run B	5.1	2.0	10.2	2.0	19.6	-2.0
Gravimetric						
Run A	5.0	0	9.6	-4.0	18.6	-7.0
Run B	(no second run)		9.9	-1.0	18.9	-5.5
Container III						
Dye dilution						
Run A	5.1	2.0	9.6	-4.0	19.2	-4.0
Run B	5.0	0	10.4	4.0	19.2	-4.0
Gravimetric						
Run A	4.7	-6.0	10.3	3.0	19.3	-3.5
Run B	(no second run)		9.5	-5.0	18.9	-5.5
Container IV						
Dye dilution						
Run A	5.2	4.0	10.2	2.0	19.2	-4.0
Run B	5.0	0	10.2	2.0	19.6	-2.0
Gravimetric						
Run A	5.0	0	10.0	0	19.3	-3.5
Run B	(no second run)		9.5	-5.0	19.2	-4.0
Container V						
Dye dilution						
Run A	4.9	-2.0	10.2	2.0	18.9	-5.5
Run B	5.1	2.0	10.2	2.0	18.5	-7.5
Gravimetric						
Run A	4.8	-4.0	9.8	-2.0	19.7	-1.5
Run B	(no second run)		9.6	-4.0	18.8	-6.0
DD[a] $\bar{x}$ (SD)	5.0(0.2)	-0.2(3.8)	10.1(0.3)	0.6(2.7)	19.2(0.4)	-4.2(1.8)
GR[b] $\bar{x}$ (SD)	4.8(0.3)	-4.8(5.8)	9.7(0.3)	-3.2(3.2)	19.0(0.4)	-5.2(2.0)

[a] DD = Dye dilution studies

[b] GR = Gravimetric studies

Table 13

Actual Volume and Percent Error Obtained from Davol Uri-Meters

	20 ml level		60 ml level		100 ml level	
	Actual Volume	% Error	Actual Volume	% Error	Actual Volume	% Error
Container I						
Dye dilution						
Run A	18.5	-7.5	55.6	-7.3	90.9	-9.1
Run B	18.2	-9.0	61.2	2.0	94.3	-5.7
Gravimetric						
Run A	19.9	-0.5	59.8	-0.3	101.5	1.5
Run B	20.5	2.5	60.8	1.3	102.3	2.3
Container II						
Dye dilution						
Run A	19.2	-4.0	56.6	-5.7	94.3	-5.7
Run B	18.9	-0.5	54.5	-9.2	90.9	-9.1
Gravimetric						
Run A	19.8	-1.0	60.3	0.5	102.0	2.0
Run B	21.2	6.0	60.3	0.5	102.7	2.7
Container III						
Dye dilution						
Run A	18.9	-0.5	52.6	-12.3	90.9	-9.1
Run B	18.5	-7.5	53.6	-10.7	84.7	-15.3
Gravimetric						
Run A	19.8	-1.0	59.8	-0.3	100.6	0.6
Run B	20.2	1.0	59.3	-1.2	101.5	1.5
Container IV						
Dye dilution						
Run A	18.9	-0.5	53.6	-10.7	100.0	0
Run B	18.5	-7.5	51.7	-13.8	92.6	-7.4
Gravimetric						
Run A	19.9	-0.5	60.9	1.5	101.9	1.9
Run B	21.0	5.0	60.8	1.3	100.2	0.2
Container V						
Dye dilution						
Run A	19.2	-4.0	56.6	-5.7	96.2	-3.8
Run B	19.2	-4.0	56.6	-5.7	96.2	-3.8
Gravimetric						
Run A	19.8	-1.0	60.3	0.5	102.1	2.1
Run B	20.7	3.5	61.2	2.0	103.2	3.2
Container VI						
Dye dilution						
Run A	19.2	-4.0	58.8	-2.0	89.3	-10.7
Run B	18.9	-0.5	53.6	-10.7	94.3	-5.7
Gravimetric						
Run A	19.5	-2.5	59.9	-0.2	99.9	-0.1
Run B	19.5	-2.5	59.6	-0.7	100.3	0.3
DD[a] $\bar{x} \pm$ (SD)	18.8(0.3)	-4.1(3.2)	55.4(2.7)	-7.8(4.5)	92.9(3.9)	-7.1(3.9)
GR[b] $\bar{x} \pm$ (SD)	20.2(0.6)	0.8(2.9)	60.3(0.6)	0.4(1.0)	101.5(1.1)	1.5(1.1)

[a] DD = Dye dilution studies

[b] GR = Gravimetric studies

Table 14

Actual Volume and Percent Error Obtained from Tomac Urinals

	200 ml level		400 ml level		1000 ml level	
	Actual Volume	% Error	Actual Volume	% Error	Actual Volume	% Error
Container I						
Dye dilution						
Run A	204.1	2.1	400.0	0	1020.4	2.0
Run B	200.0	0	400.0	0	1000.0	0
Gravimetric						
Run A	189.6	-5.2	391.5	-2.1	999.4	-0.1
Run B	183.7	-8.2	384.9	-3.8	992.8	-0.7
Container II						
Dye dilution						
Run A	212.8	6.4	416.7	4.2	1020.4	2.0
Run B	222.2	11.1	408.2	2.1	1020.4	2.0
Gravimetric						
Run A	186.7	-6.7	387.6	-3.1	1005.7	0.6
Run B	190.7	-4.7	392.1	-2.0	999.3	-0.1
Container III						
Dye dilution						
Run A	200.0	0	400.0	0	1020.4	2.0
Run B	204.1	2.0	408.2	2.1	1020.4	2.0
Gravimetric						
Run A	183.9	-8.1	384.7	-3.8	987.5	-1.3
Run B	185.3	-7.4	385.7	-3.6	991.9	-0.8
DD[a] $\bar{x}$ (SD)	207.2(8.7)	3.6(4.4)	405.5(6.8)	1.4(1.7)	1017.0(8.3)	1.7(0.8)
GR[b] $\bar{x}$ (SD)	186.7(2.9)	-6.7(1.5)	387.8(3.3)	-3.1(0.8)	996.1(6.6)	-0.4(0.7)

[a] DD = Dye dilution studies

[b] GR = Gravimetric studies

Table 15

Actual Volume and Percent Error Obtained from American Urinals

	200 ml level		400 ml level		1000 ml level	
	Actual Volume	% Error	Actual Volume	% Error	Actual Volume	% Error
Container I						
Dye dilution						
Run A	204.1	2.1	416.7	4.2	980.4	-2.0
Run B	222.2	11.1	408.2	2.1	1000.0	0
Gravimetric						
Run A	193.7	-3.2	394.3	-1.4	977.5	-2.3
Run B	186.6	-6.7	394.8	-1.3	973.7	-2.6
Container II						
Dye dilution						
Run A	204.1	2.1	425.5	6.4	980.4	-2.0
Run B	208.3	4.2	408.2	2.1	1000.0	0
Gravimetric						
Run A	191.7	-4.2	405.1	1.3	991.4	-0.9
Run B	194.7	-2.6	396.7	-0.8	993.1	-0.7
DD[a] $\bar{x}$ (SD)	209.7(8.6)	4.9(4.3)	414.7(8.3)	3.7(2.1)	990.2(11.3)	-1.0(1.2)
GR[b] $\bar{x}$ (SD)	191.7(3.6)	-4.2(1.8)	397.7(5.0)	-0.6(1.3)	983.9(9.8)	-1.6(1.0)

[a] DD = Dye dilution studies

[b] GR = Gravimetric studies

Table 16

Actual Volume and Percent Error Obtained from American Triangle Graduates

	200 ml level		400 ml level		1000 ml level	
	Actual Volume	% Error	Actual Volume	% Error	Actual Volume	% Error
Container I						
Dye dilution						
Run A	200.0	0	392.2	-2.0	1000.0	0
Run B	196.1	-1.9	392.2	-2.0	1000.0	0
Gravimetric						
Run A	194.7	-2.7	394.8	-1.3	990.6	-0.9
Run B	196.8	-1.6	392.3	-1.9	990.6	-0.9
Container II						
Dye dilution						
Run A	196.1	-1.9	392.2	-2.0	1000.0	0
Run B	196.1	-1.9	392.2	-2.0	980.4	-2.0
Gravimetric						
Run A	193.4	-3.3	389.7	-2.6	987.1	-1.3
Run B	196.6	-1.7	391.5	-2.1	988.2	-1.2
Container III						
Dye dilution						
Run A	200.0	0	392.2	-2.0	1000.0	0
Run B	196.1	-1.9	392.2	-2.0	980.4	-2.0
Gravimetric						
Run A	193.7	-3.2	388.8	-2.8	984.0	-1.6
Run B	196.1	-2.0	393.0	-1.8	986.3	-1.4
DD[a] $\bar{x}$ (SD)	197.4(2.0)	-1.3(1.0)	392.2(0)	-2.0(0)	993.5(10.1)	-0.7(1.0)
GR[b] $\bar{x}$ (SD)	195.2(1.5)	-2.4(0.8)	391.7(2.2)	-2.1(0.5)	987.8(2.6)	-1.5(0.7)

[a] DD = Dye dilution studies

[b] GR = Gravimetric studies

CHAPTER IV

DISCUSSION

Since many different brands and kinds of devices were tested, it is convenient to organize this discussion in a fashion similar to that reported in the results. Accordingly, the results are discussed in the following sequence: (1) I.V. infusion sets, (2) infant feeding bottles, (3) medicine cups, (4) urine collection devices, and (5) graduated triangles.

Intake Devices

I. V. infusion sets. Intravenous infusion sets with graduated containers are used clinically for infusing precise amounts of fluid. They are frequently used in fluid therapy for critically ill adults, pediatric patients, as well as the especially vulnerable premature infants. Nurses visually monitor fluid levels in and regulate flow of the solutions from these devices. In the clinical setting, these infusion sets are considered to be very accurate and considerable faith is placed in their accuracy. In contrast to this clinical assumption, results from these controlled laboratory experiments showed that as much as 14.5% (2.9 ml) error was found in this equipment at the lowest volume tested (20 ml). While a stable adult may easily adapt body homeostatic mechanisms to this error in the volume administered, a critically ill patient or a premature infant may not be capable of adjusting satisfactorily. This 2.9 ml error may be multiplied if serial volumes of fluid are measured at the same level and then infused over the space of several hours or a day.

The percent error found in both brands of infusion sets was greater at lower volumes. The percent error was increased at low volumes because the magnitude of error was nearly constant at each volume tested (Tables 6, 7, 8). The larger percent error at low volume measurements is particularly significant when these devices are used for I. V. infusions in full term and premature infants. When these devices are used for this age group, they generally contain only 10 ml of fluid at any one time. This small volume is used to prevent bolus injection of larger volumes of fluid. Since premature infants are especially vulnerable to the dangers inherent in volume expansion, great care should be exercised in measuring volumes to be infused. If volumes less than 20 ml were to be measured using these devices, then errors greater than 14.5% would probably be found. Over a period of twenty-four hours, the actual volumes that might be given would be considerably greater than intended.

The graduated fluid levels are printed, rather than embossed on both brands of I. V. infusion sets. It is possible that the plastic is not printed uniformly. Evidence supporting this potential source of error was found in this study (Table 7). It can be seen that Container II was found to have a consistently higher magnitude of error and mean percent error at all levels tested compared to the other two containers. These data suggest that quality control in the manufacturing process is not sufficiently rigid to produce devices with the accuracy required for critically ill patients. The sample size was small in this study, hence it may not be appropriate to generalize the results to all infusion sets. However, these samples

do represent typical examples of infusion sets selected at random from hospital supplies.

Infant feeding bottles. Feeding bottles are used in the hospital setting to feed neonates, young infants, and those premature infants capable of obtaining nourishment from a bottle. Volumes of the fluid to be ingested are measured using the scale provided on the bottle itself. When fluid intake is restricted in older children, the two smaller containers (Ross Volu-Feed and Mead-Johnson Grad-U-Feed) are often used to measure the volumes to be given. In the clinical setting, these devices are generally considered to be accurate.

Less percent error was found in the two smaller feeding bottles (Volu-Feed and Grad-U-Feed) at the same volumes tested than was found in the I. V. infusion sets (Tables 6, 9, 10, 11). In fact, Mead-Johnson Grad-U-Feed bottles were the most accurate (Tables 6, 9). The results of this study indicate that one could use the Grad-U-Feed containers and expect less than 4% error from the containers themselves. However, critically ill children may need more exacting measurements of oral fluid intake. In these circumstances, nurses should use a measuring device with less error, such as a Monoject syringe, which has approximately 1% error (Bergstrom, Bracis, and Robbins, 1980). It should be noted that there is a certain amount of error inherent in the feeding process itself. One source (Appendix A) suggests that the error in the process of infant feeding might be within 5%.

Enfamil Nursettes are used to deliver larger volumes of fluid for ingestion. Since the lowest volume marked on the device is 30 ml, these containers should not be used to measure volumes less than 30 ml.

However, at the volumes tested, these bottles, on the average, had an error less than 5% (Tables 6, 11).

Medicine cups. Two kinds of medicine cups are available in many hospitals. Small paper medicine cups are used for dry medications such as capsules and tablets. Graduated plastic medicine cups are provided for use in measuring oral fluid medications such as oral pediatric antibiotics, antacids, and digitalis elixir. These plastic medicine cups are frequently used on pediatric wards, because (1) many children cannot or will not swallow tablets or capsules, and (2) dosages vary with age and weight of the child and variable doses can be measured more accurately using liquids than by using portions of tablets.

The need for accuracy in measurment of medications is essential in all patients. Plastic medicine cups may not provide the accuracy needed. Although the mean percent error of measurement using the medicine cups was small, there was wide variation about the mean (Tables 6, 12). In some cases, as much as 14% error was found in volumes measured using medicine cups. This amount of error is unacceptable for measuring doses of medications. Monoject syringes or other comparably accurate devices should be used in these critical fluid medication measurements.

Output Devices

Davol Uri-Meters, Urinals, American Triangle Graduates. Davol Uri-Meters and urinals are used to collect urine from patients in the clinical setting. Uri-Meters are connected to urinary bladder catheters for hourly or more frequent measurement of urine volume.

The use of the catheter and, thus, the Uri-Meter is generally reserved for patients who are more critically ill because of the potential for infection which frequently accompanies the use of indwelling catheters. Therefore, these devices must be accurate at small volumes as well as at larger volumes. Accuracy of the Uri-Meters is readily assumed in adult patient settings. However, the accuracy of this equipment has not always been as well accepted in the pediatric clinical units. Some pediatric nurses drain the urine from the exit port of the device and then measure the volume in graduated cylinders.

The dye dilution and gravimetric techniques did not give the same results with the Uri-Meter (Table 13). One reason for the difference may be that concentrated dye used in the dye dilution technique tended to collect in the exit port and thus, could not be thoroughly mixed. Since samples were always taken via the exit port, they may have contained more dye than would have been found in the main body of the container. If this circumstance actually occurred, the net result would be that the dye would appear to be less dilute and would lead to a smaller calculated volume.

Both urinals tested in this study were blue colored plastic devices with widely separated volume markings. No fluid meniscus could be seen in any of these devices due to the opaque material used in their construction. Fluid levels were difficult to see, and yet, the devices were within 2% mean error at the levels tested (Table 6). Even though the mean percent errors were small, it should be noted that the standard error of the mean was quite large especially at the

200 ml level (Tables 14, 15). Clinically, these devices will be accurate when the volume of urine contained exactly matches the volume marker on the device. The wide graduations make this an awkward container to use for precise measurements between volume markings. Since these devices are probably more aesthetically acceptable at the patient's bedside than the clear plastic containers, the urine should be transferred to another suitable container for more accurate measurements.

The dye dilution and gravimetric techniques used with the urinals provided unequal results at the levels tested. The reason for this discrepancy is unknown.

Triangles. Triangle graduates are used to measure volumes of both intake and output fluids. These devices have volume markings of up to one liter molded into the plastic. Since these devices are wide and no fluid meniscus can be seen, one would not necessarily expect to obtain accurate readings of fluid volumes. In fact, nurses often weigh the dry container and then weigh the container filled with the fluid to be measured, whether it is a formula for gastric feedings or return fluid from peritoneal dialysis. This practice is probably sufficiently accurate for the majority of patients, if the scale or balance is accurate. However, some clinical settings do not provide scales for these measurements. Nurses then use the triangle graduates to measure these fluids. The results from this study show that these triangles are within 4% error at all levels tested (Tables 6, 16). Gravimetric procedures with an accurate scale or balance may be used if more exacting measurements are needed. Those using gravimetric

techniques must remember that the density of different fluids may vary significantly from the density of water, and this must be taken into account in these measurements. When an accurate scale or balance is not available, a more accurate device for measurement of fluid volume, such as a graduated cylinder that has been calibrated against known standards, could be used.

The following conclusions may be drawn from the results of this research if the containers tested were representative of those found in general supply.

1. Abbot and McGaw I. V. infusion sets, when used in isolation from other equipment, are not sufficiently accurate for use with critically ill patients or premature infants.

2. The infant feeding bottles tested were generally accurate to within 5% error and are adequate for most feeding purposes. Nurses caring for those infants for whom fluid volume measurements must be more accurate should use the Mead-Johnson Grad-U-Feed bottles, which had less than 3% mean error.

3. Medicine cups obtained from American Hospital Supply are not sufficiently precise for measuring doses of fluid medications. Monoject syringes or comparably accurate devices should be used for measuring fluid medications.

4. Davol Uri-Meters were accurate at the levels tested. It is appropriate to use this piece of equipment with critically ill patients.

5. Urinals and triangle graduates are acceptable for use for estimates of fluid volumes. Triangle graduates were consistently within 4% of the expected volume at the levels tested and were the

most accurate device of the three tested. These three devices should not be used if container error less than 4% is required.

Finally, it should be recognized that differences were not evaluated using standard statistical tests. The issue is not amenable to discussion via statistical analysis because whether an error is statistically significant has no real bearing in a clinical situation. The real significance of these errors is clinical. Given the accuracy of the methods used for calibration I found the magnitude and percent error of several of the devices tested to be unacceptable for many clinical uses. In no circumstance should a medication be given when there is a possibility of 10 or 15% error in the dose measured because the container used is not calibrated properly.

CHAPTER V

SUMMARY AND CONCLUSIONS

This study was conducted to determine the magnitude of error in ten commonly used fluid measuring devices. Two to three fluid levels were tested in each device. The majority of equipment was accurate at the volumes tested to within 5% of the stated volume (Table 6). The equipment having unacceptable errors and/or large variability for their intended use included two brands of intravenous infusion sets (Abbot and McGaw) and the American Hospital Supply plastic medicine cups.

Nurses must use particular caution when using these devices with patients who are at high risk for body fluid imbalances. In these circumstances, nurses must use a second method to validate or improve the accuracy of fluid measurements. When using the Abbot or McGaw infusion sets, a properly calibrated, accurate infusion pump will improve accuracy of volumes of fluids administered. Monoject syringes or other comparably accurate devices should be used in addition to medicine cups when measuring and administering doses of medications to patients. Finally, an accurate top loading balance should be available to nurses caring for critically ill patients to accurately measure volumes of fluid intake and output. The density of the fluids used must also be known to use this device properly.

The results of this study demonstrate that the intravenous infusion sets tested are not accurate. An accurate device with a consistently low error (1% or less) should be constructed by the companies. An alternative to construction of new devices for measuring fluid volumes would be development of a method to rapidly and accurately calibrate

fluid measurement receptacles in the clinical setting. This method should be applicable to any container used to measure fluid volumes.

Nurses must become involved in testing the accuracy of devices used in the clinical setting. We will then recognize which devices are inaccurate, and can take steps to improve the accuracy of the measurements. Accurate fluid volume measurements will improve the accuracy of the fluid balance records. Medication dosages will also be more accurate and therefore nursing care provided for the patient should ultimately be improved.

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APPENDIX A

Letters Received from Manufacturing Companies

Ross

Mead-Johnson

American Hospital Supply

American Hospital Supply

Division of
American Hospital Supply
Corporation

1450 Waukegan Road
McGaw Park IL USA 60085

Telephone 312 473-0400

November 25, 1981

Ms. Maribeth Cross Bergstrom, RN, B.S.N.
918 Southwest Gaines Street, No. 16
Portland, Oregon 97201

Dear Ms. Bergstrom:

Thank you for your letter of November 7, 1981, to our Corporate office.

Generally speaking, the tolerance of error for measuring devices is to be plus or minus 5% of the amount measured. However, with some very small quantities of measurement, it's impossible to maintain 5%. For instance, a 1cc syringe may not be plus or minus 5%, whereas a 1,000cc graduate will be within plus or minus 5%.

The magnitude of error, or tolerance, is determined by actual measurements of the quantities that a container will hold. This is done by taking water at 20° centigrade from a graduated cylinder and comparing it to the measurement equipment.

I would suggest that you simply test the American urinals, triangle graduates and medicine cups against a graduated cylinder with water at room temperature. I believe you will find these pieces of equipment to be within plus or minus 5% of the total volume. This should be more than adequate for maintaining good records for input and output measurements with patients requiring fluid monitoring.

If we may be of further assistance, please don't hesitate to write.

Sincerely,

[redacted]

Richard B. Farb
Vice President of Regulatory
Affairs & Quality Assurance

RBF:cs

Mead Johnson NUTRITIONAL DIVISION
EVANSVILLE, INDIANA 47721 / TELEPHONE (812) 426-2000

June 23, 1981

Maribeth Cross Bergstrom, R.N., B.S.N.
918 S.W. Gaines #16
Portland, OR 97201

Dear Ms. Bergstrom:

Thank you for your letter requesting information about our Grad-U-Feed and our eight ounce Enfamil Nursette bottles. We do not have specifications for the accuracy of the calibration of these units; however, our package engineers assure me that the accuracy is within ± 5% of the indicated volume. These feeders are intended to provide approximate values, and for most feeding purposes, 5% is probably as accurate as the rest of the feeding process would be.

Thank you again for your interest in our products. If we may provide you with any additional information, please let me know.

Sincerely,

[redacted]

Roland J. Talley
Supervisor, Medical Information

RJT/llf/LF-162

ROSS LABORATORIES COLUMBUS, OHIO 43216
A DIVISION OF ABBOTT LABORATORIES

July 10, 1981

Maribeth Cross Bergstrom, RD, BSN
918 SW Gaines #16
Portland, Oregon 97201

Dear Ms Bergstrom

Thank you for writing concerning the accuracy of Ross Laboratories' Volu-Feed nurser. We are happy to be able to supply information on our products.

The accuracy of the Volu-Feed is measured in two ways. In the first, water is added carefully to a specific mark and the contents weighed. The line is read as the meniscus of the water coincides with the line of the mark. We have found a systematic error of 0.2 ml over each 10 ml. The total capacity by this method appears to be 44.4 ml instead of 45.0 ml. This will depend on how the individual reads the meniscus.

The second method is to add a specific amount of water from an accurate instrument and read the volume from the position of the water meniscus. A discerable error could not be detected by this method. The graduation line is about 1/32 inch wide and the meniscus is nearly 1/32 inch wide so it is not possible to read more closely than the nearest ml.

When the Volu-Feed is used for a measurement that requires accuracy, the individual should test the accuracy of the measurement they are making. If formula is being measured, the meniscus will be read differently than a clear solution. One of the above methods can be used. When weighing an infant formula at 20 Cal/oz, the weight of one ml is 1.0295 g.

If you need further information on Ross products, please feel free to contact me.

Sincerely

[redacted]

Duane A Benton, PhD
Director of Nutritional Research

/sdr

cc: Paul Lucento, terr 8517

APPENDIX B

Methods for Preparing Stock Standards

APPENDIX B

Methods for Preparing Stock Standards

100 mg % Potassium Chromate:

Stock standard was prepared by dissolving 1.0000 g of K_2CrO_4 (potassium chromate), weighed on a Sartorious analytical balance, in about 50 ml 0.05N KOH. The solution was then transferred quantitatively into a 1 liter volumetric flask and diluted with 0.05N KOH to a volume of 1 liter. The solution was then thoroughly mixed.

50 mg % Potassium Chromate:

This stock standard was prepared as described above, but only one half of the amount of dye was used, thereby halving the concentration of potassium chromate (0.5000 g K_2CrO_4 was diluted to a final volume of 1 liter).

APPENDIX C

Table of Manufacturers, Presumed Trademarks, and Synonyms of Devices Tested

APPENDIX C

Table of Manufacturers, Presumed Trademarks, and Synonyms of Devices Tested

The following table gives the manufacturer, presumed trademark, and synonym(s) of each kind of device tested in this study. This table is included to provide a complete listing of all devices used as well as to avoid the unnecessary and cumbersome practice of trademark notation every time a trade name is used in the text.

Manufacturer	Presumed Trademark	Synonyms
Abbot McGaw	Soluset Metriset, Buret	(Abbot and McGaw) Also called infusion sets, intravenous sets, I. V. sets, intravenous infusion sets.
Mead-Johnson Mead-Johnson Ross	Grad-U-Feed Enfamil Nursettes Volu-Feed Nursers	(Feeding Bottles) Also called feeding bottles, nursers, infant feeding bottles.
American Hospital Supply	American Medicine Cups	Also called medicine cups.
Davol	Davol Uri-Meters	Also called catheter collection devices.
American Hospital Supply Tomac	American Urinals Tomac Urinals	(Urinals) Also called urinals.
American Hospital Supply	Triangle Graduates	Also called triangles.

Devices tested were selected at random from hospital supply. No company furnished any of the containers.

AN ABSTRACT OF THE THESIS OF

MARIBETH CROSS BERGSTROM

For the MASTER OF NURSING

Date of Receiving this Degree: June, 1982

Title: EVALUATION OF THE ACCURACY OF DEVICES COMMONLY USED TO MEASURE FLUID VOLUMES FOR RECORDING INTAKE AND OUTPUT

Approved: [redacted]
Jack L. Keyes, [illegible], Thesis Advisor

In this descriptive study visual measurements of fluid volume were made in ten containers using the scale provided by the manufacturer. The dye dilution and gravimetric techniques were then used to calibrate the scale provided. The devices selected for testing were those most frequently used in two hospital settings in the Portland metropolitan area. The devices tested were typical examples selected at random from hospital supplies.

The results showed three devices (Abbot and McGaw intravenous infusion sets, American Hospital Supply medicine cups) were dangerously inaccurate at certain volumes tested. Errors were frequently greater than 10% of the expected volume at certain levels. Large percent errors, large magnitude of error, and/or wide variability about the mean indicated unacceptable inaccuracies in these devices.

The following were concluded from the results of this study.

1. Abbot and McGaw intravenous infusion sets are not sufficiently accurate to be used in isolation for use with critically ill patients or premature infants.
2. Infant feeding bottles tested were generally accurate for most feeding purposes.
3. Medicine cups obtained from American Hospital Supply are not sufficiently precise for measuring doses of fluid medications.
4. Davol Uri-Meters are accurate at the levels tested.
5. Urinals and triangle graduates are acceptable for use in estimating fluid volumes, but should not be used if container error less than 4% is required.