UNIVERSITY OF ALBERTA

An Evaluation of Rectal, Axillary, and Tympanic Temperature Measurements in Neonates in the Intensive Care Unit

by

Linda G. McConnan

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF NURSING

FACULTY OF NURSING

Edmonton, Alberta

Fall, 1992

ISBN 0-315-77138-0

U N I V E R S I T Y   OF   A L B E R T A

RELEASE FORM

NAME OF AUTHOR: LINDA G. MCCONNAN

TITLE OF THESIS: AN EVALUATION OF RECTAL, AXILLARY, AND TYMPANIC TEMPERATURE MEASUREMENTS IN NEONATES IN THE INTENSIVE CARE UNIT

DEGREE: MASTER OF NURSING

YEAR THIS DEGREE GRANTED: 1992

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DATED:
October 8, 1992

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FACULTY OF GRADUATE STUDIES AND RESEARCH

THE UNDERSIGNED CERTIFY THAT THEY HAVE READ, AND RECOMMEND TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH FOR ACCEPTANCE, A THESIS ENTITLED AN EVALUATION OF RECTAL, AXILLARY, AND TYMPANIC TEMPERATURE MEASUREMENTS IN NEONATES IN THE INTENSIVE CARE UNIT SUBMITTED BY LINDA MCCONNAN IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF NURSING.

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Abstract

Temperature assessment and control are important to the survival and well-being of sick and premature infants. Temperature can be measured with a tympanic thermometer or with glass and electronic thermometers used at the rectal and axilla sites. The purpose of this study was to examine the accuracy of these thermometers and to assess the effect of the preterm infant's environment on temperature. A convenience sample was obtained of 50 term and preterm neonates who had been admitted to two urban Neonatal Intensive Care Units. Six different temperature measures were obtained on two occasions, once when the infant was in a radiant warmer and later when in an incubator. The six measures included those taken by glass thermometers at the rectal and axilla sites, electronic thermometers (IVAC 2080A) at the rectal and axilla sites, and the tympanic thermometer (FirstTemp Genius) in the calibration and core modes. These were compared to the core rectal temperature obtained using the Hi-Lo thermometer (Mallinckrodt). Analyses included measures of association and assessment of limits of agreement for each temperature measure with the core temperature. The measures which had the closest agreement with the core rectal, in both

environments, were electronic and glass thermometers used at the rectal sites. Nonetheless, these temperature measures were not identical to the core temperature nor were they systematically higher or lower than the core temperature. On further examination of the data, it seemed that poor agreement occurred for low birthweight infants especially with axilla temperatures. The infant's need for a neutral thermal environment was weighed against the potential risks associated with the various temperature assessment methods. The electronic rectal temperature was recommended, particularly for very low birthweight infants. The electronic thermometer, used at the axilla site is also suitable for infants over 1200 grams who are in the incubator. Further research should be undertaken to examine the effect of infant size upon accuracy of temperature measurement.

Acknowledgements

I would like to express my appreciation and gratitude to the many individuals who assisted in making this study possible.

To Dr. J. Lander, my supervisor, for her ability to critique and provide positive feedback, and for her friendship.

To Dr. M. Harrison, a member of the committee, for her understanding, willingness to help, and constructive participation.

To Dr. N. Finer, an external member of the committee, whose contributions as an expert in Neonatology and research, were invaluable.

To the nurses in NICU at the Royal Alexandra Hospital, who asked the question that prompted the study, for their interest, support, and assistance.

To the nursing staff in NICU at the University of Alberta Hospitals, who facilitated my data collection.

To my friends, Agnes Van Der Klaauw and Angela Weir, who were so supportive and encouraging.

To my husband, Ian, and children, Meghan, Courtney, and Kelly, who were always there for me. I thank you very much.

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An Evaluation of Rectal, Axillary, and Tympanic Temperature Measurements in Neonates in the Intensive Care Unit

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Like all homeothermic animals, infants must maintain a relatively stable core temperature to support tissue life and body functioning. Important nursing responsibilities in caring for neonates include providing an environment that supports thermoregulation, monitoring the infant's temperature, and observing for signs of hypo- or hyperthermia.

Normal heat production in the neonate occurs mainly as the result of nonshivering thermogenesis which involves the metabolism of brown fat which is stored at the nape of the neck, between the scapulae, in the mediastinum, and surrounding the kidneys and adrenals. This metabolism is stimulated by norepinephrine, which is accompanied by a dramatic increase in oxygen consumption (Bruck, Parmelee, & Bruck, 1962; Scopes & Ahmed, 1966). In a sick neonate, this increase in oxygen consumption may lead to an oxygen debt with a resulting lactic acidosis. Nonshivering thermogenesis is impaired in infants during the first twelve hours of life (Smales & Kime,

1978) and in asphyxiated or hypoxic states (Scopes & Ahmed, 1966; Bruck, Adams, & Bruck, 1962).

Premature and low birthweight infants are at increased risk for hypothermia for a number of reasons (see Appendix A for a more extensive review of this and related literature). Care of infants, particularly those who are sick or premature, includes the provision of a neutral thermal environment in which the infant is able to balance heat production with heat loss, and maintain core body temperature. The neutral thermal environment consists of a narrow range of temperatures that enables the infant to live with minimal energy expenditure (Baumgart, 1991).

Currently, very premature and/or critically ill neonates are nursed under radiant warmers, which are platform beds open to the environment, with an overhead source of radiant heat. These beds provide easy access to the infant for the tests and procedures that are required during the initial critical period. The temperature of the bed is controlled by a skin probe attached to the infant that regulates a powerful heat source which responds quickly to warm the infant. It has, however, been noted that there is a tremendous increase in insensible water loss from the infant under this warmer (Baumgart, 1982; Marks, Gunther, Rossi, &

Maisels, 1980). This water loss results, concomitantly, in heat loss equivalent to .58 kcal per ml (Baumgart, 1991).

An alternative to the radiant warmer is the incubator, which provides heat by convection, as well as normal or added humidity. The advantage of the incubator over the radiant warmer is derived from reduced water loss and decreased metabolic requirements experienced by the infants (Marks, Nardis, & Momin, 1986). There has been some suggestion that very low birthweight infants cannot maintain their core temperature as well in an incubator as under a radiant warmer (Wheldon & Rutter, 1982).

Temperatures should, ideally, be measured at the thermoregulatory center in the hypothalamus but this site is inaccessible. Other sites from which the core temperature can be obtained include the deep rectal and esophageal sites. These are considered to be too invasive for routine clinical purposes. Therefore, the thermometer is placed adjacent to large arteries in more convenient places that are not as influenced by environmental temperature changes. In neonates, the sites of choice have been the distal rectum, the axilla, and, more recently, the tympanic membrane. These sites are assumed to have a direct relationship to the core temperature. The core temperature, measured at the hypothalamus, esophagus, or deep rectum, may all have different values. The deep rectal temperature is accessible for any infant. Because the thermometer is inserted beyond the internal sphincter, the temperature reading is unlikely to be influenced by the environment.

A variety of instruments are available for temperature measurement. These include mercury-in-glass thermometers, intermittent electronic thermometers, thermistor probes (or continuous electronic thermometers), and tympanic infrared-sensing thermometers.

Glass thermometers are inexpensive and easy to use, but require cleaning. In studies of new glass thermometers tested in controlled water baths through the range of temperatures, as many as 8 to 50% were inaccurate by 0.1 to 2 degrees centigrade (Abbey, Anderson, Close, Bertwig, Scott, Sears, Willens, & Parker, 1978; Purintun, & Bishop, 1979).

Much of the research examining the relationship between rectal and axilla temperatures has been conducted with adults (Morley, Hewson, Thornton, & Cole, 1992; Nichols, Ruskin, Glor, & Kelly, 1966). The times for temperature stabilization at a maximum or optimum temperature in term and preterm infants varied between 3 to 5 minutes for rectal temperatures and 3 to 5 minutes for axilla temperatures (Torrance, 1968; Mayfield, Bhatia, Nakamura, Rios, & Bell, 1984; Haddock, Vincent, & Merrow, 1986; Haddock, Merrow, & Vincent, 1988; Bliss-Holtz, 1989; Hunter, 1991). Temperature stabilization times were approximately 0.5 to 1 minute earlier in preterm infants than in term infants (Khan, Ahmed, & Fakhir, 1990; Mayfield, et al., 1984; Moen, Chapman, Sheehan, & Carter, 1987).

Case study reports published 20 to 30 years ago cited the use of glass thermometers for rectal temperature-taking in neonates as the cause of injury or death related to rectal perforation and pneumoperitoneum (Fonkalsrud, & Clatsworthy, 1965; Greenbaum, Carson, Kincannon, & O'Loughlin, 1969; Merenstein, 1970; Horwitz, & Bennett, 1976; Frank, & Brown, 1978). Although prevalence is low, reported mortality rates from 40 to 70% emphasize the seriousness of the problem. The reason for this injury appears to be that, anatomically, the neonate's bowel makes a fairly sharp curve posteriorly, about 2 cm from the sphincter. Introduction of a thermometer beyond this point risks perforation of the bowel. Current practice in many nurseries is to restrict or prohibit rectal temperature-taking.

Intermittent electronic thermometers were introduced in the early seventies as an alternative to mercury-in-glass thermometers. A thermistor or thermocouple sensor in the probe produces electrical signals that vary with changes in temperature. The advantages are speed of operation, portability, and availability for a number of sites. Disadvantages are the potential for cross-contamination when the unit is moved from bedside to bedside, and cost of the probe covers.

When rectal and axilla temperatures of term infants were measured with glass and electronic thermometers, rectal temperatures were found to be .5 degrees F. higher than axilla with both instruments (Eoff, Meier, & Miller, 1974). The temperature readings, glass compared to electronic, were significantly different with large standard deviations, but because a core temperature reading was unavailable, it was impossible to determine which was more accurate.

Tympanic thermometers consist of an otoscope-like probe that houses an infrared-sensing device, and a base containing microprocessor circuitry and calibration mechanisms. The sensor gathers emitted infrared energy, mainly from the tympanic membrane.

The procedure takes about one second. The equipment has the capability of adjusting the tympanic temperature (by adding a constant) so that a reading is given for oral, rectal, or core sites. It can also report the actual temperature reading without conversion.

Two early studies with tympanic thermistor probes in neonates demonstrated higher tympanic temperatures than those obtained from either the esophagus or rectum (Stratton, 1977; Mayfield, Nakamura, Bhatia, Rios, & Bell, 1984). When a small group of term and preterm infants had temperature measured using the Thermoscan tympanic thermometer and the IVAC electronic thermometer, a greater correlation was found between axilla and tympanic temperatures for the fullterm group compared to the preterm group, and for the right tympanic than for left tympanic temperatures (Weiss, 1991). The type of bed the infants were in was not indicated. Finding from another study (Johnson, Bhatia, & Bell, 1991) indicated no difference between tympanic readings obtained from both ears. The researchers concluded that temperature could be taken from the accessible ear without consequence to the measurement.

Although research on adults has indicated that environment affects tympanic temperature measures

(Sellars, & Yoder, 1961; Nadel, & Horvath, 1970; Marcus, 1973a; Marcus, 1973b), studies have not been conducted with neonates.

Research related to temperature measurement in neonates, especially preterm infants, is limited. The effect of a warmer's radiant heat on tympanic temperature measurements has not been explored. Moreover, the effect of an incubator's circulating heat upon temperature measures, is unknown also. As well, the use of a core temperature measurement, which could be used to define the accuracy of other temperature measurements, has been inconsistent.

It is critical that measurements with thermometers accurately reflect the internal temperature of the neonate so that negative sequelae related to the loss of a neutral thermal environment can be prevented. It has been shown that core temperature changes, as little as 0.5 degrees centigrade, can have a negative impact on the neonate's ability to cope with metabolic demands (Baumgart, 1991).

The purpose of this study was to determine the accuracy of temperatures measured with glass, electronic, and tympanic thermometers used with neonates nursed under a radiant warmer and in an incubator in the Neonatal Intensive Care Unit. The specific research questions addressed in this study were:

1. What is the agreement of each of the temperature measures to the core temperature measures?
2. What is the relationship of each of the temperature measures to the other measures?
3. Which is the most accurate method of temperature measurement in each of the environments, radiant warmer or incubator?

Method

Sample and Setting. A convenience sample was obtained consisting of 50 infants admitted to one of two Neonatal Intensive Care Units in a large urban center. One unit consists of 40 beds, separated into Levels I, II, and III, which designated intensive, intermediate, and observation or convalescent areas, respectively. The second unit has 56 beds separated into the three levels.

Infants admitted to these NICU who are low or very low birthweight (less than 1500 g) and/or critically ill neonates who require close observation and multiple interventions, including mechanical ventilation, are initially placed under a radiant warmer. When their condition stabilizes, they are transferred to incubators which continue to provide an external heat source to maintain their temperatures. Infants are nursed in this environment until they are able to maintain their body temperature without a direct external heat source. The decision to move an infant to an incubator is based on the infant's condition following medical and nursing consultation.

The criteria for inclusion of infants in this study were:

1. remaining under a radiant warmer at the time of enrollment,
2. up to 7 days old,
3. not receiving greater than 75% inspired oxygen,
4. within 30 minutes prior to data collection:
   a) no increase in inspired oxygen greater than 10%,
   b) no increase or decrease in the mean blood pressure,
   c) no fluid bolus requirements related to a low blood pressure, and
5. parental informed consent.

The criteria for exclusion were:

1. evidence of necrotising enterocolitis,
2. history of blood in the stools,
3. major congenital anomalies,

4. on strict isolation, and
5. a candidate for, or on, the Extracorporeal Membrane Oxygenation (ECMO) program.

Instruments. Four types of thermometers were used in this study. Before the study was commenced, all thermometers except the tympanic were tested for accuracy by dipping them into a well-stirred water bath with a temperature regulated to .01 degrees centigrade. Only glass thermometers found to be within .1 degree centigrade from the water temperature were used in the study.

1. Becton-Dickinson Mercury-in-Glass Thermometers.

These thermometers can measure temperatures in the range from 34 to 41 degrees centigrade. They were guaranteed accurate by the manufacturer to 0.1 degree centigrade.

2. IVAC 2080A Electronic Thermometer.

The electronic thermometer has the capability of measuring temperatures from 26.7 to 42.2 degrees centigrade, with accuracy to 0.1 degrees centigrade. Two probes were used in this study, one for axilla and one for rectal temperature measurement. The thermometer was used in the predictive mode which measures the initial rate of temperature change and displays a predicted final temperature extrapolated from a standard temperature-versus-time curve. The calibration of the IVAC was done by a hospital technician who used the calibration tester provided by the manufacturer.

3. The FirstTemp Genius 3000A (Intelligent Medical Systems).

This tympanic thermometer has a temperature-reading range of 21.1 to 43.3 degree centigrade, with accuracy to 0.1 degrees centigrade. The FirstTemp has five modes of operation available: tympanic, core, rectal, oral, and calibration. It can be used to measure the temperature of the tympanic membrane, and the skin surface. When a tympanic temperature is taken, one of five modes can be selected (tympanic, core, rectal, oral, or calibration). The digital reading will then be the tympanic measurement converted to the equivalent of the mode selected. The calibration mode displays the absolute temperature reading without this conversion. For the purposes of this study, FirstTemp was operated in the calibration mode and in the core mode.

Although the FirstTemp has an internal calibrator, it was also tested with manufacturer-provided calibration equipment at the start of the data collection period, weekly for four weeks, then monthly until the end of the study. This protocol was recommended by the manufacturer of FirstTemp.

4. Hi-Lo Temp Continuous Electronic Thermometer (Mallinckrodt Inc.).

This thermometer has the capability to measure from 0 to 50 degrees centigrade with an accuracy to 0.1 degree centigrade. Calibration and accuracy-testing was done at the beginning and at the end of the study according to manufacturer specifications by a hospital technician.

Procedure. Each NICU was contacted in person or by telephone on a daily basis to ascertain whether any infants who met the inclusion criteria had been admitted. The study was described to the parents of infants who met the criteria and informed consent was obtained (see Appendix B).

There were two temperature measurement sessions for each subject. The first session took place when the infant was under the radiant warmer and the second when the infant was in the incubator. Room temperature was measured at the beginning of both data collection sessions. It was recorded 30 to 50 cm from the infant's bed with the Hi-Lo thermometer. The temperature reading of the servo-control skin probe for the radiant warmer also was recorded during the first session. The incubator temperature was obtained in the second session by suspending the Hi-Lo thermometer 10 cm down from the top of the incubator, without opening any doors.

At the beginning of a session, the infant was prepared for temperature measurement, with minimal handling. If diapers were in place, these were removed. Two glass thermometers, two probe covers for the IVAC thermometer, and a #8 Mallinckrodt rectal probe were selected.

The temperature measures were taken using the following instruments at these sites: 1) glass thermometers, at the axilla and rectal sites, 2) intermittent electronic thermometer, at the axilla and rectal sites, and 3) electronic tympanic thermometer, at the tympanic site, using the calibration and core modes. A rectal probe was inserted at the beginning and end of each session of temperature measures to obtain two core rectal temperatures. Thus, a total of eight infant temperatures were recorded each session.

The Hi-Lo Temp continuous electronic thermometer was used to obtain the core rectal temperature. The probe was attached to the thermometer and lubricated. For infants weighing 1000 grams or less, it was inserted 2 cm. For infants weighing greater than 1000 grams, the probe was gradually advanced to a maximum of 5 cm. The probe reading was taken when the temperature reading had stabilized for one minute.

Rectal thermometers, both glass and electronic, were lubricated and inserted 1 cm for infants 1000 grams or less and 2 cm for infants greater than 1000 grams. The rectal thermometers were held in place for the required time: 5 minutes for glass, and until the electronic thermometer beeped and displayed the reading. The measurements were read twice for each instrument for verification.

Axillary temperatures were obtained by placing the glass thermometer or probe centrally in the most accessible axilla and gently supporting the infant's arm next to the body, leaving it in place for five minutes.

Tympanic measures were taken by supporting the infant's head, gently pulling the pinna of the most easily accessed ear outward until the auditory canal was visibly straightened. When the infant was side-lying, his/her position was not changed to do the tympanic measure. If the infant was back-lying, either the right or the left ear was selected. The choice of ear was alternated for back-lying infants.

The probe was placed firmly on the external meatus and the scan button depressed. It was held in place until beeps sounded and a reading appeared. Two FirstTemp tympanic thermometers were used, one in the calibration mode and the other in the core mode. The mode which was selected first was alternated from infant to infant.

When the measures were completed, the infant was diapered, if appropriate. The nurse who was caring for the infant was informed about the infant's temperature.

The sequences of temperature measures to be done during the radiant warmer and incubator sessions were systematically varied. Two sequences of temperature measures were planned which minimized handling of the infant. Half the subjects started with one sequence in the radiant warmer and switched to the other sequence in the incubator. The other half of the subjects received the opposite sequence.

The sequences were:

Sequence I. Core temperature, then glass thermometer (rectal), then glass thermometer (axilla), then electronic thermometer (axilla), then electronic thermometer (rectal), then tympanic (calibration and core modes), and finally, a core temperature.

Sequence II. Core temperature, then electronic thermometer (rectal), then tympanic (calibration and core modes), then glass thermometer (rectal), then glass thermometer (axilla), then electronic thermometer (axilla), and finally, a core temperature.

The first infant was randomly assigned to sequence I. The sequence was alternated for all infants thereafter. The timing and patterns of the measures are depicted in Figure 1.

The following data were also collected: date of birth, birthweight, gestational age, and current weight. The gestational age was that number recorded on the infant's history, as determined by the neonatologist.

Design. A descriptive design was employed to examine three temperature measurement instruments (glass thermometers, the IVAC 2080A electronic, the FirstTemp Genius tympanic), used in two infant environments

Figure 1

Sequences of Temperature Measures for Two Sessions

	Sequence I	Sequence II
Radiant warmer	Core rectal	Core rectal
	5 minutes*	5 minutes
	Glass rectal	Electronic rectal
	5 minutes	20 seconds
	Glass axilla	Tympanic(calibration)
	5 minutes	5 seconds
	Electronic axilla	Tympanic(core)
	20 seconds	5 seconds
	Electronic rectal	Glass rectal
	20 seconds	5 minutes
	Tympanic(core)	Glass axilla
	5 seconds	5 minutes
	Tympanic(calibration)	Electronic axilla
	5 seconds	20 seconds
	Core rectal	Core rectal
	5 minutes	5 minutes
Incubator	Core rectal	Core rectal
	5 minutes	5 minutes
	Electronic rectal	Glass rectal
	20 seconds	5 minutes
	Tympanic(core)	Glass axilla
	5 seconds	5 minutes
	Tympanic(calibration)	Electronic axilla
	5 seconds	20 seconds
	Glass rectal	Electronic rectal
	5 minutes	20 seconds
	Glass axilla	Tympanic(calibration)
	5 minutes	5 seconds
	Electronic axilla	Tympanic(core)
	20 seconds	5 seconds
	Core rectal	Core rectal
	5 minutes	5 minutes

* Duration of time thermometer in place before temperature was recorded.

(radiant warmer, incubator). Repeated measures were taken on infants for each temperature measure and both environments.

Results

Preparation of Data for Analyses. The data were coded, entered for computer analysis, and examined for coding and entry errors. One extreme low electronic rectal temperature taken in sequence I in the incubator was not included in data analyses as the reading appeared to be incorrectly recorded. All variables were examined to determine the nature of their distributions.

The mean of the core temperature was computed for each session. This was achieved by calculating the mean of the core temperatures obtained from each infant at the start and end of each temperature measurement session. The resulting mean core temperatures for radiant warmer and incubator were used in analyses involving the core temperature.

Subject Characteristics. A convenience sample of 58 infants admitted to NICU was obtained during the period of March to August, 1992. Eight infants were enrolled in the study but data collection only partially completed. These infants either were not moved to an incubator or were moved out of the incubator before data collection could be completed. Data from these

Table 1

Sample Characteristics

	Mean	S.D.	Range
Gestational age (weeks)	32.6	4.9	24-42
Birthweight (grams)	2020	996	600-4115
Age (Radiant warmer) (days)	1.9	1.9	0-7
Weight (Radiant warmer) (grams)	2014	1004	660-3467
Age (Incubator) (days)	6.9	7.9	0-38
Weight (Incubator) (grams)	1987	1006	574-4020

Table 2

Mean Temperatures for Radiant Warmer Session

	Mean	S.D.	Range
Room temperature	24.7	.85	22.4-26.8
Skin probe	36.7	.47	35.5-37.4
Glass rectal	36.8	.50	35.6-38.1
Electronic rectal	36.9	.49	35.8-38.4
Glass axilla	37.0	.34	36.2-37.8
Electronic axilla	37.2	.39	36.3-38.0
Tympanic (calibration)	36.7	.51	35.3-37.9
Tympanic (core)	37.9	.55	36.5-39.0
Core (1)	36.9	.44	35.8-38.1
Core (2)	36.9	.46	35.7-38.0
Mean core	36.9	.44	35.7-38.0

Table 3
Mean Temperatures for Incubator Session

	Mean	S.D.	Range
Room temperature	24.4	.77	23.0-26.0
Incubator	33.4	2.12	29.7-38.8
Glass rectal	36.6	.45	35.6-37.5
Electronic rectal	36.9	.51	35.7-38.1
Glass axilla	36.8	.46	35.7-38.0
Electronic axilla	37.0	.40	36.0-37.8
Tympanic (calibration)	36.3	.46	35.3-37.4
Tympanic (core)	37.5	.55	36.2-38.6
Core (1)	36.8	.45	35.7-37.9
Core (2)	36.8	.44	35.7-37.9
Mean core	36.8	.44	35.7-37.9

infants were not included in the analyses.

The infants' gestational ages, birth weights and ages and weights at the time of the temperature measurements are presented in Table 1. Nine of the infants weighed less than 1000 grams at birth. The primary diagnoses included the following: prematurity, sepsis, hyaline membrane disease, transient tachypnea of the newborn, and diaphragmatic hernia.

Mean temperatures for the subjects in this study are presented in Tables 2 and 3. These are presented separately for the two environmental conditions.

Agreement Between Temperature Measures and the Core. Several analytical approaches were employed in the assessment of accuracy of the various thermometers compared with the core temperature. These included measures of association and assessment of agreement.

Pearson correlation coefficients were computed to determine strength and direction of association for each of seven temperature measures with the core temperature under the radiant warmer condition (the seventh temperature measure was that from the radiant warmer skin probe). Correlations were also computed for each of six temperature measures with the core temperature under the incubator condition (Table 4).

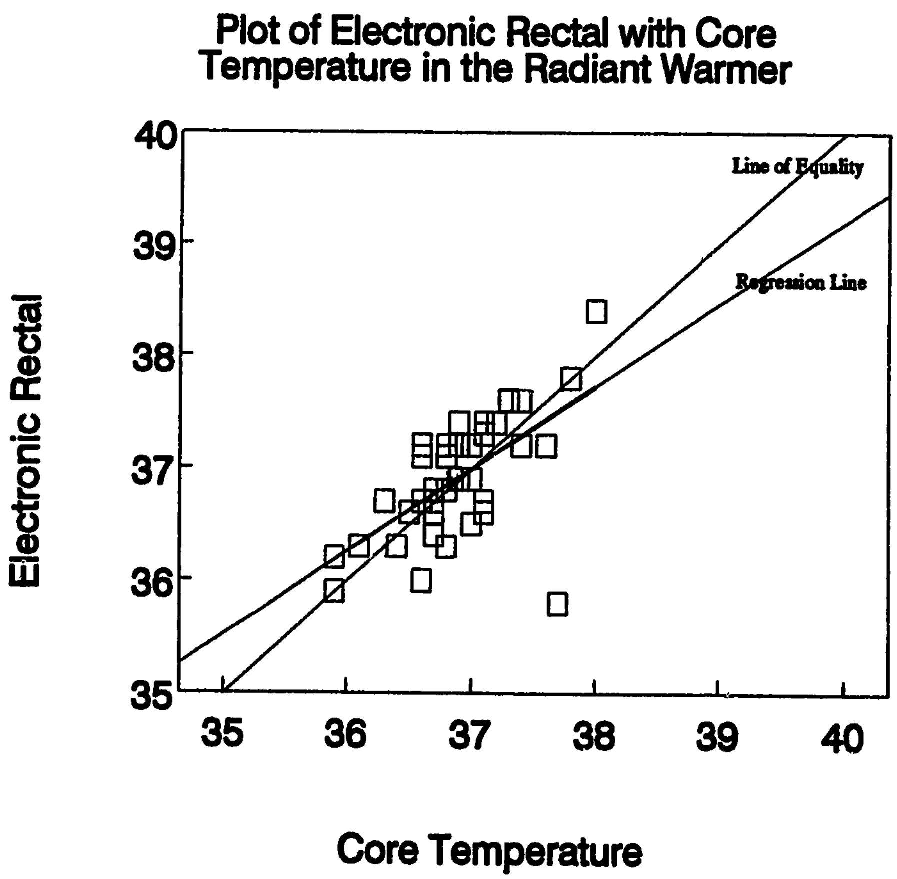
Table 4

Correlations of Each Temperature with the Mean Core in Two Environments

	With Mean Core in Radiant Warmer	With Mean Core in Incubator
Glass rectal	.80**	.82**
Electronic rectal	.80**	.82**
Glass axilla	.52**	.73**
Electronic axilla	.69**	.76**
Tympanic (calibration)	.53**	.60**
Tympanic (core)	.51**	.57**
Skin probe (radiant warmer)	.01	

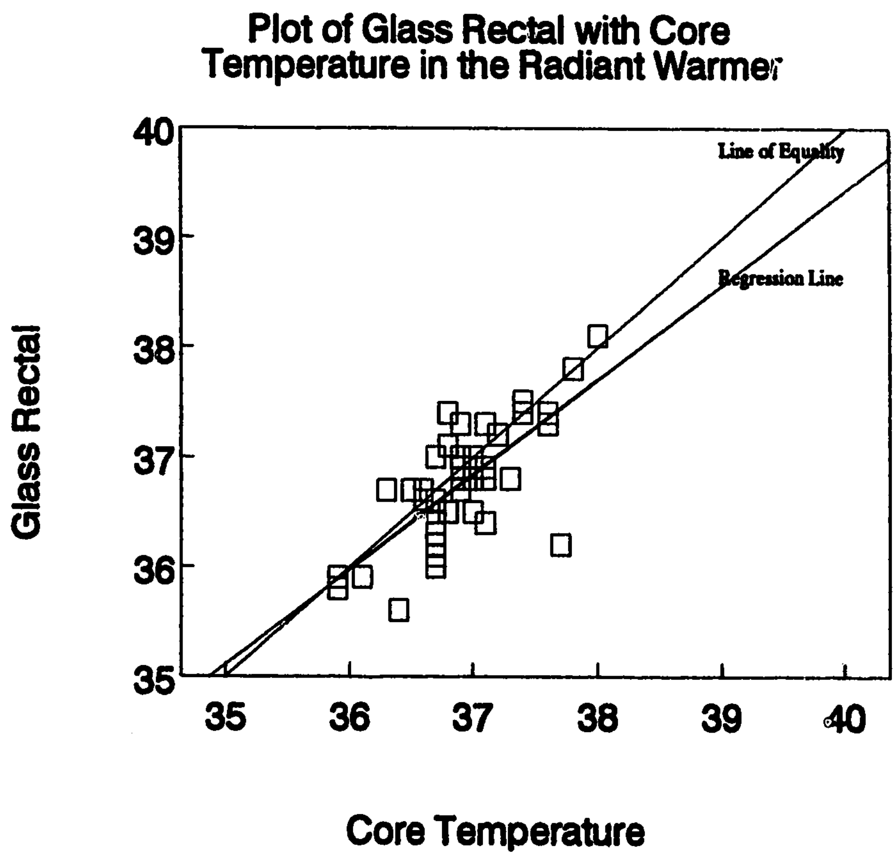
** $p \leq .01$

Figure 2



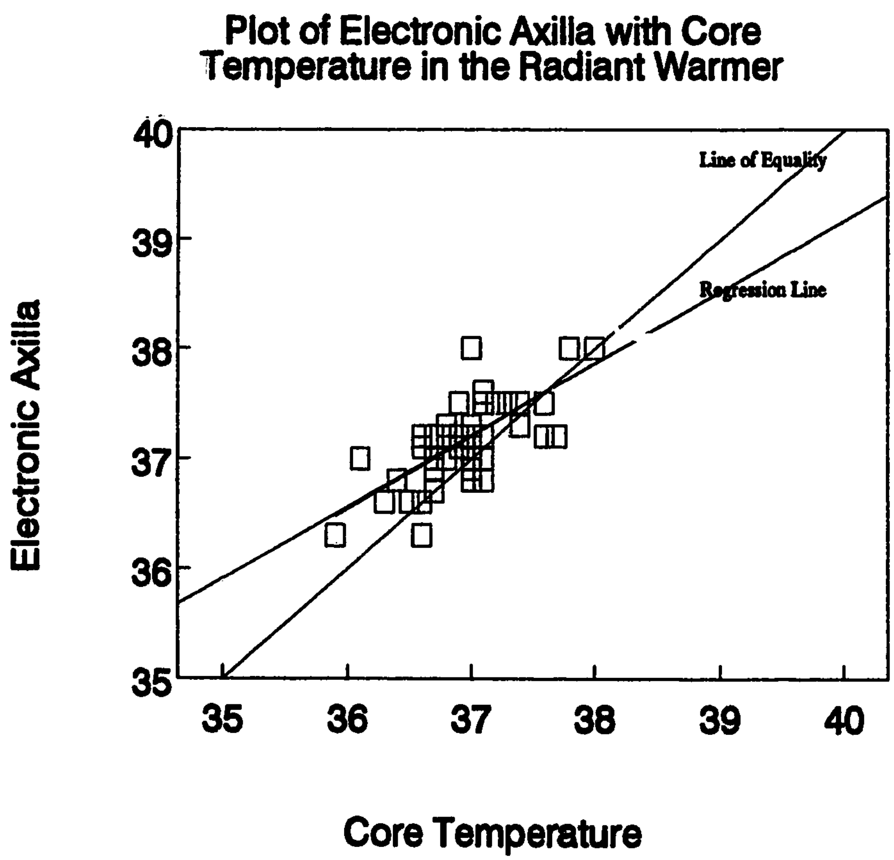
r .80
r-squared .64
S.E. Est. .30
Intercept (S.E.) 3.09 (3.59)
Slope (S.E.) .91 (.10)

Figure 3



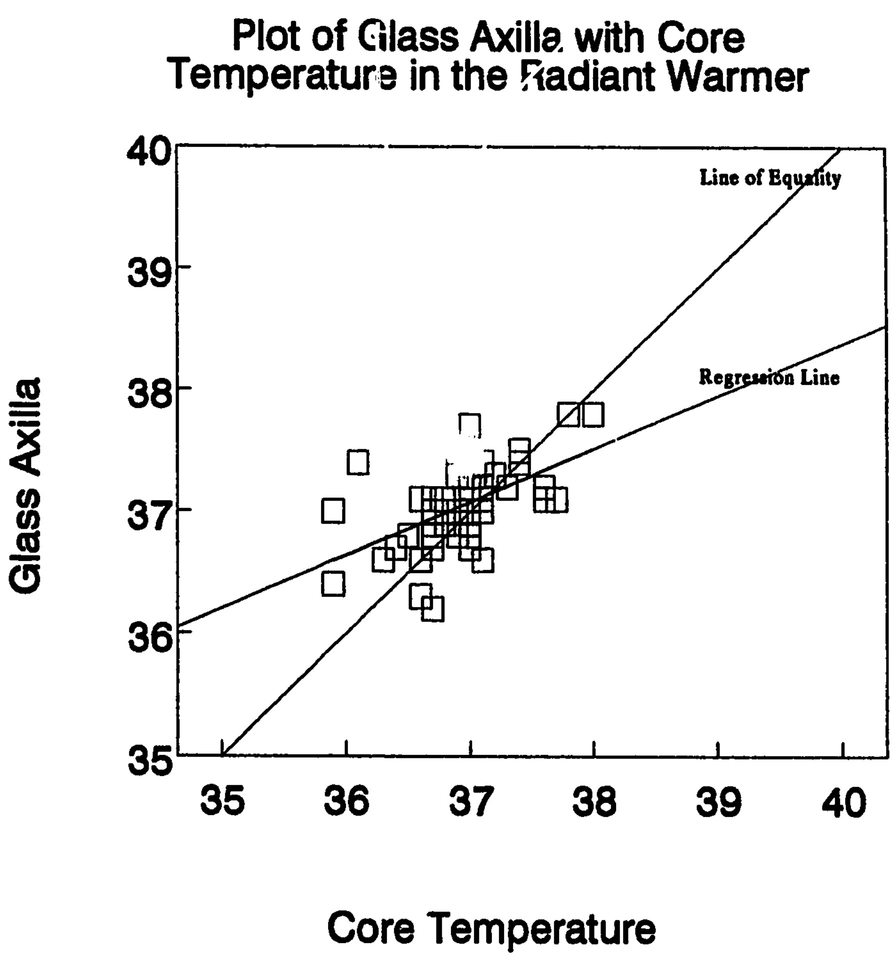
r .80
r-squared .65
S.E. Est. .30
Intercept (S.E.) 3.57 (3.55)
Slope (S.E.) .90 (.10)

Figure 4



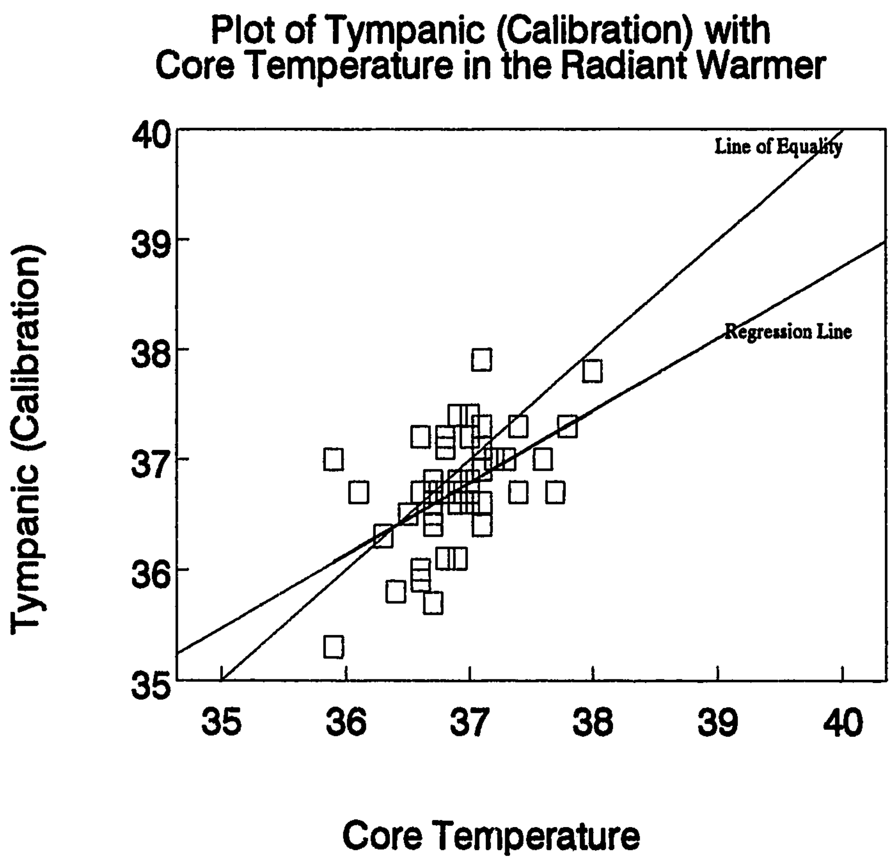
r .52
r-squared .27
S.E. Est. .30
Intercept (S.E.) 22.22 (3.52)
Slope (S.E.) .40 (.10)

Figure 5



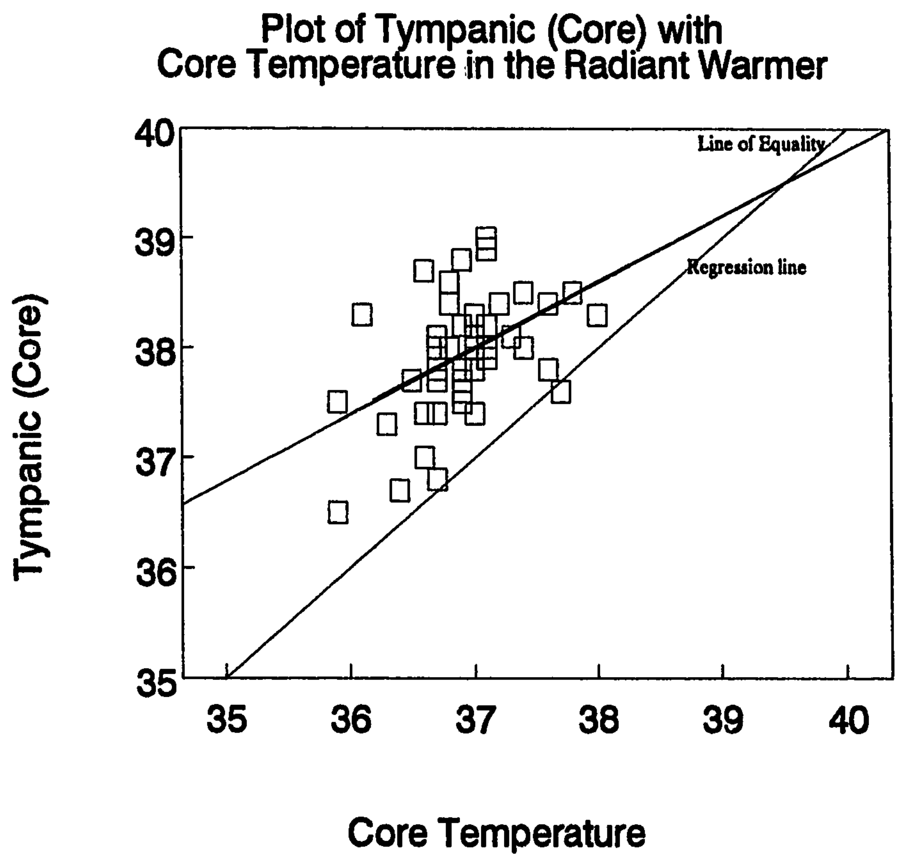
r .69
r-squared .48
S.E. Est. .28
Intercept (S.E.) 14.98 (3.35)
Slope (S.E.) .60 (.09)

Figure 6



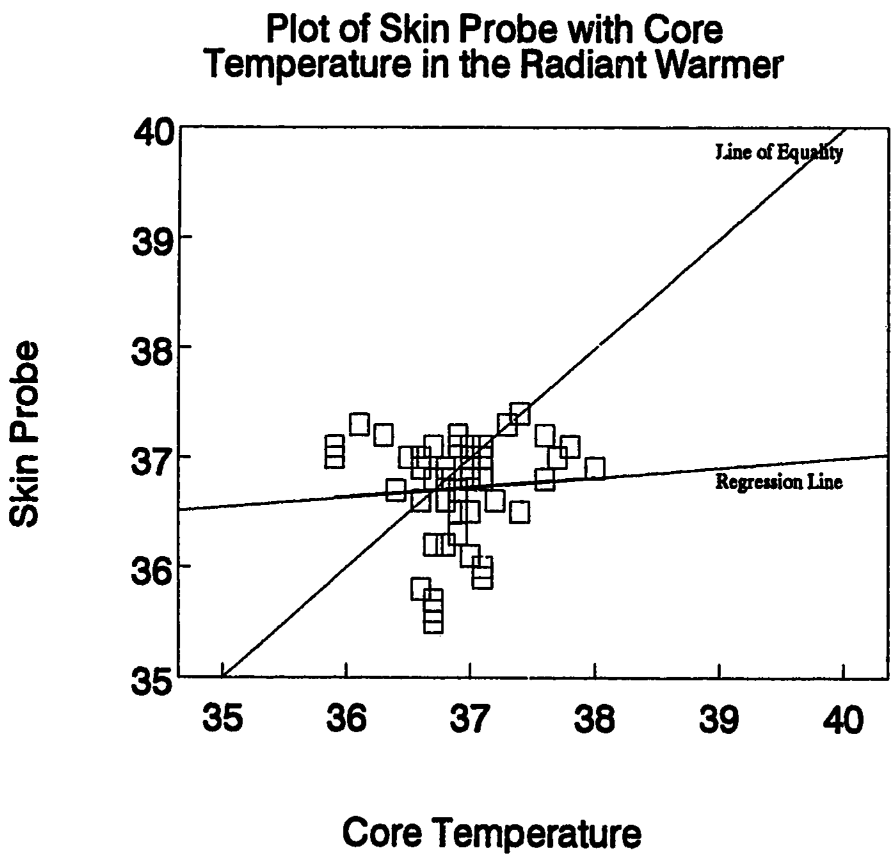
r .53
r-squared .28
S.E. Est. .44
Intercept (S.E.) 14.04 (5.19)
Slope (S.E.) .62 (.14)

Figure 7



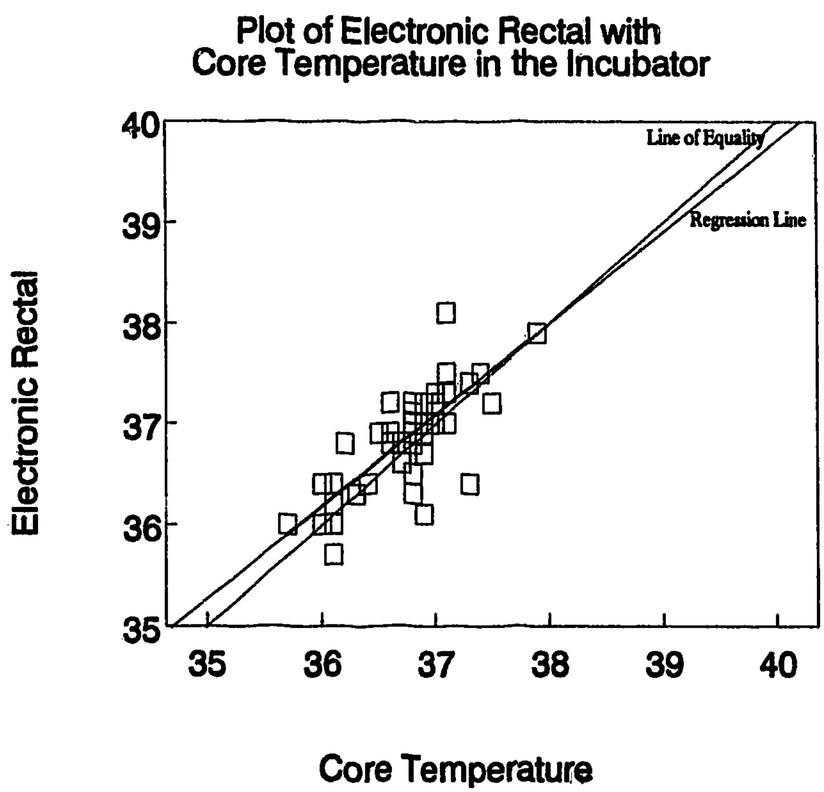
r .51
r-squared .26
S.E. Est. .48
Intercept (S.E.) 14.47 (5.75)
Slope (S.E.) .64 (.16)

Figure 8



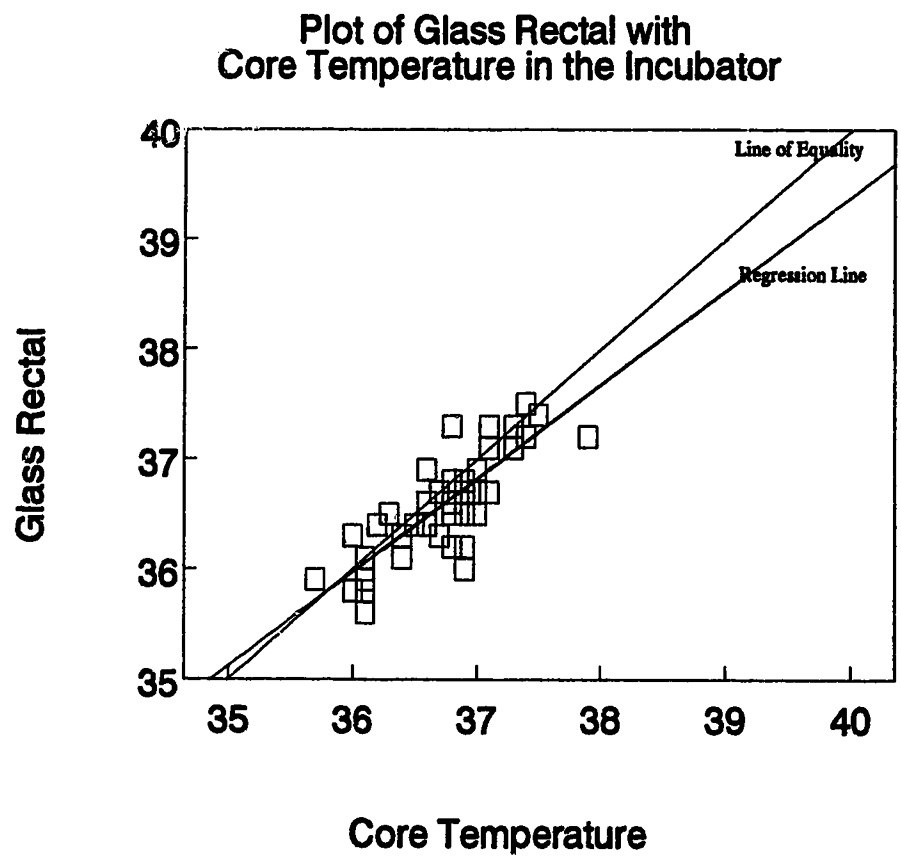
r .03
r-squared .00
S.E. Est. .47
Intercept (S.E.) 35.55 (5.65)
Slope (S.E.) .03 (.15)

Figure 9



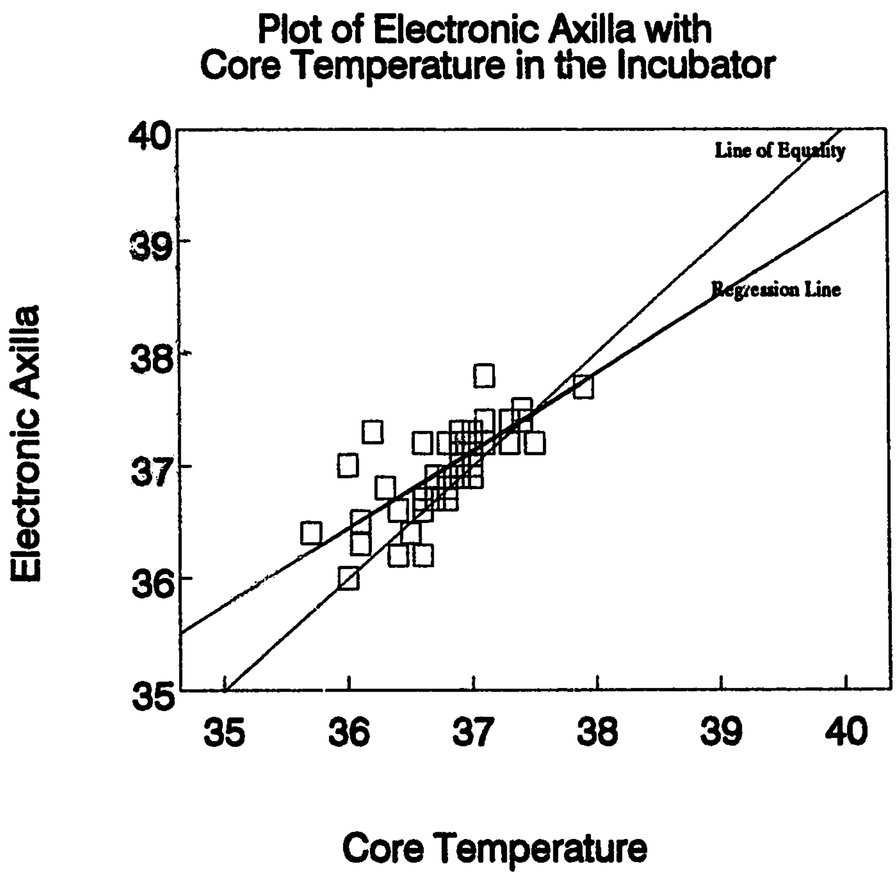
r .82
r-squared .67
S.E. Est. .26
Intercept (S.E.) 5.57 (3.13)
Slope (S.E.) .84 (.09)

Figure 10



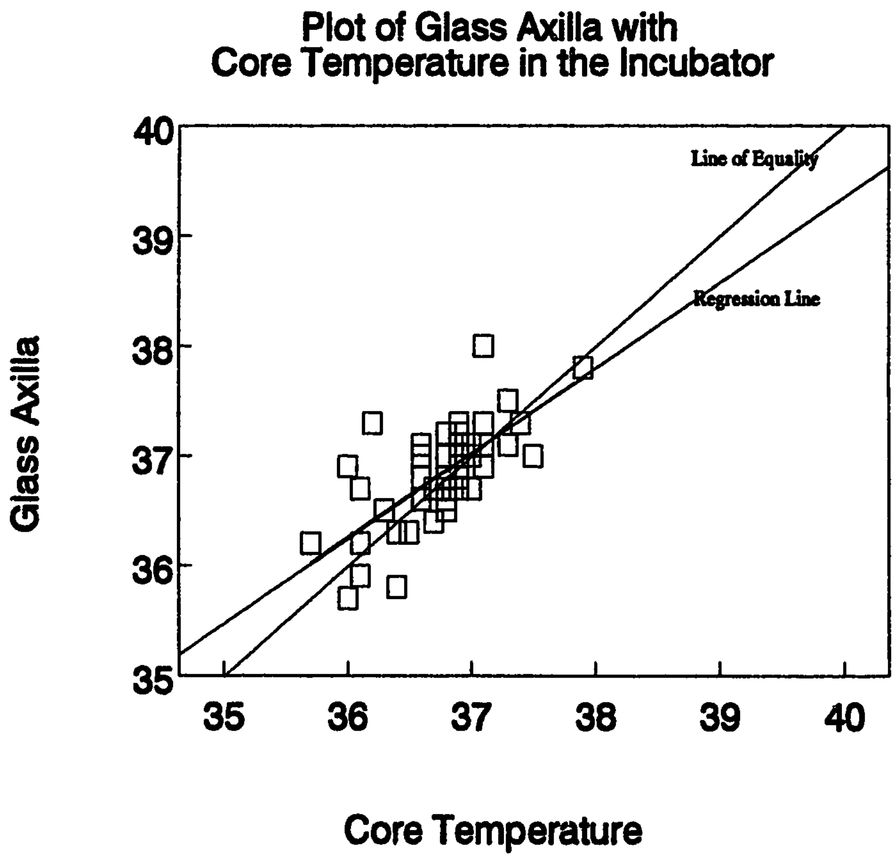
r .82
r-squared .67
S.E. Est. .30
Intercept (S.E.) 1.93 (3.61)
Slope (S.E.) .95 (.10)

Figure 11



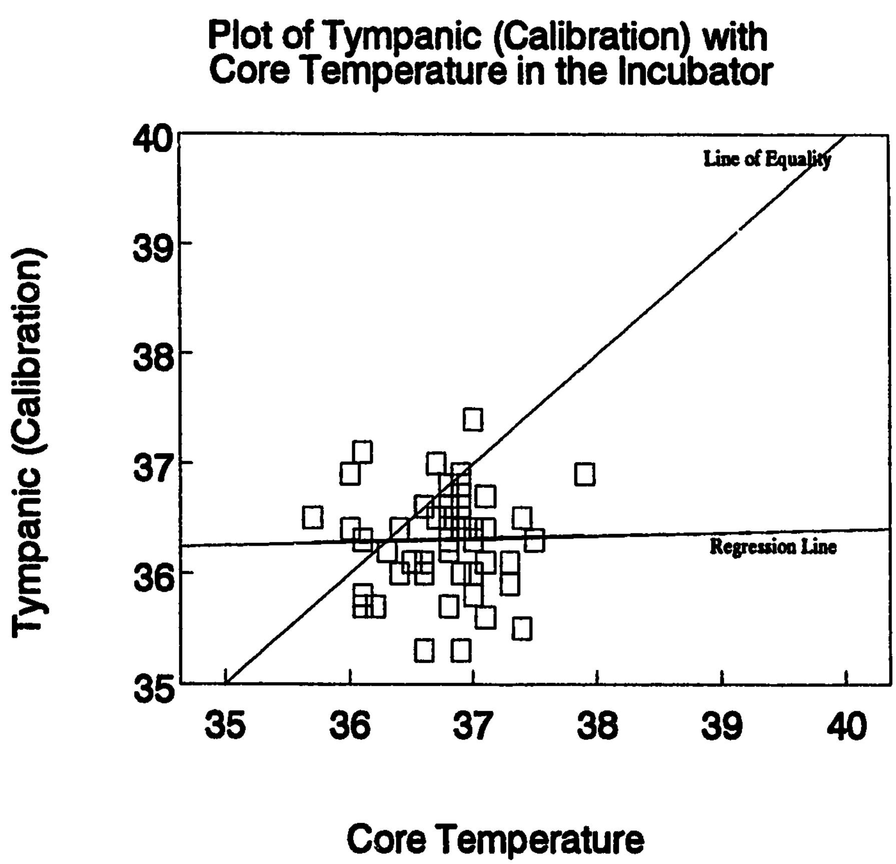
r .73
r-squared .53
S.E. Est. .32
Intercept (S.E.) 8.69 (3.86)
Slope (S.E.) .77 (.10)

Figure 12



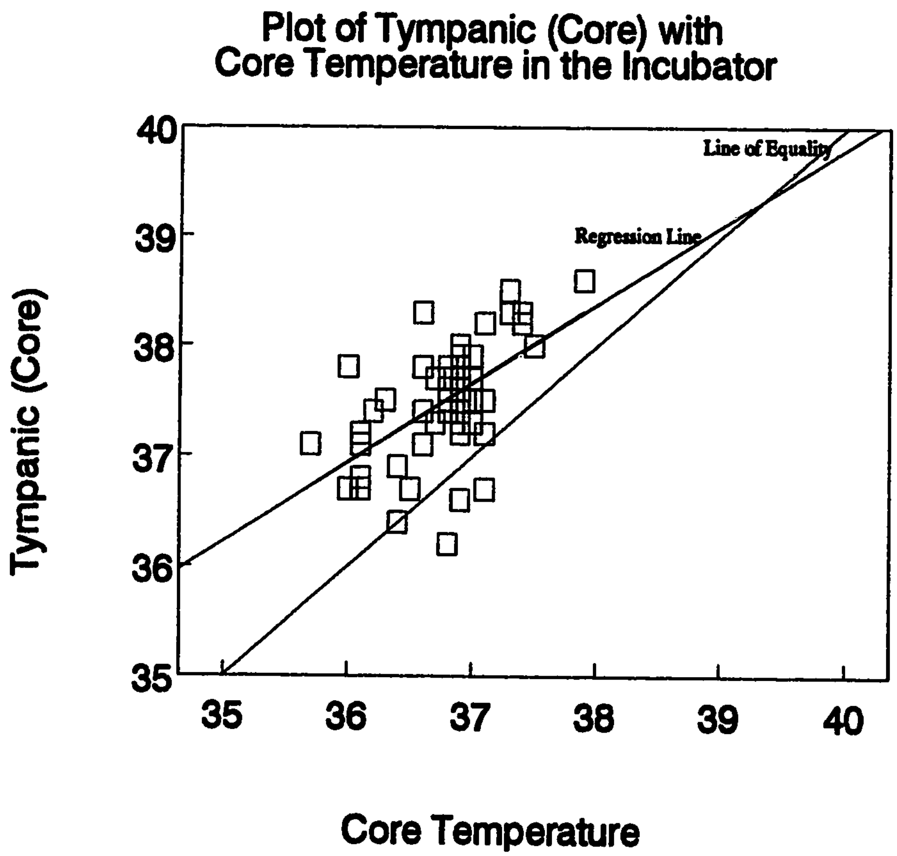
r .76
r-squared .58
S.E. Est. .26
Intercept (S.E.) 11.59 (3.12)
Slope (S.E.) .69 (.08)

Figure 13



r .60
r-squared .37
S.E. Est. .37
Intercept (S.E.) 12.69 (4.50)
Slope (S.E.) .64 (.12)

Figure 14



r .57
r-squared .32
S.E. Est. .46
Intercept (S.E.) 11.17 (5.49)
Slope (S.E.) .72 (.15)

The relationship between each set of variables was described in a series of 13 scatter diagrams. Figures 2 to 14 present the scatter diagrams, least squares regression line, slopes, and correlation coefficients.

The line of equality was drawn on each scatter diagram representing the relationship between core temperature and another measure of temperature (Figures 2 to 14). All data points would lie on this line if the two measures of temperature agreed for every subject. For temperatures recorded under the radiant warmer, the strongest positive relationships with the core temperature were obtained for glass rectal ($r=.80$, $p\leq.01$) and electronic rectal thermometers ($r=.80$, $p\leq.01$). For the incubator, the strongest positive relationships with core temperature were obtained for glass rectal ($r=.82$, $p\leq.01$) and electronic rectal thermometers ($r=.82$, $p\leq.01$).

Regression equations were determined for the seven temperatures in the radiant warmer environment and six temperatures in the incubator environment. These equations and their 95% confidence intervals are shown in Table 5. The regression equations can be used to predict core temperature based on any observed value of temperature obtained by the six methods under two environments. The confidence interval is a statement

Table 5

Regression Equations and Confidence Intervals for All Temperature Measures in Two Environments

	Regression Equation	Confidence Intervals
	Radiant Warmer	
Glass rectal	x = y-3.09/.91	y±.59
Electronic rectal	x = y-3.60/.90	y±.59
Glass axilla	x = y-22.22/.40	y±.59
Glass electronic	x = y-14.98/.60	y±.55
Tympanic (calibration)	x = y-14.04/.61	y±.86
Tympanic (core)	x = y-14.47/.63	y±.94
Skin probe	x = y-35.55/.03	y±.92
	Incubator	
Glass rectal	x = y-5.57/.84	y±.51
Electronic rectal	x = y-1.93/.95	y±.59
Glass axilla	x = y-8.69/.77	y±.63
Electronic axilla	x = y-11.59/.69	y±.51
Tympanic (calibration)	x = y-12.69/.64	y±.73
Tympanic (core)	x = y-11.17/.72	y±.90

of degree of confidence that the true equation lies in the specified interval.

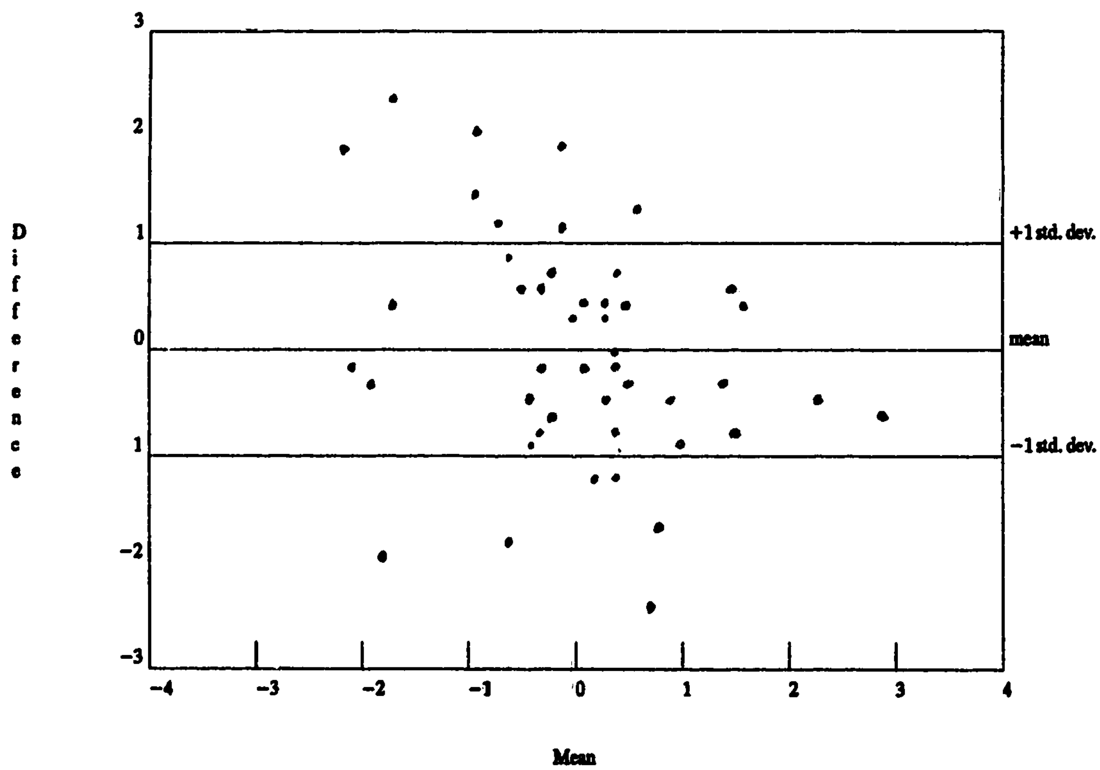
Since strong or weak measures of association do not necessarily reflect strong or weak agreement between measures, the approach recommended by Bland and Altman (1986) was also undertaken.

In order to determine the limits of agreement for the glass rectal thermometer with core temperature, the difference between the two temperatures was computed. The mean of the glass rectal and core temperatures was computed also. Both the difference score and the mean score were then converted to standardized scores. The standardized difference score was then plotted against the standardized mean temperature for all subjects. Last, the limits of agreement and confidence intervals were determined (formulae are located in Appendix C). This procedure was repeated for the remaining 12 temperature measures under the two environmental conditions. The 13 plots are presented in Figures 15 to 27. Horizontal lines have been drawn for zero difference and ± one standard deviation. The mean of the difference score, the limits of agreement and confidence intervals are presented in Tables 6 and 7 for the radiant warmer and incubator, respectively.

Figure 15

Plot of Difference 'Core - Glass Rectal' with

Mean 'Core and Glass Rectal' in the Radiant Warmer

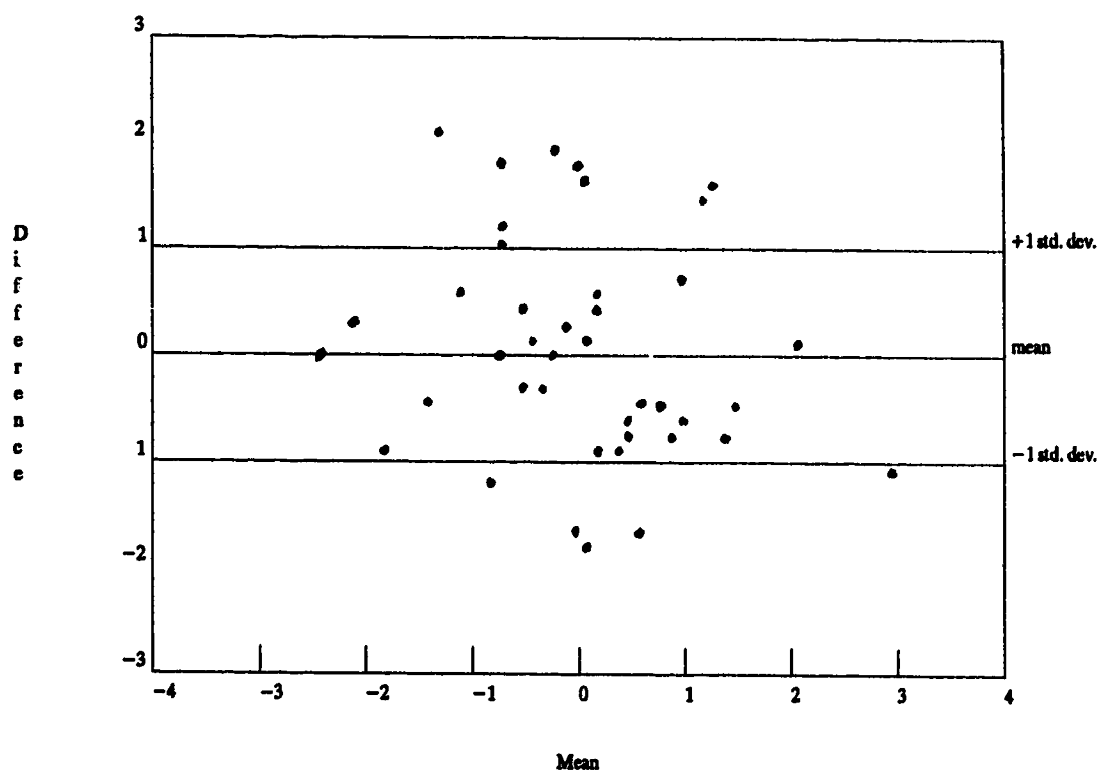


Mean of difference .13
S.D. .30
S.E. Mean .04
Range -.60 to .85

Figure 16

Plot of Difference 'Core - Electronic Rectal' with

Mean 'Core and Electronic Rectal' in the Radiant Warmer

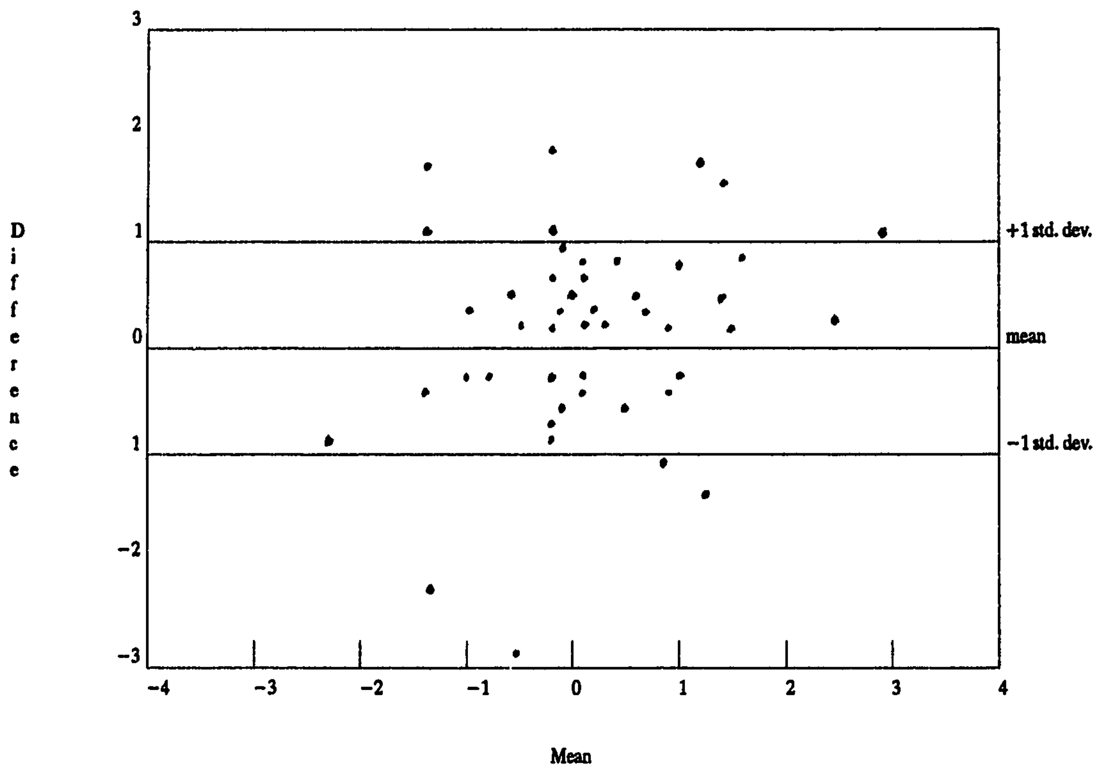


Mean of difference -.03
S.D. .30
S.E. Mean .04
Range -.55 to .60

Figure 17

Plot of Difference 'Core - Glass Axilla' with

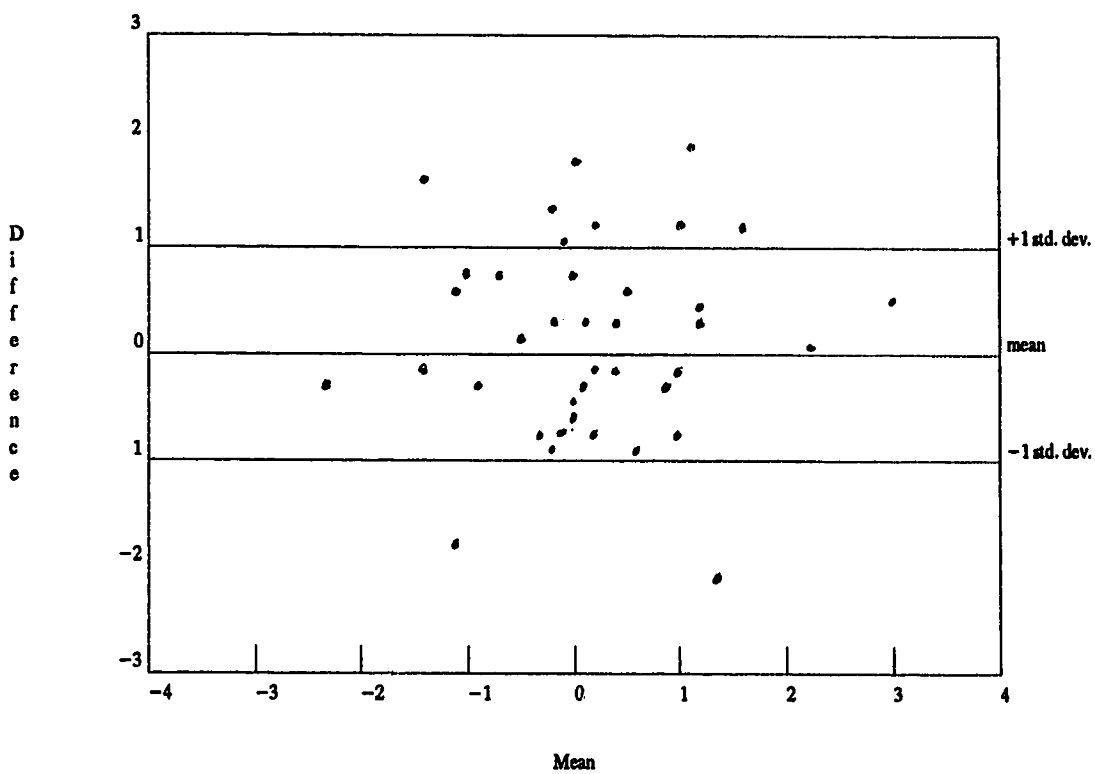
Mean 'Core and Glass Axilla' in the Radiant Warmer



Mean of Difference -.14
S.D. .39
S.E. Mean .06
Range -1.39 to .55

Figure 18

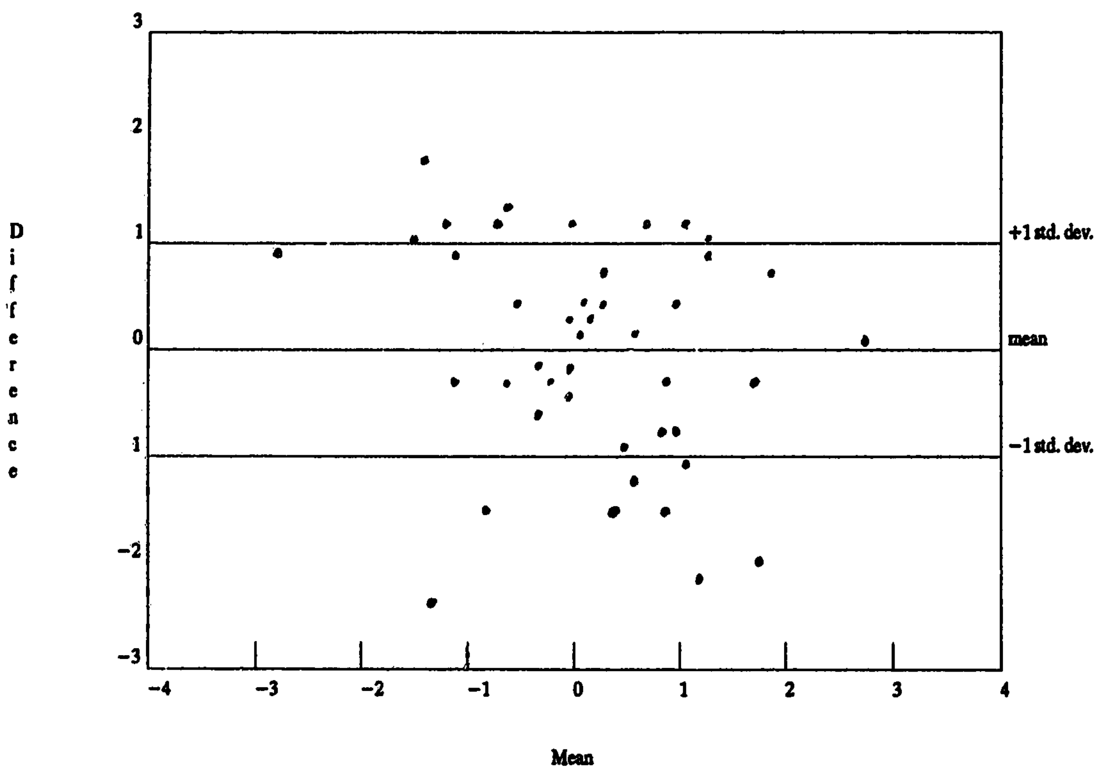
Plot of Difference 'Core - Electronic Axilla' with Mean 'Core and Electronic Axilla' in the Radiant Warmer



Mean of difference -.25
S.D. .33
S.E. Mean .05
Range -1.45 to .40

Figure 19

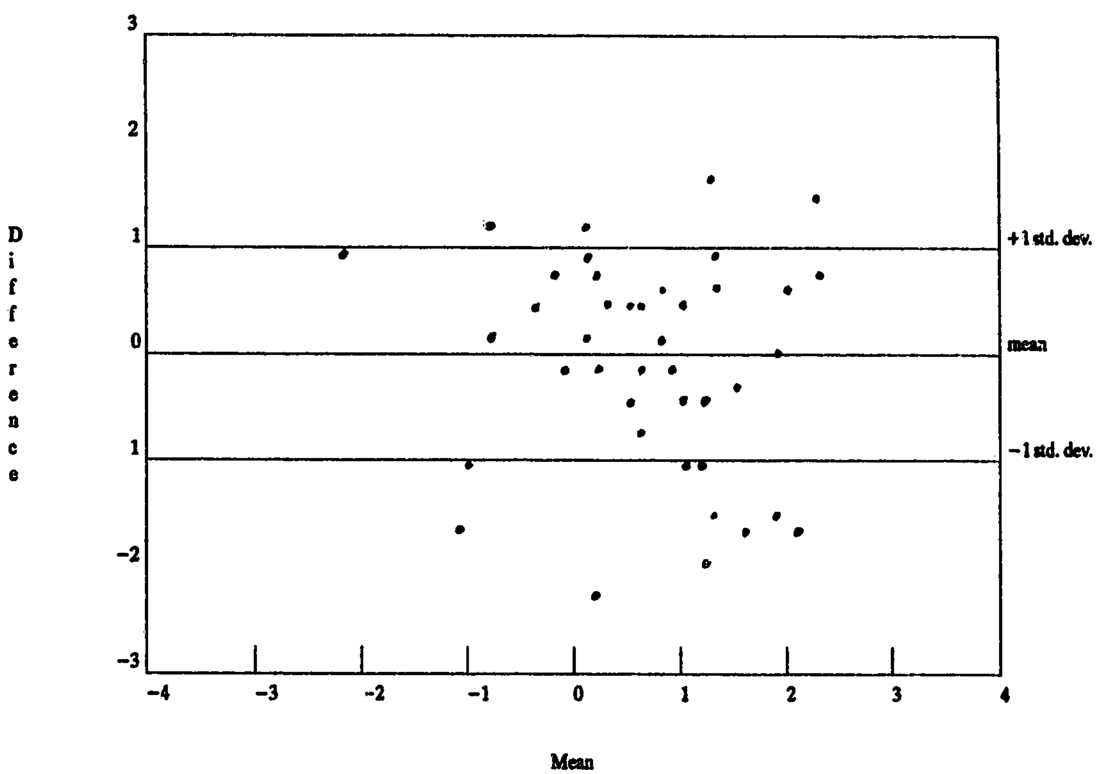
Plot of Difference 'Core - Tympanic (calibration)' with Mean 'Core and Tympanic (calibration) in the Radiant Warmer



Mean of Difference .17
S.D. .46
S.E. Mean .07
Range -1.05 to 1.00

Figure 20

Plot of Difference 'Core - Tympanic (core)' with Mean 'Core and Tympanic (core)' in the Radiant Warmer

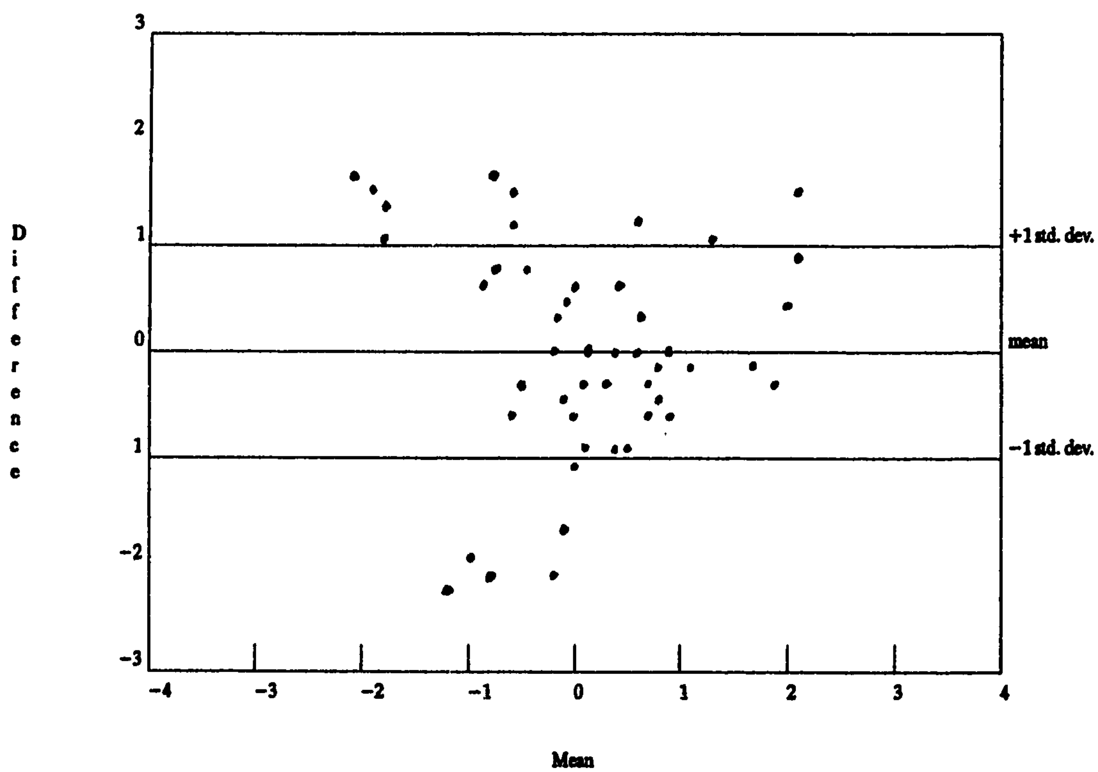


Mean of Difference -1.04
S.D. .50
S.E. Mean .07
Range -2.15 to -.10

Figure 21

Plot of Difference 'Core - Skin Probe' with

Mean 'Core and Skin Probe' in the Radiant Warmer

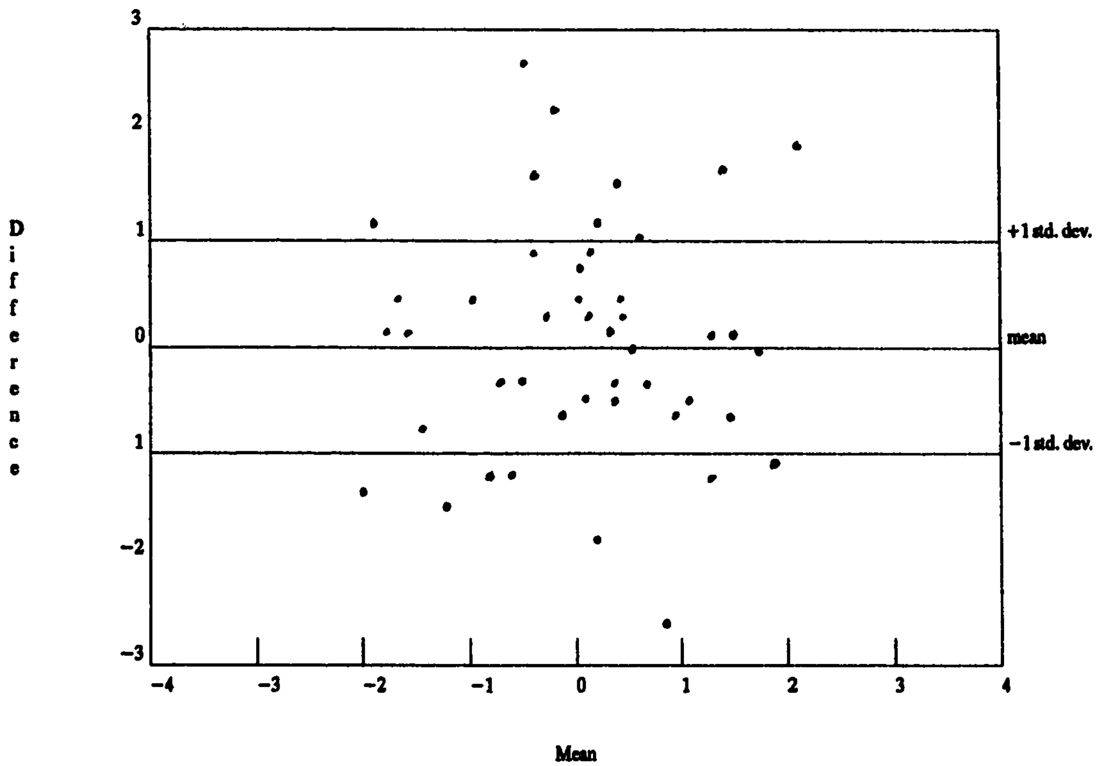


Mean of Difference .17
S.D. .64
S.E. Mean .09
Range -1.25 to 1.25

Figure 22

<u>Plot of Difference 'Core - Glass Rectal' with</u>

<u>Mean 'Core and Glass Rectal' in the Incubator</u>

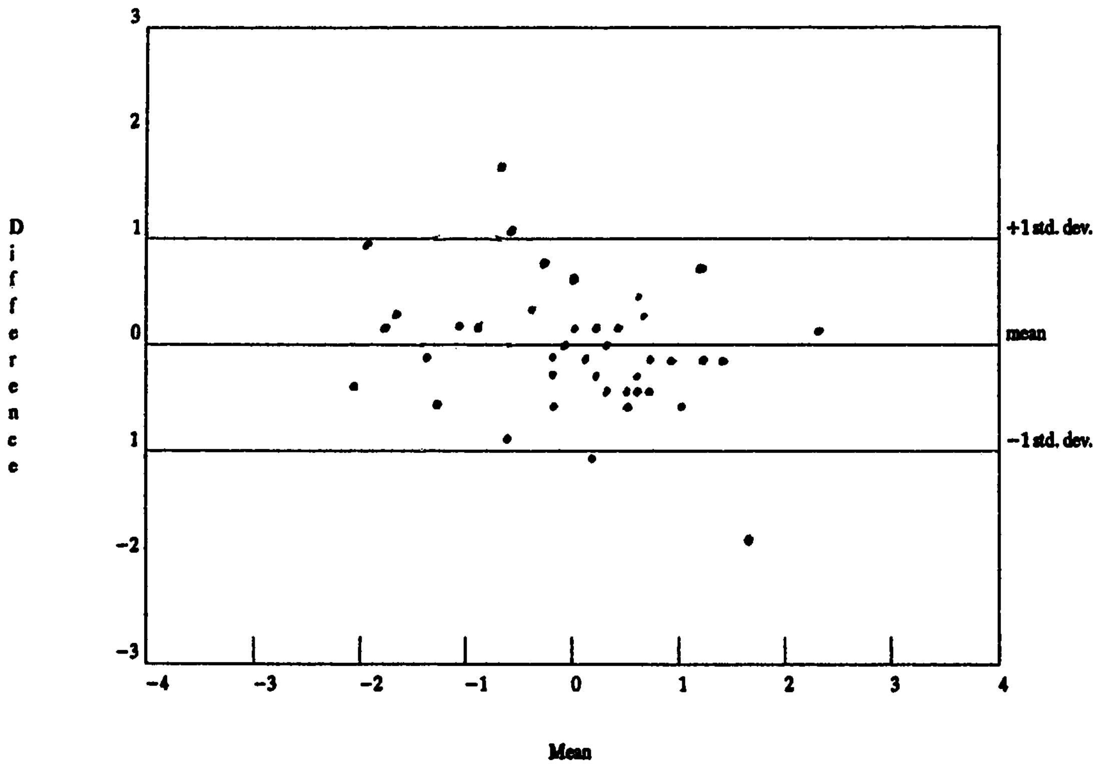


Mean of Difference .17
S.D. .27
S.E. Mean .04
Range -.50 to .90

Figure 23

Plot of Difference 'Core - Electronic Rectal' with

Mean 'Core and Electronic Rectal' in the Incubator

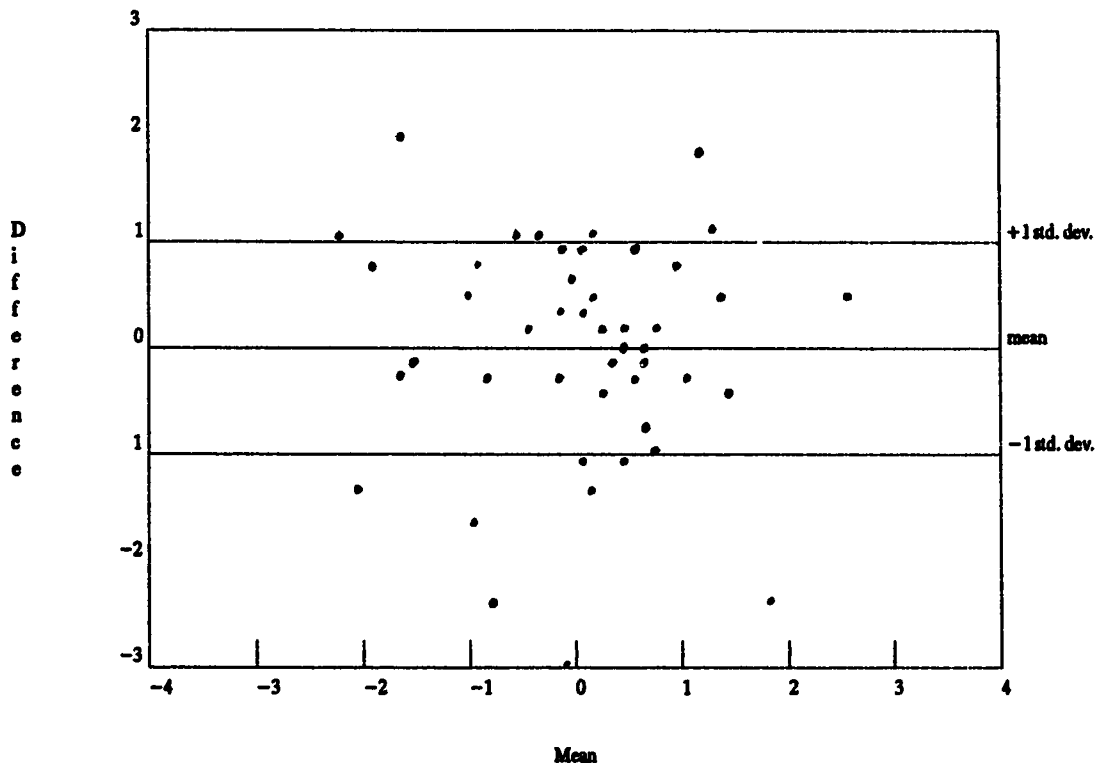


Mean of Difference -.11
S.D. .29
S.E. Mean .04
Range -.95 to .80

Figure 24

Plot of Difference 'Core - Glass Axilla' with

Mean 'Core and Glass Axilla' in the Incubator

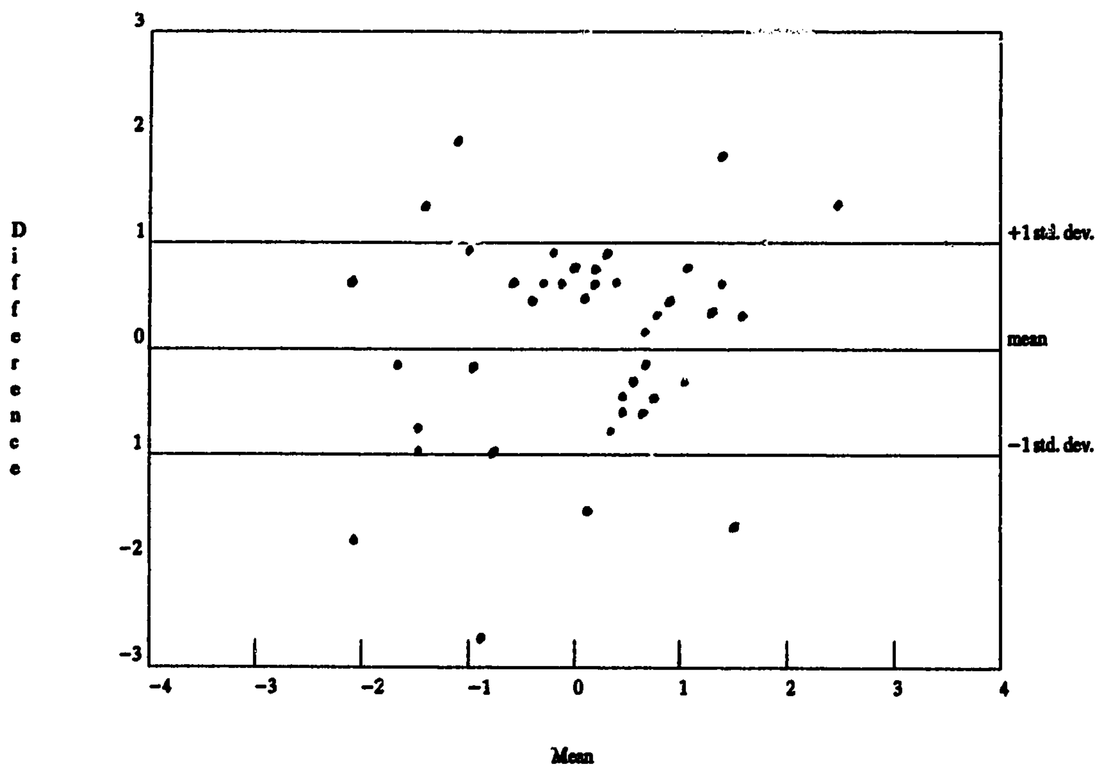


Mean of Difference -.06
S.D. .33
S.E. Mean .05
Range -1.05 to .60

Figure 25

Plot of Difference 'Core - Electronic Axilla' with

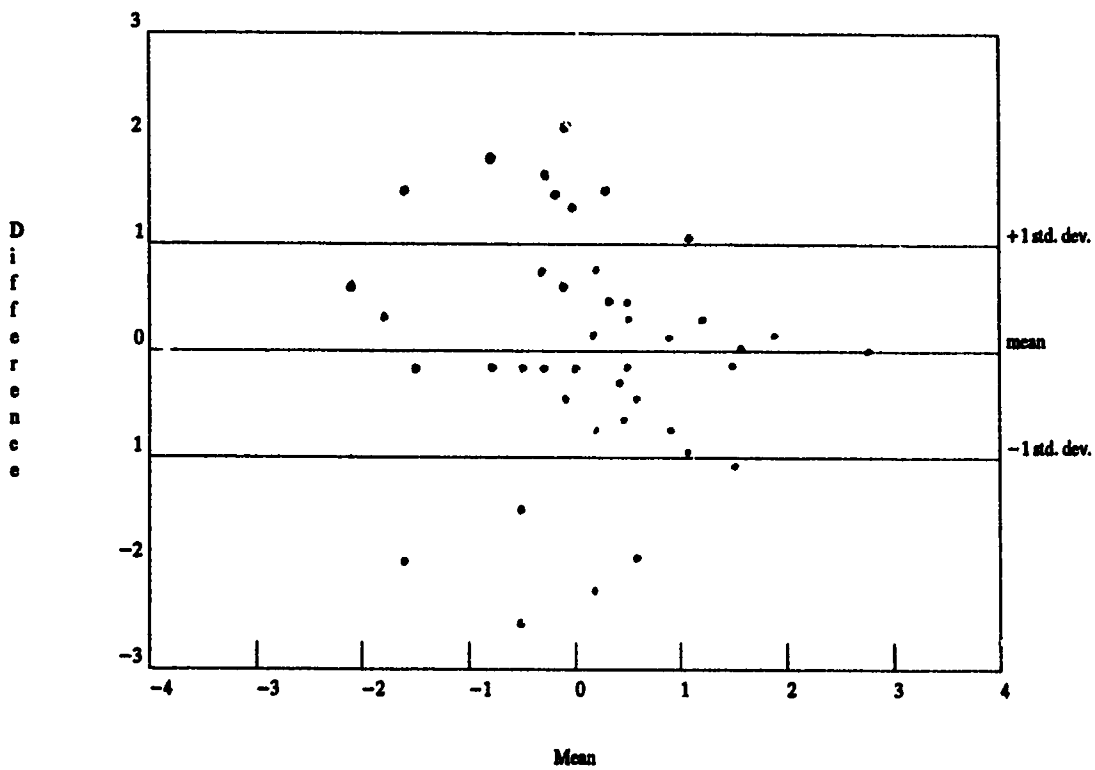
Mean 'Core and Electronic Axilla' in the Incubator



Mean of Difference -.18
S.D. .29
S.E. Mean .04
Range -1.05 to .40

Figure 26

Plot of Difference 'Core - Tympanic (calibration)' with Mean 'Core and Tympanic (calibration)' in the Incubator

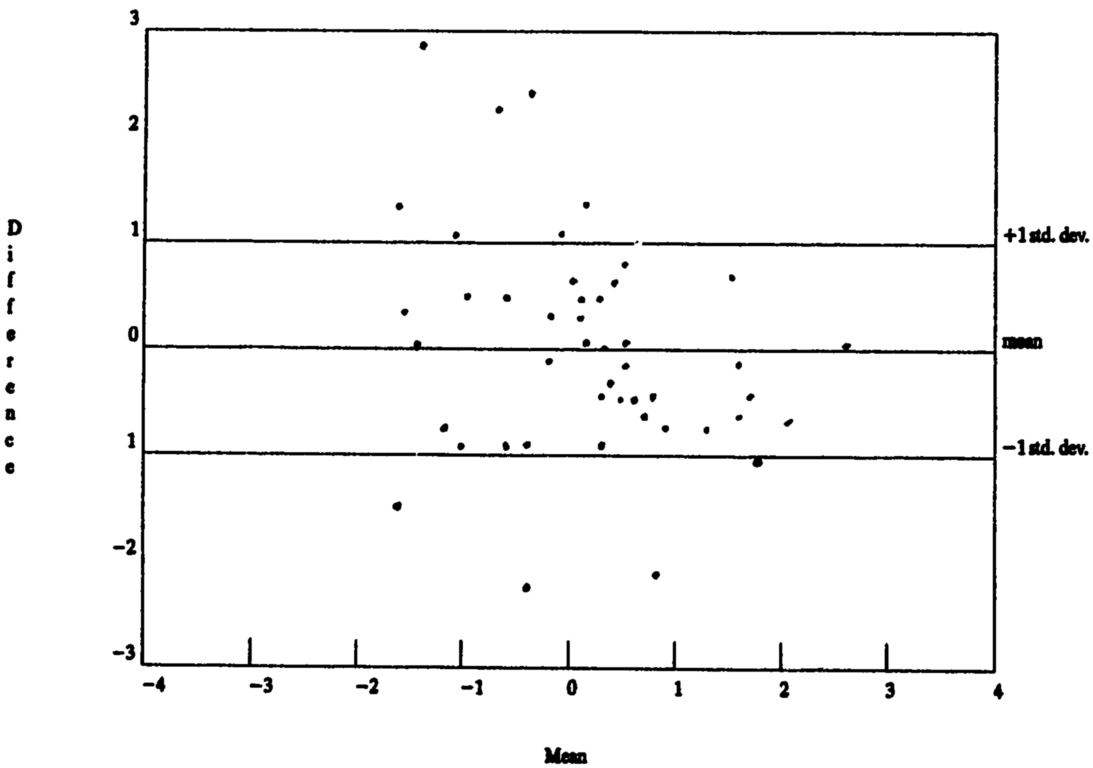


Mean of Difference .48
S.D. .40
S.E. Mean .06
Range -.55 to 1.30

Figure 27

Plot of Difference 'Core - Tympanic (core)' with

Mean 'Core and Tympanic (core)' in the Incubator



Mean of Difference -.71
S.D. .47
S.E. Mean .07
Range -1.75 to .60

Table 6

Mean Differences, Limits of Agreement and Confidence Intervals-Radiant Warmer

	Mean difference±SD	Limits of agreement	Confidence interval
Glass rectal	.13±.30		
-lower		-.47	-.62 to -.33
-upper		.73	.59 to .88
Electronic rectal	-.03±.30		
-lower		-.62	-.77 to -.48
-upper		.57	.43 to .71
Glass axilla	-.14±.39		
-lower		-.93	-1.12 to -.74
-upper		.65	.46 to .84
Electronic axilla	-.25±.33		
-lower		-.91	-1.07 to -.75
-upper		.41	.25 to .57
Tympanic (calibration)	.17±.46		
-lower		-.76	-.98 to -.54
-upper		1.09	.87 to 1.32
Tympanic (core)	-1.04±.50		
-lower		-2.05	-2.29 to -1.81
-upper		-.03	-.28 to .21
Skin probe	.17±.64		
-lower		-1.10	-1.40 to -.79
-upper		1.44	1.14 to 1.75

Table 7

Mean Differences, Limits of Agreement and Confidence Intervals-Incubator

	Mean difference±SD	Limits of agreement	Confidence interval
Glass rectal	.17±.27		
-lower		-.37	-.24 to -.50
-upper		.70	.57 to .83
Electronic rectal	-.11±.29		
-lower		-.70	-.56 to -.84
-upper		.47	.33 to .62
Glass axilla	-.06±.33		
-lower		-.72	-.88 to -.56
-upper		.61	.45 to .77
Electronic axilla	-.18±.29		
-lower		-.76	-.90 to -.62
-upper		.40	.26 to .54
Tympanic (calibration)	.48±.40		
-lower		-.33	-.52 to -.13
-upper		1.28	1.09 to 1.47
Tympanic (core)	-.71±.47		
-lower		-1.65	-1.87 to -1.42
-upper		.23	.00 to .45

The limits of agreement consisted of the mean difference score plus or minus two standard deviations. The narrower the computed limits of agreement and the closer the mean difference score to zero, the more the temperature measure agrees with the core temperature for the sample data and thus, the better the measure. The confidence intervals indicate that 95% of the time, with repeated samples, the limits of agreement will be within the specified boundaries.

The skin probe used in the radiant warmer recorded temperature from 1.1 degrees C. above to 1.4 degrees C. below the core temperature in the sample (Table 6). The confidence intervals indicate that this error could be less or substantially greater in repeated samples.

The glass rectal thermometer in the radiant warmer and incubator tended to measure temperature somewhat lower than core (Table 7). Temperatures were recorded at .7 degrees C. below and .5 degrees C. above core rectal in the radiant warmer and .7 degrees C. below and .4 degrees above in the incubator. Similar results were obtained with the electronic rectal thermometer in both environments.

The glass axilla thermometer, in both environments, recorded temperatures a little higher than the core temperature. The temperatures were recorded at .7 degrees C. below and .9 degrees above in the radiant warmer and .6 degrees below and .7 degrees above the core in the incubator. With the electronic axilla thermometer, similar results were obtained in both environments.

The tympanic thermometer in the calibration mode recorded temperatures from 1.1 degrees C. below to .8 degrees C. above the core in the radiant warmer and from 1.3 degrees C. below to .3 degrees C. above in the incubator. The confidence intervals show that this error could be considerably less or greater in repeated samples.

The tympanic thermometer in the core mode provided temperature readings above the core rectal temperature, from 2.0 degrees C. above to .1 degree C. above in the radiant warmer, and from .2 degrees C. below to 1.7 degrees above in the incubator.

In summary, for the radiant warmer, the limits of agreement were narrowest and equivalent for glass and electronic rectal measures. These were followed by the glass axilla and then electronic axilla measure. The limits of agreement were widest for tympanic measures and the skin probe.

For the incubator, the limits of agreement were

Table 8

Significant Correlations of All Measures in the Radiant Warmer

	Rectal Glass	Elect.	Axilla Glass	Elect.	Tympanic (cal)
Room temperature					.33*
Birthweight		.37**			
Electronic (Rectal)	.80**				
Glass (Rectal)	.51**	.40**			
Electronic (Axilla)	.60**	.54**	.82**		
Tympanic (calibration)	.43**	.29 *	.58**	.54**	
Tympanic (core)	.43**	.37**	.58**	.58**	

* $p \leq .05$
** $p \leq .01$

Table 9

Significant Correlations of All Measures in the Incubator

	Rectal Glass	Elect.	Axilla Glass	Elect.
Electronic (R)	.85**			
Glass (A)	.73**	.74**		
Electronic (A)	.71**	.74**	.87**	
Tympanic (calibration)	.62**	.57 *	.73**	.73**
Tympanic (core)	.63**	.53**	.74**	.72**

* $p \leq .05$
** $p \leq .01$

narrowest and equivalent for glass rectal, electronic rectal, and electronic axilla measures. These were followed by the glass axilla measure. As with the radiant warmer, the tympanic measures resulted in the widest limits of agreement.

<u>Interrelationships Among Measures</u>. Separate correlation matrices for significant correlations are presented for each environment (see Tables 8 and 9). For the radiant warmer, significant correlations range from .29 to .82, that is, from modest positive to strong positive. The strongest correlations were between the electronic rectal and glass rectal ($r=.80$, $p\leq.01$) and the electronic axilla and glass axilla ($r=.82$, $p\leq.01$).

For the incubator, significant correlations ranged from .27 to .87, again from modest positive to strong positive. The strongest correlations were between the electronic rectal and glass rectal ($r=.85$, $p\leq.01$).

In the radiant warmer, the gestational age was moderately positively correlated with the core temperature ($r=.52$, $p\leq.01$) and with the electronic rectal temperature ($r=.47$, $p\leq.01$). The gestational age of the baby was also moderately, negatively correlated with the temperature of the incubator ($r=-.43$, $p\leq.01$).

Discussion

In this study, it was determined that the temperature measurement methods with the best agreement to core rectal temperatures, obtained in both environments, were electronic and glass rectal. Electronic and glass rectal temperatures also had the strongest correlations with the core temperature. It should be noted, however, that even these best measures had limits of agreement wider than one degree centigrade. From a clinical perspective, this indicates that none of the thermometers provide a temperature reading that is close to the core temperature of the infant.

This study was based, in part, on the premise that the core temperature, as measured by a deep rectal probe, was the standard against which the other measures should be compared. The establishment of a neutral thermal environment relies on the ability of the infant, with external assistance, to maintain his/her core temperature with minimal metabolic requirements. While the other temperature measures had merit, it is their agreement with the core temperature which is important.

The tympanic thermometers and the radiant warmer skin probe, which are the least invasive types of thermometer, provided temperatures with poor agreement with the core rectal temperature. The literature has suggested that the tympanic membrane temperature could be affected by radiant heat sources (Marcus, 1973b). In this sample, the agreement of tympanic to core temperature was marginally better in the incubator. However, this was true for all other types of measures, as well.

From analysis of the limits of agreement and mean difference score, the tympanic thermometer (core mode) systematically recorded temperatures higher than the core. This may be related to the manufacturer's conversion formula, which is based on adult data. If the tympanic thermometer is used, the calibration mode offers the better agreement of the two modes, particularly in the incubator.

It would be possible for nurses to compute equivalent core temperatures, with the regression equations. Given the limits of agreement and confidence intervals, particularly for the tympanic thermometer and skin probes, there may be little to gain from this exercise. For example, a tympanic (core) reading of 37 degrees centigrade would indicate a core temperature of 35.6 degrees centigrade.

The lack of agreement among temperature measures may be the result of the wide ranges of the gestational ages and weights of the infants in this sample. Particularly for the axilla temperature measurements, there was a substantial difference between the axilla temperature and the core for five of the nine infants with gestational ages 24 to 28 weeks and birthweights from 600 to 1140 grams.

In fact, all infants, whose axilla temperatures were much higher than the core rectal, had low birthweight and gestational ages. This was observed for both glass and electronic thermometers, in both environments although more pronounced in the radiant warmer.

It has been postulated that the limited amount of subcutaneous fat and large surface-to-mass ratio of very low birthweight infants contributed to the small or absent temperature gradient between sites found in previous studies (Mayfield, Bhatia, et al., 1984; Johnson, et al., 1991; Khan, et al., 1990). The somewhat higher tympanic temperature, as measured by a thermistor probe, than deep rectal, in preterm infants, was attributed possibly to the servocontrolled, external heat sources of the radiant warmer and incubator (Mayfield, Nakamura, et al., 1984). Further research with larger numbers of very low-birthweight infants is needed to confirm or refute the findings of this study.

Because no temperature measure offers accuracy and safety, the decision about the best method must be made by weighing the needs of this group of infants for a neutral thermal environment against the safety consideration. There have been documented cases of rectal perforation which have been attributed to the use rectal thermometers (Fonkalsrud & Clatworthy, 1965; Franck & Brown, 1978; Gardner, 1987; Greenbaum, Carson, Kincannon, & O'Loughlin, 1969; Horwitz & Bennett, 1976; Merenstein, 1970). All the incidents relate to the use of glass thermometers. This risk to infants must be balanced against the need to obtain the most accurate temperature measurements possible.

The glass thermometer is small and inserts easily which may facilitate its accidental insertion beyond 2 cm in a very small infant or 5 cm in a large infant. It also must be left in place for five minutes which increases the opportunity for rectal irritation or perforation. The electronic thermometer with a smooth plastic probe cover inserts easily and takes only 15 to 20 seconds to record a temperature reading. This thermometer would be less of an irritant.

Of the thermometers included in this study, the electronic thermometer, used rectally, is the method of choice, particularly for infants less than 28 weeks gestation. The electronic axilla method offers non-invasive measurement with reasonable accuracy for more mature and larger infants who are in the incubator. Since infants were moved to the incubator after being under a radiant warmer, and would have had the opportunity to increase their weight, the effects of the environment and infant weight can not be separated in this study. Hence, further research related to the effect of weight and environment is required.

The gestational age of the infants was moderately, negatively correlated with the incubator temperature ($r=-.43$, $p\leq.01$). This reflects the increased heat requirements of less mature and smaller infants, as well as the related efforts to provide a neutral thermal environment.

The purpose of this study was to evaluate methods and sites of temperature measurement in term and preterm neonates in an Intensive Care Unit. While several methods were identified as demonstrating some agreement with the core temperature reading, agreement was not strong. Recommendations about thermometers can be made by considering risks to the infants against benefits of having the most accurate temperature possible. It was, therefore, concluded that electronic rectal thermometers are the method of choice with very low-birthweight, premature infants. This method combines speed of measurement, with less likelihood of rectal irritation, with accuracy. The electronic thermometer used at the axilla site is also recommended for infants with birthweights over 1200 grams. There was less of a gradient between axilla and core rectal temperatures in this group of infants, particularly in the incubator.

Further research is required with larger samples of low birthweight infants to determine factors which may contribute to inaccurate temperature measurement. As well, the measurement of skin or rectal temperature using the servocontrol features of radiant warmers and incubators should be investigated. Greater accuracy in temperature estimation can thus be achieved by knowing these factors.

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Appendix A

A Review of the Literature on Temperature Control and Measurement in Neonates

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Appendix A

A Review of the Literature on Temperature Control and Measurement in Neonates

Around 1900, Pierre Budin, historically the first neonatologist, developed an incubator following the systematic observation that decreased mortality rates occur when premature infants are kept warm (Oliver, 1965). There was little research related to thermoregulation in the neonate until the mid-1950's; since that time, research in the area has shown quantitative, as well as qualitative, differences between neonates, particularly premature infants, and adults as homeothermic organisms.

In adults, the response to cold environmental temperatures primarily involves involuntary muscle activity known as shivering. Normal heat production in the neonate occurs mainly as the result of nonshivering thermogenesis which involves the metabolism of brown fat that is stored at the nape of the neck, between the scapulae, in the mediastinum, and surrounding the kidneys and adrenals. Brown fat is multilobular, rich in sympathetic nervous fibres and blood supply (Klaus, Fanaroff, & Martin, 1986; Houdas & Ring, 1972). Its metabolism is stimulated by norepinephrine, which is accompanied by a dramatic increase in oxygen consumption (Bruck, Parmelee, & Bruck, 1962; Scopes & Ahmed, 1966). In a compromised neonate, this increase in oxygen consumption may lead to an oxygen debt with a resulting lactic acidosis. Nonshivering thermogenesis is impaired in infants during the first twelve hours of life (Smales & Kime, 1978) and in asphyxiated or hypoxic states (Scopes & Ahmed, 1966; Bruck, Adams, & Bruck, 1962).

Premature and low birthweight infants are at increased risk for hypothermia because they have a decreased supply of brown fat available which is becoming differentiated in the fetus between 26 and 30 weeks, postconception. They also have increased insensible water loss related to a large surface to mass ratio, a thinner layer of epidermis, decreased subcutaneous fat and greater body water content (Marks, Friedman, & Maisels, 1977). The epidermis is further compromised by skin damage from electrode and probe attachments (Harpin & Rutter, 1983). This transepidermal water loss is accompanied by a high loss of heat (Sedin, Hammarlund, Nilsson, Stromberg, & Oberg, 1985).

The ability of even premature infants to exert vasomotor control has been well demonstrated (Bruck, Parmelee, & Bruck, 1962; Hey & Katz, 1970) but the effect on heat conservation is minimal due to the poor insulation of subcutaneous and dermal layers in these infants.

When exposed to increased environmental temperature, sweating occurs in infants greater than 36 weeks gestation or greater than two weeks of age (Hey & Katz, 1969; Harpin & Rutter, 1982). It occurs mainly on the forehead, temples, and occiput, and is less marked in premature infants.Vasodilation occurs in premature and term infants, as demonstrated by warm, red skin (Harpin, Chellapah, & Rutter, 1983).

Neutral Thermal Environments

Care of infants, particularly those who are sick or premature, includes providing a neutral thermal environment in which the infant is able to balance heat production with heat loss and maintain core body temperature. The neutral thermal temperature has been defined as "the environmental temperature range within which the oxygen consumption and thus heat production of homeothermic subjects is minimal" (Bruck, Parmelee, & Bruck, 1962). The neutral thermal environment is a narrow range of temperatures that enables the infant to live with minimal energy expenditure (Baumgart, 1991).

Actual environmental temperature is only relevant when the factors of ambient air temperature, humidity, air flow, and radiant heat exchange are also considered (Scopes & Ahmed, 1966).

The above definition of neutral thermal environment was refined and operationalized for infants 29 to 34 weeks gestation who do not necessarily increase oxygen consumption with a fall in environmental temperature below the neutral range, but rather have a fall in core temperature. The neutral temperature for these infants is "the ambient temperature at which the core temperature of the infant at rest is between 36.7 and 37.3 degrees Celsius and the core and mean skin temperatures are changing less than .2 and .3 degrees Celsius per hour respectively" (Sauer, Dane, & Visser, 1984, p. 18).

The positive consequences of maintaining premature infants in a neutral thermal environment have been documented. There is a reduced mortality rate, particularly for infants of 1250 to 1500 grams birthweight (Buetow & Klein, 1964). In a less well controlled study, this reduced mortality rate was found for those infants weighing 800 to 1599 grams at birth (Day, Caliguiri, Kamenski, & Ehrlich, 1964). There is also an increase in growth, both weight and length

(Glass, Silverman, & Sinclair, 1968; Reichman, Chessex, Patet, Verellen, Smith, Heim, & Swyer, 1982).

Incubators and Radiant Warmers

Currently, very premature and/or critically ill neonates are nursed under radiant warmers, which are platform beds open to the environment, with an overhead source of radiant heat. These beds provide easy access to the infant for the tests and procedures that are required during the initial critical period. The beds are servo-controlled, with a powerful heat source that responds quickly to warm the infant. It has, however, been noted that there is a tremendous increase in insensible water loss from the infant under this warmer (Baumgart, 1982; Marks, Gunther, Rossi, & Maisels, 1980). This water loss results, concomitantly, in heat loss equivalent to .58 kcal per ml (Baumgart, 1991). The evaporative losses can be controlled by using a plastic wrap suspended over a frame surrounding the baby (Baumgart, Fox, & Polin, 1982; Fitch & Korones, 1984). Babies often have relatively colder extremities when nursed under a radiant warmer (Levison, Linsao, & Swyer, 1966; Wheldon & Rutter, 1982). They spent more time in active sleep and less in quiet sleep, although these were not defined and the consequences of this is not known (Wheldon & Rutter, 1982). Also, there is a potential for hyperthermia , excessive drying of the skin, and burns (Noerr, 1984).

An alternative to the radiant warmer is the incubator, which provides heat by convection, as well as normal or added humidity. The advantage of the incubator over the radiant warmer is derived from reduced water loss and decreased metabolic requirements (Marks, Nardis, & Momin, 1986). There has been some suggestion that very low birthweight infants cannot maintain their core temperature as well in an incubator as under a radiant warmer (Wheldon & Rutter, 1982).

Temperature Measurement

Temperatures should, ideally, be measured at the thermoregulatory center in the hypothalamus but this site is inaccessible. Other sites from which the core temperature can be obtained include the deep rectal and esophageal sites. These are considered to be too invasive for routine clinical purposes. Therefore, the thermometer is placed adjacent to large arteries in more convenient places that are not as influenced by environmental temperature changes. In neonates, the sites of choice have been the distal rectum, the axilla, and, more recently, the tympanic membrane. These sites are assumed to have a direct relationship to the core temperature. The core temperature, measured at the hypothalamus, esophagus, or deep rectum, may all have different values. The deep rectal temperature is accessible for any infant and, because the thermometer is inserted beyond the internal sphincter, the temperature reading is not as influenced by the environment.

A variety of instruments are available for temperature measurement. These are mercury-in-glass thermometers, intermittent electronic thermometers, thermistor probes (or continuous electronic thermometers), and tympanic infrared-sensing thermometers.

In an effort to maintain a neutral thermal environment for very low-birthweight and low-birthweight infants, probes are attached to the skin surface to continuously monitor the neonate's surface temperature and to thermostatically adjust the output of the bed's heater. In this way, a fall or rise in temperature beyond the preselected measure will cause the heater to increase or decrease output. Because the temperature of the neonate is monitored at the skin surface, it is affected by environmental factors such as room temperature, humidity, and ambient air flow, as well as internal factors such as cardiac output and peripheral perfusion. These factors affect the relationship between surface temperature and core temperature. In order that nurses can make adjustments to the thermostatic controls to maintain an adequate core temperature, intermittent temperature measurements are done. It is critical that these measurements accurately reflect the internal temperature of the neonate so that the negative sequelae related to the loss of a neutral thermal environment can be prevented. It has been shown that core temperature changes, as little as 0.5 degrees centigrade, can have a negative impact on the neonate's ability to cope with metabolic demands (Baumgart, 1991).

Glass Thermometers. Glass thermometers are inexpensive and easy to use, but require cleaning. In studies of new glass thermometers tested in controlled water baths through the range of temperatures, as many as 8 to 50% were inaccurate by 0.1 to 2 degrees centigrade (Abbey, Anderson, Close, Bertwig, Scott, Sears, Willens, & Parker, 1978; Purintun, & Bishop, 1979).

In attempting to determine the relationship between rectal and axilla temperatures using glass thermometers, it was found that rectal temperatures were higher than axilla temperatures 98% of the time.

The mean difference was .7 degrees centigrade, with a range of 3 degrees centigrade (Morley, Hewson, Thornton, & Cole, 1992).

The time that is required for stabilization at a maximum or optimum temperature with glass thermometers has been studied for both the rectal and axillary sites. An early study using adult subjects (Nichols, Ruskin, Glor, & Kelly, 1966) found that 90% of rectal temperatures reached maximum at 4 minutes, with no significant change after 2 minutes. The maximum reading was attained at 11 minutes for the axilla site, with no significant change after 10 minutes. Similar results were found in term infants who were in bassinettes (Kunnel, O'Brien, Munro, & Medoff-Cooper, 1988; Schiffman, 1982), however, in the latter study, the increase in axilla temperature after 3 minutes was clinically insignificant. These findings were supported in a study of 40 term infants in incubators (Stephen & Sexton, 1987). In four other studies, the times for stabilization varied between 3 to 5 minutes for rectal temperatures and 3 to 5 minutes for axilla temperatures (Torrance, 1968; Mayfield, Bhatia, Nakamura, Rios, & Bell, 1984; Haddock, Vincent, & Merrow, 1986; Haddock, Merrow, & Vincent, 1988; Bliss-Holtz, 1989; Hunter, 1991). When preterm infants were studied, temperature stabilization times were approximately 0.5 to 1 minute earlier than fullterm infants (Khan, Ahmed, & Fakhir, 1990; Mayfield, et al., 1984; Moen, Chapman, Sheehan, & Carter, 1987).

Case reports from 20 to 30 years ago cited the use of glass thermometers for rectal temperature-taking in neonates as the cause of injury or death related to rectal perforation and pneumoperitoneum (Fonkalsrud, & Clatsworthy, 1965; Greenbaum, Carson, Kincannon, & O'Loughlin, 1969; Merenstein, 1970; Horwitz, & Bennett, 1976; Frank, & Brown, 1978). Although prevalence is low, reported mortality rates from 40 to 70% emphasize the seriousness of the problem. The reason for this injury appears to be that, anatomically, the neonate's bowel makes a fairly sharp curve posteriorly, about 2 cm. from the sphincter. Introduction of a thermometer beyond this point risks perforation of the bowel. Current practice in many nurseries is to restrict or prohibit rectal temperature-taking with neonates.

Intermittent Electronic Thermometers. Intermittent electronic thermometers were introduced in the early 1970's as an alternative to mercury-in-glass thermometers. A thermistor or thermocouple sensor in the probe produces electrical signals that vary with changes in temperature. The advantages are speed of operation, portability, and availability for a number of sites. Disadvantages are the potential for cross-contamination when the unit is moved from bedside to bedside, and the cost of the probe covers.

In a study of adult intensive care patients with pulmonary artery catheters in place (thus providing core temperatures), the glass thermometers were found to be significantly closer to core than electronic, based on measurements taken at the axilla (Giuffre, Heidenreich, Carney-Gersten, Dorsch, & Heidenreich, 1990). When rectal and axilla temperatures of term infants were measured with glass and electronic thermometers, rectal temperatures were found to be slightly higher than axilla with both instruments (Eoff, Meier, & Miller, 1974).

Tympanic Thermometers. Tympanic thermometers consist of an otoscope-like probe that houses an infrared-sensing device, and a base containing microprocessor circuitry and calibration mechanisms. The sensor gathers emitted infrared energy, mainly from the tympanic membrane. The procedure takes about one second. The equipment has the capacity of adjusting the tympanic temperature (by adding a constant) so that a reading is given for oral, rectal or core sites. It can also report the actual temperature reading without conversion.

The tympanic membrane is perfused by the same blood supply as the hypothalamus. Animal research has shown similar temperature readings for probes embedded in the hypothalamus or resting on the tympanic membrane; however, the reading from the tympanic membrane was minimally cooler (Baker, Stacking, & Meehan, 1972). Other research using probes resting on the tympanic membrane found similarities with oral temperatures (Gibbons, 1967). Four sites within the auditory canal were measured and demonstrated a similar response to environmental warming as oral, but not rectal, measurements (Cooper, Cranston, & Snell, 1964). With anaesthetized adults, a strong relationship between tympanic and esophageal, but not rectal, measurements, was found (Benzinger, 1969). Two early studies with tympanic thermistor probes in neonates demonstrated higher tympanic temperatures than either esophageal or rectal (Stratton, 1977; Mayfield, Nakamura, Bhatia, Rios, & Bell, 1984). The variations in reported results may be related to small sample sizes, uniqueness of the sample (for example, anesthetized subjects), or lack of calibration of instruments.

Early studies of the tympanic membrane with thermistor probes all indicated some effect of environmental temperature, including radiant heat, on tympanic membrane measurements (Sellars, & Yoder, 1961; Nadel, & Horvath, 1970; Marcus, 1973a; Marcus, 1973b).

Shinozaki, Deane, and Perkins (1988) demonstrated that FirstTemp closely tracked the core temperature of adult patients, as measured with a pulmonary artery catheter. Ros (1989) found poor correlations between rectal or oral and tympanic measurements. No core reading was used for comparison purposes.

In infants and children, measures with electronic and tympanic thermometers showed a high correlation between tympanic and rectal (electronic) temperatures (Terndrup, Allegra, & Kealey, 1989; Rogers, Carley, Driscoll, LeBlanc, Libman, McCarty, & Kerrigan, 1991). It was concluded following a comparison of the tympanic with glass thermometer (oral, rectal, or axilla) that the tympanic thermometer was not accurate. Temperature measurements were taken by a large number of people who may have not used consistent technique (Freed & Fraley, 1992).

When a small group of term and preterm infants had temperatures measured using the Thermoscan tympanic thermometer and the IVAC electronic thermometer, a greater correlation was found between axilla and tympanic temperatures for the fullterm group, and for the right tympanic than for left tympanic temperatures compared to the electronic axilla temperature. The environment in which the infants were maintained was not indicated (Weiss, 1991).

A small group of term and preterm infants were studied where the FirstTemp was used to obtain tympanic membrane and axilla temperatures, a glass thermometer was used for axilla temperatures, and a thermistor probe used for tympanic and rectal temperatures (Johnson, Bhatia, & Bell, 1991). Using the cal-surface mode of FirstTemp, measurements of the tympanic membrane temperature in both premature and term infants were sufficiently close to tympanic thermistor readings, for clinical purposes. An additional finding was that there was no difference between tympanic readings when both ears were tested, indicating that using the most easily accessed ear is appropriate. The significance of these findings is diminished by the small sample size and because the type of bed was not considered as a variable.

Summary and Conclusions

There would appear to be support for the validity of the tympanic thermometer, mainly in the adult population. Research with neonates, including preterm infants, is limited, however, leaving some questions about the most appropriate method(s) for measuring temperatures. In addition, the effect of radiant heat from a warmer on the tympanic temperature measurements, as well as circulating heat in an incubator, on temperature measures, has not been explored. This is an important concern in Neonatal Intensive Care Units where most infants are nursed in one, or both, of these environments. As well, the use of a core temperature measurement which can be used to determine which methods are most valid has been inconsistent.

It is concluded that research related to the most accurate method of temperature measurement in the radiant warmer and incubator, using a core temperature measure is needed.

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Appendix B

Consent for Infant Participation in Temperature Measurement Study

Title of Research-A Comparison of Rectal, Axillary, and Tympanic Temperature Measurements in Neonates

Researcher	Advisor
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Purpose of the Study

To take the temperature of babies using four kinds of thermometers, at three different places.

Procedure

The baby's temperature will be taken in bed.
The baby will be awakened only if it is time for a feeding or some other test.
The baby's temperature will be taken with four kinds of thermometers.
The temperatures will be taken under the arm, in the rectum, and in the ear.
All temperatures will be taken at two different times.
It will take about 15 minutes to take the temperatures.
Your baby's temperature is normally taken in one of these ways.

Risks and Benefits

Babies usually do not like having their temperature taken. This is because they do not like being undressed or moved.
This study will give your baby's nurse one temperature reading.
It will also give important information about the best way to take the temperatures of small babies.

Voluntary Participation

Your baby does not have to be in this study. Your baby's care will not change if he/she is or is not in this study.

If you change your mind about having your baby in this study, you can drop out at any time. Just tell me or the nurse looking after your baby.

I will be happy to answer any questions now. I will also answer any questions you have later. Just call me at 477-4607 or 466-9812.

Consent

I, ______________________________,

agree to have my baby,
______________________________, be in the study "A Comparison of Rectal, Axillary, and Tympanic Temperature Measurements in Term and Preterm Infants". I have been given a copy of this paper.

______________________________ ______________
signature of participant date

______________________________ ______________
signature of researcher date

Appendix C

Calculations of Limits of Agreement and Confidence Intervals

<u>Calculation of Limits of Agreement</u>

1. Compute mean of differences plus or minus two standard deviations. These are the limits of agreement.

2. Compute 95% confidence intervals for the bias: mean difference ± (1.96 x standard error of the mean difference)

<u>Calculations of the Confidence Intervals for the Limits of Agreement</u>

1. Compute the standard error of the limits: square root of (3 x s-squared/ n)

2. Confidence intervals for the limits of agreement:
   a. For the lower limit:

      lower limit of agreement ± (1.96 x S.E. of the limit)

   b. For the upper limit:

      upper limit of agreement ± (1.96 x S.E. of the limit)