

# **Thermal Probe for Neurological Examination**

October 19, 2001

**Team Leader:** Andrew Hoyord  
**Communications Leader:** Paul Victorey  
**Web Implementation:** Bern Jordan  
**Course Improvement:** Paul Thottakara  
**Team Member #5:** Dana Mueller

**Client:**

Misha-Miroslav Backonja, M.D.  
Department of Neurology

**Advisor:**

Willis Tompkins, Ph.D.

**Biomedical Engineering 400 - Fall 2001  
University of Wisconsin at Madison**

## Abstract

To help diagnose neurological disorders, a portable thermal probe is needed to determine if a patient has a loss of temperature sensation in a specific area of the body. The device will attach to the Welch Allyn ophthalmoscope/otoscope handle, which is already widely used in medical examining rooms. We brainstormed a number of design paths and chose a final solution that involves a newly designed prototype. The prototype consists of a resistive heating element on a handle and a digital circuit to control temperature. Future work includes adding a timer to the prototype that alerts the user after the device has been in contact with a subject's skin for five seconds. We also need to choose a suitable material for the device housing.

## Problem Statement

Doctors are now finding it necessary to test patients who experience pain or numbness with warm/heat sensitivity for neurological damage. Currently, there is no portable device that a physician can use to apply hot sensations to a patient's skin. Physicians investigating sensory loss could use a device that heats up to warm and hot target temperatures of 38°C and 45°C respectively as a prescreening process before a more rigorous quantitative sensory test is performed. This device should be convenient to use and safe to apply to patients.

## Background

Injuries and diseases affecting peripheral nerves, the spinal cord, or the brain can be diagnosed in part with heat and cold sensitivity testing. The severity of injury or disease can be determined by the temperature threshold at which a patient first senses the heat or cold (Hilz, *et al.*, 1999). Patients suspected of having a neurological sensory disorder often undergo quantitative sensory testing. In this procedure, the patient is exposed to sensory stimuli (vibrations, changing temperature, etc.) that gradually increase in magnitude. The patient responds to the stimuli and the amount of sensory loss may be quantified. Unfortunately, this type of test takes 30 to 60 minutes and must be performed in a lab with specialized equipment.

In a clinical setting, heat and cold sensations may be used to help diagnose patients suspected of neurological damage. A quick, convenient method of temperature sensation testing could be used to prescreen patients before undergoing quantitative sensory testing. Currently available devices that heat up to known temperatures for heat sensitivity testing are bulky and inconvenient, so generally only cold sensation testing is performed because ice and tap water are readily available.

### *Physiology of Temperature Sensation*

Cold is sensed via myelinated Ad-fibers and heat is sensed via unmyelinated C-fibers. Testing with only cool tap water and cold ice water is inadequate (Susser, *et al.*, 1999) because damage to the heat-sensing fibers may be overlooked. For sensory testing, 45°C is considered to be a hot temperature and 38°C is considered to be a warm one (Konietzny, 1984). Temperatures above 50°C can cause pain and skin burns with very short contact times, so no heat sensitivity testing is done above 50°C.

Thermal sensitivity thresholds have relatively little to do with increasing age (Merchut & Toleikis, 1990). In mammals, temperature sensitive neurons from the skin transmit signals to the hypothalamus where they are processed. Warm-sensitive neurons are affected by the physical state of lipids, changes in protein conformation, and membrane skeleton activity (Vasilenko, 1994).

Our client, Dr. Backonja, would like to have a small device to use in his clinic for heat sensitivity testing. The surface of the thermal probe should reach the target temperatures of 38°C and 45°C relatively quickly and should be safe to use. (See Appendix A for a list of client and design requirements.) While not required, a thermal warm/heat probe may be designed as an attachment for Welch Allyn ophthalmoscope/otoscope handles. Because these handles are readily available at clinics and hospitals, many physicians could easily use such an attachment.

### *Welch Allyn Power Handle*

Welch Allyn, Inc. makes several models of power handles for clinical use. The Welch Allyn ophthalmoscope/otoscope handle used for this design contains a 3.5 V rechargeable Nickel-Cadmium (NiCd) battery. The handle is made of stainless steel and textured to ensure good grip. The lower portion of the handle can be removed and plugged into an electrical outlet for recharging. A picture of the handle is shown in Figure 1.



**Figure 1.** A picture of the Welch Allyn convertible power handle ["3.5v," 2000].

The ophthalmoscope and otoscope heads are secured to the top of the handle through a mechanism that requires pushing the head down and rotating clockwise. Voltage is delivered to the top of the handle by depressing the button on the collar and rotating the collar clockwise. Turning the collar adjusts a rotary potentiometer inside the handle, providing a source resistance from 0 to 5  $\Omega$ . The circuit uses the outer casing of the handle and locking mechanism as the negative terminal and the spring-loaded pin at center of the locking mechanism as the positive terminal.

## **Ethical Issues**

There are a limited number of ethical issues surrounding our design project. First, the device would be tested on human subjects in order to make sure the probe reaches optimal temperatures. It is necessary to supply the subjects with complete information regarding the purpose of the device and the risks of being involved in the study. In order

to conduct human testing, the researchers are required to write a protocol on how and why the testing will be conducted. The University of Wisconsin Health Sciences Human Subjects Committee must also approve the protocol before testing can commence.

The purpose of our design project is to test patients who experience pain or numbness for neurological damage. This involves applying heat to the suspected damaged area. In the process of applying heat to the patient, a component in the device has the possibility of malfunctioning. In this case, the device could heat above the desired temperature and potentially burn the patient. The timer could also fail, resulting in the probe being held on the skin for too long. This could also cause the patient to be burned because a hot surface is in contact with the skin for a long period of time. We hope to minimize, these potential problems by making our final design digital. In this case, if one element in the device fails, the whole device will fail and no heat would be produced.

## Product Design Criteria

The Device should:

- Be safe and not burn patients; i.e. the temperature must never rise above 50°C
- Heat up to target temperatures of 38°C and 45°C relatively quickly ( $\pm 1^\circ\text{C}$ )
- Maintain the target temperature through several successive tests on the same patient
- Have a probe surface with an area of 4.0 cm<sup>2</sup>
- Indicate when the probe surface has reached the target temperature
- Indicate when the probe has been applied to a patient's skin for five seconds
- Be convenient to use and easy to clean with alcohol and/or soap and water
- Attach to a Welch Allyn ophthalmoscope/otoscope handle or some other common clinical-setting power source

## Previous Prototype

This project is a continuation from previous semesters. The previous team built a prototype, but little testing was done due to time constraints.

The previous prototype solution was a discrete digital design, including distinct DIP integrated circuits for binary logic gates, flip-flops, counters, comparators, and multiplexers, and an analog-to-digital converter (ADC). The heating element was implemented as a flat coil of NI-Chrome wire, sandwiched between an insulating coating of epoxy and thermally conductive electrical barrier of heat-sink tape. The heat-sink tape contacted the disc of aluminum that was the probe surface. A thermistor was embedded into the aluminum, sealed with metal-filled epoxy (Figure 4).

The temperature control was achieved with a thermistor as the temperature sensor. The thermistor was in a simple bridge with a balancing resistor connected to ground, and the thermistor connected to Vcc. The voltage across the balancing resistor was proportional to temperature, and was converted into a 12-bit binary word for use by the digital portion of the control circuit. 12-bit words equivalent to each target temperature were hardwired in the design. If the converted temperature word was greater than the selected hardwired word, then the probe was too hot and power to the heating element would be cut. If the converted word was lower, power would be turned on.

There was a timer included in the design, requiring the user to press a momentary switch that started a 5 second timer. A LED would turn on for 1 second after the 5 second timer had elapsed. The timer would reset any time the switch was pressed, even if the current countdown hadn't finished.

## Alternate Solutions

The design of the device involves three distinct subcomponents: the heating element, a temperature control circuit, and a timer control circuit. After the heating element and battery, the temperature control circuit is the most important component because it allows the device to reach specific target temperatures without burning patients. The timer circuit would alert a physician of prolonged heat exposure, indicating the device should be removed to avoid inadvertently burning a patient.

### *Heating Element*

By passing current through a resistor, heat can be generated in order to reach the two target temperatures. The power dissipated is equal to the resistance times the current squared through the resistive element ( $P = I^2R$ ). Because all the power is dissipated as heat, regulating the current through the resistor allows accurate control of temperature. Since the power dissipated is dependent upon resistance and the purpose of the device is to generate heat, it is important the heating resistor only minimally change resistance with temperature change.

There are a number of different types of resistors that could be used to produce the necessary heat. Most resistors are cylindrical in shape, so one method would be to place a large cylindrical resistor on the back of the probe material, with its long axis parallel to the plane of the probe surface, and rely on the probe material to disperse the heat over the probe surface. Another method of resistive heating would be to use a known length of Ni-Chrome wire (nickel-chromium alloy) to provide resistance. The Ni-Chrome wire could be formed into whatever shape is needed to maximize the contact between the resistor and the probe material, resulting in even dispersal of heat over the probe surface.

The probe surface must be easy to clean, corrosion resistant, and thermally conductive. Various metals and plastics are currently used for clinical devices, but since the surface must be thermally conductive, metals are preferable to polymers. Copper has the best thermal conductivity of the common metals, but poses some problems with surface oxidation reactions and sterilization. Aluminum is less reactive than copper and also has high thermal conductivity to allow efficient heat transfer between the heating element and probe and between the probe and skin.

The probe surface will be circular with an area of  $4.0 \text{ cm}^2$ , but the thickness of the metal will be determined through experimentation. The thermal mass of the probe should be low enough so that target temperatures can be reached quickly. It should also be high enough so the surface temperature will not decrease rapidly when the probe is applied to the patient's skin or when the device is turned off momentarily during a thermal sensitivity examination.

### *Temperature Control*

A thermistor may be used to measure the temperature of the probe. A thermistor coupled closely with the probe surface will allow for a nearly direct way to monitor the temperature of the surface. The change in resistance due to a change in temperature could be used in an analog or digital circuit to control temperature. Last semester, a discrete digital circuit was designed that could be adjusted to different temperatures.

Using an analog-to-digital converter and microprocessor would allow for convenient temperature control. The microprocessor could be used to turn off the power to the resistor once the probe surface reached the target temperature and could also be programmed to light a diode corresponding to the appropriate temperature.

### *Timer Control*

To prevent possible burns, a timer will be built into the device. In the prototype, this timer will not be responsible for turning off the power to the heating element; instead, once the probe has been applied for five seconds, the physician will be alerted by a sound or light. Because the probe will retain some heat after the power is shut off, the only sure way to stop heating the skin is to remove the probe. It will be left up to the operator to remove the probe from the skin after five seconds have elapsed.

The timer could be activated by the physician pressing a switch to indicate when contact began. It would also be possible to use a design with two electrodes that would close the circuit once the device was brought into contact with the skin. Because we do not want the physician to push the device into the patient's skin, any method used must require little pressure for activation.

A timer could be made from a digital counter that would be reset when a switch was pressed and would send a signal to an LED after a number of counts equal to five seconds has occurred. Timing could be implemented with a microprocessor using the above digital counter or writing code that would be executed in approximately the same amount of time each time it was run. If the main loop of a program included code to do temperature control and timing, and it always took  $N$  ms to execute, the 5 second timer could work by counting through  $(5000 \text{ ms}/N \text{ ms})$  iterations of that loop.

## **Comparison of the Solutions**

The digital temperature control circuit of the previous prototype would be a convenient method of controlling the power supplied to the heating element. The circuit is simple in design, but rather large when implemented as distinct IC's for each part. Condensing the logic into a programmable logic device or translating the control and timing algorithm into code to program a microprocessor would be very desirable.

Using a microprocessor would make the hardware smaller. Learning how a particular microprocessor is programmed would be difficult, but problems could be fixed by changing the program, which would be easy. The rechargeable battery of the Welch Allyn handle only provides 3.5 V, so it would be necessary to find a low power microprocessor or to use a separate power source. This separate source could come in the form of another battery only used for the microprocessor or a dc/dc converter to amplify the 3.5 V higher than 5 V to power the microprocessor.

## Sanitation

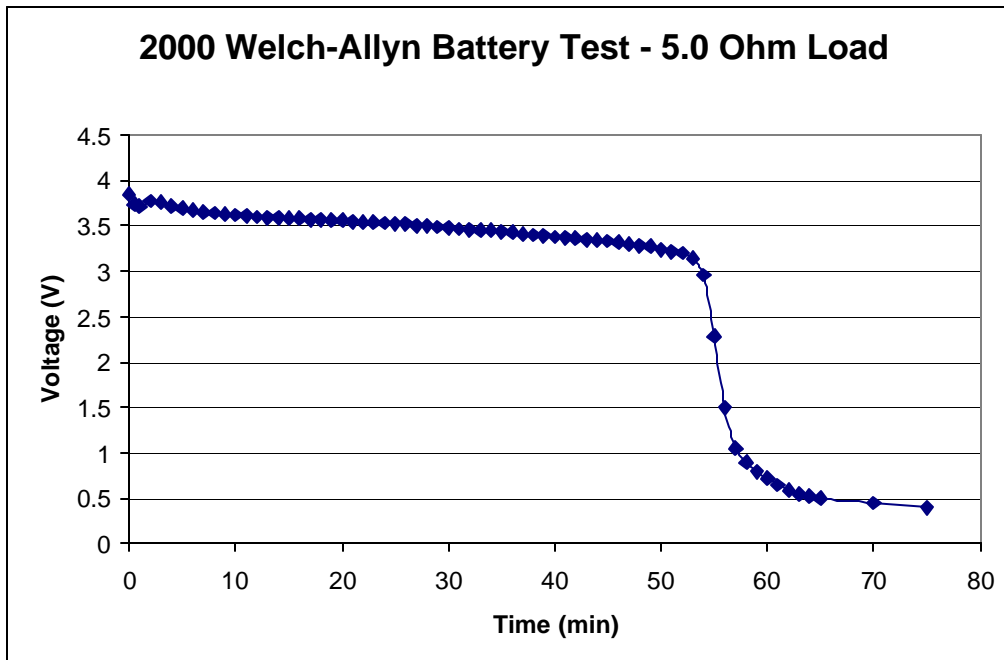
The probe surface, which must be sanitary, should maintain its physical characteristics while staying thermally conductive. For placement upon the skin, ethanol wiping of a metal surface is typically a sufficient cleaning method. Aluminum will stand up well to such a maintenance procedure.

## Current Design

Because of its small size, as well as ease of troubleshooting and altering the design, a microprocessor was chosen to implement the design. The Welch Allyn battery will be used to provide power for the heating element. The heating element is implemented as a flat coil of resistive wire.

## Battery

When we tested the properties of the NiCd battery in the Welch Allyn handle, we noticed that the battery held its voltage well before it finally died. The drainage with a 5 Ohm load is shown in Figure 2.



**Figure 2.** Voltage output versus time for 5 Ohm load with the Welch Allyn battery.

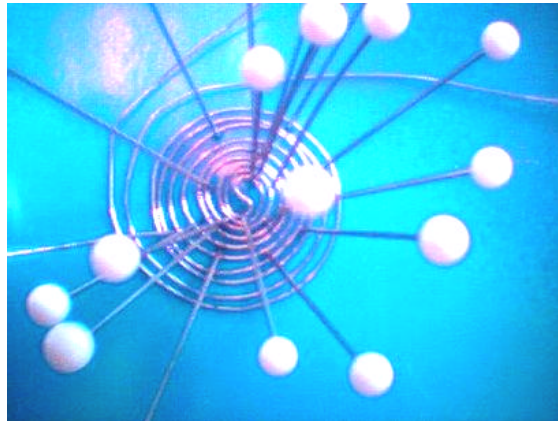
This new battery showed discharge patterns far better than the previous battery that was tested, which was at least 14 years old. The old battery output 2.4 KJ to a 5.0 Ohm load before the voltage dropped significantly, while the new battery output 8 KJ to a 5.0 ohm load before the voltage dropped.

One patient may be tested up to 3-4 minutes at 38 °C and 3-4 minutes at 45 °C. Testing of the current probe prototype showed a required energy input of 69 J to reach 38 °C from room temperature, and 66 J to reach 45 °C from 38 °C. Other testing showed that the power required to maintain the probe at 38 °C was 0.263 W, and the power to maintain 45 °C was 0.472 W. Knowing these data, one patient worth of testing would

require approximately 311 J from the Welch-Allyn battery. Testing 10 patients would require 3100 J, less than half of the energy available from the new battery. This is the expected amount of testing per charge of the battery.

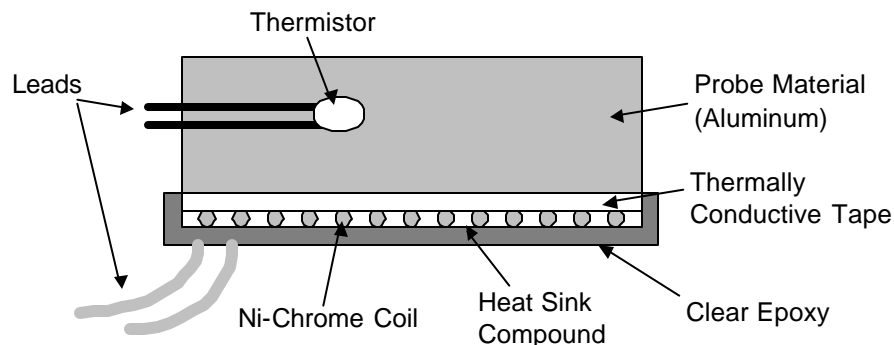
### *Heating Element*

We wanted to create a heating element that would produce all of its heat close to the probe to avoid wasting energy. We researched available elements, but could not find ones that were inexpensive and would suit our design. To build the element, we created the flat coil from Ni-Chrome wire shown in Figure 3.



**Figure 3.** The Ni-Chrome resistive wire coil. In this figure, the coil is pinned to a rubber surface to help it maintain its shape.

The Ni-Chrome coil is the main component of a multi-layer element. A cross-sectional sketch of the heating element is shown in Figure 4.



**Figure 4.** A cross-section of the heating element with labeled components. Note: The sketch is not to scale.

We made the probe of an aluminum disk with a thickness of 4.5 mm and a diameter of 23 mm. We drilled a small hole in the side of the aluminum disk for the thermistor. After placing the thermistor, this hole was filed with heat sink compound and then sealed with metal-filled epoxy. We attached heat sink tape to the reverse side of the aluminum disk and adhered the coil to it. Between the wire coils, we filled the gaps with heat sink

compound to help even the thermal flux. Finally, we sealed the back of the entire probe with clear epoxy as an insulating layer.

### *Analog Circuitry*

The temperature control will be achieved with a digital circuit. This digital circuit interfaces with a small analog circuit containing a thermistor to measure temperature. A NTC (negative temperature coefficient) thermistor changes resistance as a negative exponential in relation to temperature. We are considering using this thermistor in a simple bridge configuration, with the thermistor hooked to Vcc, and a balancing resistor between ground and the thermistor. The voltage between them would rise as temperature increased, but not go too much higher or lower than  $0.5 \cdot V_{cc}$ . We are also considering using the thermistor in a wheatstone bridge configuration, so that the voltage equivalent to temperature would have the range from ground to Vcc. An analog-to-digital converter will read this voltage and give the microprocessor an accurate digital representation of the probe surface temperature.

### *Digital Control Circuitry*

The digital representation of the temperature will be an n-bit word. The number of bits necessary for this is dependant on the desired precision in reading the temperature. We have to consider thermistor temperatures from 30°C to 55°C, a minimum temperature to start monitoring at knowing that the probe will always be signaled to heat if below, and the maximum temperature of the probe surface due to heating, with 5°C added to allow the circuitry to read voltage at 50°C without problems. If an 8-bit converter were used, the maximum temperature resolution would be  $(55-30)/2^8 = 0.1^\circ\text{C}$ . The actual resolution depends on how the temperature voltage fluctuates over the range of possible temperatures.

We will have our target temperatures stored in the memory of the microprocessor as n-bit words equal to the n-bit word produced by the converter when the thermistor is at the target temperature. We will also store the digital representations of the temperatures corresponding to  $\pm 1^\circ\text{C}$  of the targets. The operator will select the desired target temperature, and the microprocessor will compare the selected temperature word to the word output by the ADC. If the converted word is lower than the target word, the microprocessor will output a signal to heat, a voltage of logic "1". This voltage feeds into the base of a switching transistor, allowing current to pass to the heating element. If the temperature is higher than the target, the microprocessor will output a low voltage to the transistor and current will not be allowed to flow through the heating element.

The system needs a clock to run the microprocessor and so the temperature voltage is sampled periodically. The microprocessor will execute its code in a given amount of time based on the number of instructions executed. This can be used to implement a 5 second timer to limit patient contact.

Several lights and switches will be placed on the device for a user interface. A switch will allow the user to select from either of two target temperatures. A switch will allow the user to enable or disable a sound upon timer expiration. A button will allow the user to signal the start of a timing sequence. There will be an LED to signal when the timer had expired. There will be a green LED, flashing when the probe temperature was below target  $- 1^\circ\text{C}$ , and solid when the temperature was within  $\pm 1^\circ\text{C}$  of the target.

There will be a red LED to signal when the probe temperature is more than target + 1 °C. The red LED will also blink to signal the user if there is a malfunction in the heating circuit upon starting the device. If the digital representation of the probe temperature does not cross a pre-determined threshold after a pre-determined amount of time, this means that the device is not functioning properly and should not be used.

## Future Plans

The plans for the coming weeks are outlined below, listing the major obstacles to the progression of our designing and prototyping. For now we have split the group 60/40 putting Paul Victorey and Bern Jordan in charge of programming the microprocessor. Andrew Hoyord, Paul Thottakara and Dana Mueller will be in charge of the rest of the prototype circuitry including the thermistor bridge, analog-to-digital converter, and any switches, LEDs, and other circuit parts necessary.

When the functionality of the microprocessor control has been demonstrated and tested, the design will be revised as a whole to improve parts that could be improved. Then construction of the final prototype will begin, consolidating the circuitry into the size required so it will fit on the Welch-Allyn power handle. Also, we will need to design and fabricate a piece that will allow our device to connect to the handle.

10/25 – 10/31: Continue programming microprocessor. Design and construct the rest of the prototype circuitry.

11/1 – 11/7: Testing microprocessor with rest of prototype.

11/8 – 11/14: Continue testing. Revise design and uP program as necessary.

11/15 – 11/21: Continue testing and revisions.

11/22 – 11/28: Construct next generation prototype.

11/29 – 12/5: Design connection to the welch-allyn handle. Begin work on final reports.

12/5 – 12/11: Make handle connection piece and implement device on the handle.

Prepare final reports and final design presentation.

12/12 – 12/18: Final Design presentation. Attend final design meeting.

## Appendix A – Product Design Specifications

### Thermal Probe for Neurological Examination

Version 9: Oct 19, 2001

Andrew Hoyord, Bern Jordan, Dana Mueller,  
Paul Thottakara and Paul Victory

#### *Function*

Doctors are now finding it necessary to test patients experiencing pain or numbness for neurological damage and warm/heat sensitivity by applying hot sensations to their skin. A device that heats up to a “warm” and “hot” target temperatures could be used by the physician as a prescreening method before a quantitative sensory test is recommended. This device should be convenient to use, and safe to apply to patients.

#### *Client Requirements*

The product should:

- Be safe and not burn patients; i.e. the temperature must never rise above 50°C
- Heat up to target temperatures of 38°C and 45°C relatively quickly ( $\pm 1^\circ\text{C}$ )
- Maintain the target temperature through several successive tests on the same patient
- Have a probe surface with an area of 4.0 cm<sup>2</sup>
- Indicate when the probe surface has reached the target temperature
- Indicate when the probe has been applied to a patient’s skin for five seconds
- Be convenient to use and easy to clean with alcohol and/or soap and water
- Attach to a Welch Allyn ophthalmoscope/otoscope handle or some other common clinical-setting power source

#### *Design Requirements*

##### **Physical and Operational Characteristics**

**Performance:** The probe surface should heat from room temperature to 38°C and 45°C ( $\pm 1^\circ\text{C}$ ) within 30 seconds [check with Client again on this because tests have showed 1 min warm-up time to reach 38°C].

The heating element should use minimal power from the battery.

The device should be able to be used to test a maximum 10 patients on a single charge, each including up to 3-4 minutes of testing at 38 °C and 3-4 minutes of testing at 45 °C.

- Safety:** The probe temperature must not exceed 50°C in any event (including user abuse and circuit element failure)
- The risk of electrical shock to user and patient must be minimized.
- A five-second timer should be used to alert physician to remove device from patient's skin.
- To minimize pathogen transmission, the probe should be able to withstand frequent washing with soapy water and alcohol
- The probe must be free of sharp edges, rough surfaces, or spaces that would allow for pinching
- Accuracy and Reliability:** The device should heat up to within 1°C of the specified target temperature. Once target temperature is reached, the temperature should remain constant until power is turned off.
- The five-second timer to limit patient contact should be accurate to within 0.1 s.
- With repeated use, the device should consistently attain target temperatures. Probe temperature (or temperature display) should not be dependent on battery strength.
- Life in Service:** Device should be able to withstand frequent cleaning with soap water and alcohol.
- The device will be used on at most 20 patients per day, up to 10 minutes for each (max 200 minutes on per day).
- Two to ten years of use expected before replacement.
- Shelf Life:** Indefinite if kept at room temperature free from high humidity and excessive dust.
- Operating Environment:** The device will be used under normal indoor hospital/clinical conditions (20-25°C, 1 atm pressure, less than 60% relative humidity, and very little dust) by trained physicians.
- The probe will primarily be used on a patient's hands and feet. The skin may possibly be moist.

- Ergonomics:** Size of probe should allow for full contact to the skin of the various areas of the body tested.
- Placement of operator controls should not cause undue strain in the hand, wrist, or fingers.
- Operation with only one hand is desired. The device will be kept relatively simple with as few buttons as possible. The buttons included will be clearly labeled as to what their specific function is. Any movable controls should only have slight frictional resistance. Controls should be adequately spaced apart and sized large enough to be recognized by touch.
- Size and Shape:** The probe surface should be circular and  $4.0 \text{ cm}^2$  in area.
- The entire device should roughly be the size of the normal head attachments to the battery pack (ophthalmoscope or otoscope heads).
- The size of any numerical display should be larger than 5 mm tall.
- Weight:** The attachment should weigh no more than 225 g.
- The mass of the probe tip should be minimized to conserve battery power, yet large enough to maintain temperature when applied to the skin.
- Materials:** All exterior materials must withstand alcohol and soap washing.
- The heated probe must be made of a non-corrosive material with high thermal conductivity.
- The body of the instrument should be made of a non-conducting material to prevent heat loss of the probe tip.
- Standard electrical components will be used for the circuitry.

### **Production Characteristics**

- Quantity:** One prototype device for client's use, possibly more if successful design.
- Target Product Cost:** The attachment should cost no more than existing attachments for eye and ear testing which run \$100-150. The prototype may cost up to \$300.

### **Miscellaneous**

- Standards and Specifications:** FDA standards applying to electrical, and electrical medical devices if the device becomes mass-produced. If it is just an experimental device, it is necessary to obtain an NIH human subjects protocol. These standards are yet to be found out.
- Customer:** Customer requirements listed above.
- Patient Related Concerns:** Patients will be concerned with the safety of the device.
- Competition:** This device will be used to prescreen patients before recommending quantitative sensory testing; a battery of sensory tests that checks for temperature sensitivity and other stimuli. There exist large AC powered heated probes used for the same type of neurological exam the device will be used for. There exists no competition from Welch Allyn (they are not interested in producing a thermal probe for neurological examinations).

## Appendix B – References

Beebe, David. Personal Communication. April 2001

Föll, Helmuth, “Thermoelectric Effects,” Online: [http://www.techfak.uni-kiel.de/matwis/amat/elmat\\_en/kap\\_2/backbone/r2\\_3\\_3.html](http://www.techfak.uni-kiel.de/matwis/amat/elmat_en/kap_2/backbone/r2_3_3.html) (Kiel, Germany: Christian-Albrechts University of Kiel, 2000) [3 May 2001]

“Frequently Asked Questions,” Online: <http://www.tellurex.com/resource/txfaq.htm> (Traverse City, Michigan: Tellurex Corporation, 2000) [3 May 2001]

Hilz, M. J.; Stemper, B.; Axelrod, F. B.; Kolodny, E. H.; and Neundörfer, B., “Quantitative thermal perception testing in adults,” *Journal of Clinical Neurophysiology*, 16(5):462-471, 1999.

Konietzny, F., “Peripheral neural correlates of temperature sensations in man,” *Human Neurobiology*, 3(1):21-32, 1984.

Merchut, M. P. and Toleikis, S. C., “Aging and quantitative sensory thresholds,” *Electromyography and Clinical Neurophysiology*, 30(5):293-297, 1990.

O’Neal, L. Burke. Personal Communication. November-December 2000.

Susser, E., Sprecher, E., Yarnitsky, D., “Paradoxical heat sensation in healthy subjects: peripherally conducted by Ad or C fibers?” *Brain*, 122(Pt 2):239-246, 1999.

Vasilenko V. Y., “Thermosensitivity: an intrinsic property of hypothalamic neurons,” *Journal of Thermal Biology*, 19(4):219-236, 1994.

“3.5v Convertible Power Handle w/rechargeable battery details,” Online: <http://www.ewelchallyn.com/data/71000-C.html> (Skaneateles, New York: Welch Allyn, 2000) [3 May 2001]