The Laryngoscope
Lippincott Williams & Wilkins, Inc., Philadelphia

Observations on Conduction of Caloric Stimulation to the Middle Ear Cavity by Thermoscanning

Shinji Nishizawa, MD

The Laryngoscope
Lippincott Williams & Wilkins, Inc., Philadelphia

Observations on Conduction of Caloric Stimulation to the Middle Ear Cavity by Thermoscanning

Shinji Nishizawa, MD

***Objective:* To elucidate the ways in which caloric stimulation conducts and the temperature recovers on the temporal bone by the caloric stimulation test. *Methods:* Four cases examined temperature changes of the bony lateral semicircular canal eminence with thermal images by caloric stimulation tests. Changes in the heat distribution were observed by means of a Thermoscan (Nihondenki Sanei Thermotracer 6T67R, Tokyo, Japan). *Results:* The temperature began to decrease from the external canal and the decrease reached the posterior cranial fossa plate through the middle ear cavity while the stimulation continued. After the end of stimulation, the stimulation advanced in the direction opposite to the order in which it was transmitted and recovered in a manner resembling a mirror image despite the difference in speed. *Conclusions:* The way in which the caloric stimulation was conducted and the way in which the temperature recovered were in the opposite direction. *Key Words:* Caloric stimulation, thermoscanning, temperature, middle ear.**

***Laryngoscope*, 112:504–508, 2002**

INTRODUCTION

How the caloric stimulation given from the external canal is conducted to the middle ear or internal ear and how it disappears have not yet been elucidated. As for temperature changes, results of observations with a thermistor have been reported. The middle ear has been observed only in the case of surgery,[1–3] and resected specimens have been used for observation of the internal ear.[4–6] In either case, temperature changes were measured at only a few places in the middle ear and internal ear and examined irrespective of anatomical features of the middle ear and internal ear, but the mode of temperature changes being transferred was not made clear. Clarifying the relation between temperature changes and anatomical features will be of help for elucidating physiological effects of the caloric test. The purposes of the present study were to examine the way in which heat conduction to the middle ear cavity by caloric stimulation by means of heat images showing anatomical features and to elucidate the mode of spreading of the cooling effect on the temporal bone by the caloric tests.

PATIENTS AND METHODS

The subjects included four patients with cases of cholesteatoma with the mastoid cavity released. In case 1, a 46-year-old woman had a right-ear cholesteatoma. The average hearing level (AHL) ([500 Hz + 1000 Hz × 2 + 2000 Hz]/4) was 55.0 dB. After surgery, the AHL improved to be 13.8 dB with a TORP. In case 2, a 49-year-old man had a right-side cholesteatoma. The AHL was 35.0 dB. Postoperatively, the AHL was 27.5 dB. In case 3, a 46-year-old man had a right-side cholesteatoma. The AHL was 47.5 dB. Postoperatively, the AHL was 31.3 dB. In case 4, a 58-year-old woman had a left-side cholesteatoma. The AHL was 53.8 dB. Postoperatively, the AHL was 53.8 dB.

Explanation of the caloric test was given in advance to the patients, and their consent was obtained. Surgery was performed with the patient under general anesthesia in all cases. The middle ear cavity was opened by postauricular incision. The posterior wall of the bony wall of the posterior superior external canal (septum between the external canal and mastoid cavity) was left intact until the end of measurement, and the perforated region of the tympanic membrane was closed with cotton and tissue sealant (Beriplast, Tokyo, Japan) to prevent the physiological saline solution stimulating the external canal from leaking into the mastoid cavity. A 20°C saline solution was directly injected into the external canal to confirm that water for stimulation was not leaking into the mastoid cavity. For caloric stimulation, 20 mL of a 20°C saline solution was injected into the external canal continuously for 20 seconds. This procedure was performed with aspiration to prevent the water overflow from entering the mastoid cavity, and water was completely removed by aspiration at the end of stimulation. Heat images of the temperature distribution over the entire surgical field including the external canal, tympanic membrane, and middle ear cavity were scanned over time with a Thermoscan (Nihondenki Sanei Thermotracer 6T67R, Tokyo, Japan) and were recorded by model PC9800 NEC, a personal computer. After recovery of the temperature, the external canal was stimulated with a 2°C saline solution and examined. Postoperatively, changes with time in the isothermal line (a line connecting the distribution areas of the same temperature) were examined.

From the Department of Otolaryngology, Bibai Rousai General Hospital, Bibai City, Japan.

Editor's Note: This Manuscript was accepted for publication October 29, 2001.

Send Correspondence to Shinji Nishizawa, MD, Department of Otolaryngology, Bibai Rousai General Hospital, Bibai City, 072-0015, Japan. E-mail: sn24@syd.odn.ne.jp

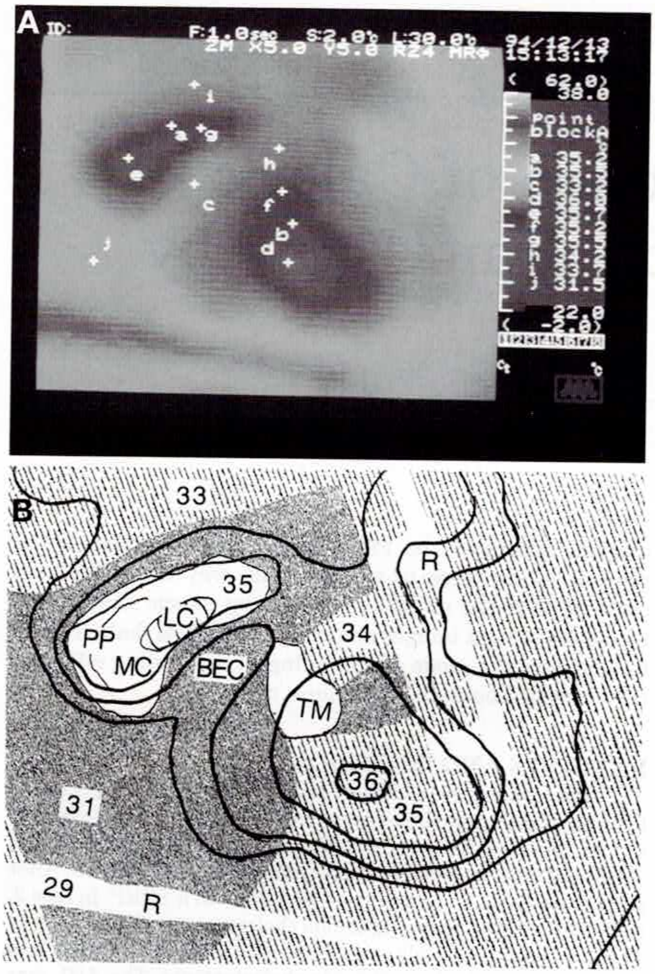

Fig. 1. Case 1. Heat image by thermoscanning before inception of stimulation (**A**) and its schematic diagram (right). On the left, (a) mastoid cavity; (b and f) tympanic membrane; (c) bony wall of the posterior superior external canal; (d) skin flap of external canal; (e) posterior cranial fossa plate in the mastoid cavity; (g) lateral semicircular canal eminence; (h) attic; (i) muscle flap; (j) bone surface (a, b, e, f, and g = 35°C; c = 33°C; d = 36°C; h = 34°C; i = 33°C; j = 31°C). (**B**) Illustrations of isothermal lines with isothermal regions connected in the left picture. Numerals show the temperature at each region. AR = arm of retractor; BEC = bony external canal wall; LC = lateral semicircular canal eminence; MC = mastoid cavity (large white area); PP = posterior cranial fossa plate in the mastoid cavity; TM = tympanic membrane (small white area); gray area = bony surface of temporal bone; other area = soft tissues.

RESULTS

Case 1

A thermoscanning image was recorded immediately before inception of the stimulation (Fig. 1). It was recorded 7 times from 20 (at the end of stimulation, Fig. 2) to 30 seconds after. After the start of stimulation, it was recorded 40 seconds after. Thereafter, it was recorded every 30 seconds. Regarding 20°C stimulation with water, as for changes in the isothermal line at 34°C, comparison of the isothermal line 20 seconds after inception of the stimulation (at the end of stimulation) and 23 seconds after the start of stimulation showed a slight diminution of the line from the bony wall of the posterior superior external canal to the lateral semicircular canal eminence 23 seconds after the start of stimulation, thus making it clear that the caloric stimulation was still conducted to the mastoid cavity even after the end of the stimulation. No change in the isothermal line was found from 23 to 30 seconds after the start of stimulation, and the cold caloric stimulation and body temperature were in a state of equilibrium. Thereafter, the isothermal line expanded like a ripple in the direction of the anterior aspect of the mastoid cavity from the posterior cranial fossa plate (PP) corresponding to the medial base of the mastoid cavity (Fig. 3) from 20 to 180 seconds after the start of stimulation), went over the elevation of the lateral semicircular canal, and spread to the attic. The line appeared in the external canal as well, 90 seconds after, and the two times were connected to expand further 120 seconds after. The isothermal line at 35°C (Fig. 4) in the mastoid cavity 180 seconds after, the isothermal line at 34°C 90 seconds after, and the isothermal line at 35°C immediately before inception of the stimulation (Fig. 1) were in agreement with one another. The highest temperature was found on the PP posterosuperior to the mastoid cavity, from which it spread in the direction of the attic. Comparison of the isothermal lines at 34°C (Fig. 3) and 35°C (Fig. 4) made clear the changes in the thermal distribution. The high-temperature region was the PP of the lateral mastoid cavity on the thin bony wall, a region that was adjacent to the posterior cranial fossa of high heat capacity and sigmoid sinus. This is a finding that observations made at one to three places with a thermistor failed to elucidate. Cold caloric stimulation of 2°C showed the same change as with the isothermal line at 20°C except that the temperature of the isothermal line in the mastoid cavity was low and time taken to return to the body temperature before stimulation was longer.

Cases 2 and 3

Changes in the isothermal line by cold caloric stimulation of 20°C and 2°C were similar to those in case 1.

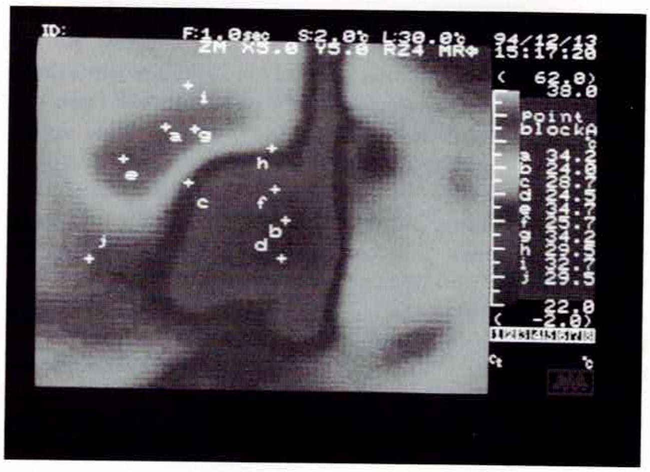

Fig. 2. Case 1. Heat image by thermoscanning 20 seconds after inception of stimulation (at the end of cold caloric stimulation). The position from A to J is the same as in Fig. 1. Water in the external canal is being aspirated upward.

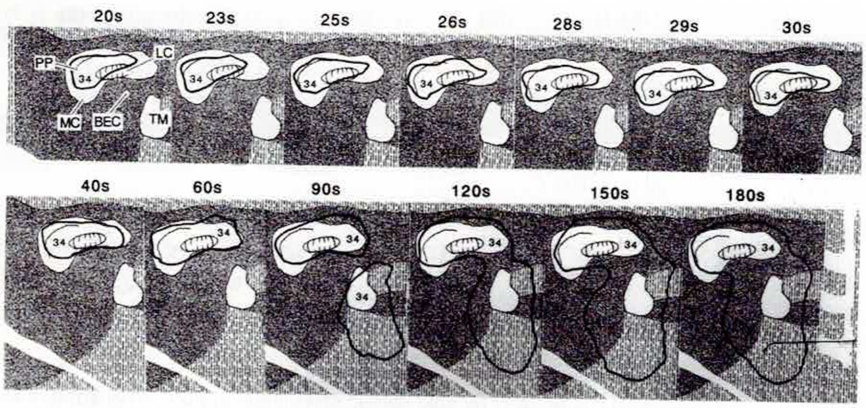

Fig. 3. Case 1. Changes in the isothermal line at 34°C by cold caloric stimulation of 20°C are arranged over time. Numerals at the top in each diagram show the time (seconds) taken from inception of stimulation. The isothermal line starts from the posterior cranial fossa plate in the mastoid cavity and spreads beyond the lateral semicircular canal eminence and attic in the mastoid cavity over time.

Case 4

In case 4, unlike in cases 1 to 3 as mentioned earlier, during stimulation the patient was examined 5, 10, and 15 seconds after inception of stimulation. Besides, measurements were obtained at 20 seconds (at the end of stimulation); at 30, 40, 50, 60, and 90 seconds after; and at 1-minute intervals from 2 to 10 minutes after. Regarding changes in the isothermal line, changes in the isothermal line at 34°C with cold caloric stimulation of 20°C were arranged (Fig. 5: 34°C). When the line was traced, it became small from 5 to 15 seconds after and disappeared 20 seconds after but appeared 30 seconds after and spread like a ripple thereafter. The reappeared isothermal line, which was spread from the posterior cranial fossa, in contrast to these diminishing changes. From 90 seconds after, the isothermal line spread to the back of the mastoid cavity obtained at 30 seconds after stimulation covered with a skin flap posterior to the surgical field. Cold caloric stimulation of 2°C showed the same change as with the isothermal lines at 20°C except that the temperature of the isothermal lines was low and time taken to return to the body temperature was long.

DISCUSSION

Regarding the isothermal line for the middle ear cavity, with cold caloric stimulation of 20°C, the temperature began decreasing from the external canal and the decrease reached the PP through the middle ear cavity while the stimulation continued (Fig. 6). After the end of stimulation, the stimulation advanced in the direction opposite to the order in which it was transmitted and recovered (Fig. 6). That is, the direction of the temperature decrease and that of recovery turned in reverse manner, like a mirror image, despite the difference in speed. Therefore, it may be said that the temperature environment lies between the external ear and posterior cranial fossa and is located in that temperature slope.

From changes in the isothermal line on images, it has been made clear that the temperature of the middle ear cavity does not make a recovery immediately after the end of stimulation even with the stimulation of 20°C, but that the recovery of temperature is preceded by a state of equilibrium of temperature against the temperature difference from the body temperature. In other words, changes in the temperature in the lateral semicircular canal was in a state of equilibrium or stopped from 23 to 30 seconds after in case 1. This region has the lateral semicircular canal inside, so the stimulation to the lateral semicircular canal was obviously continued there. The duration of this state of equilibrium was presumed to be the time during which the cold caloric stimulation is con-

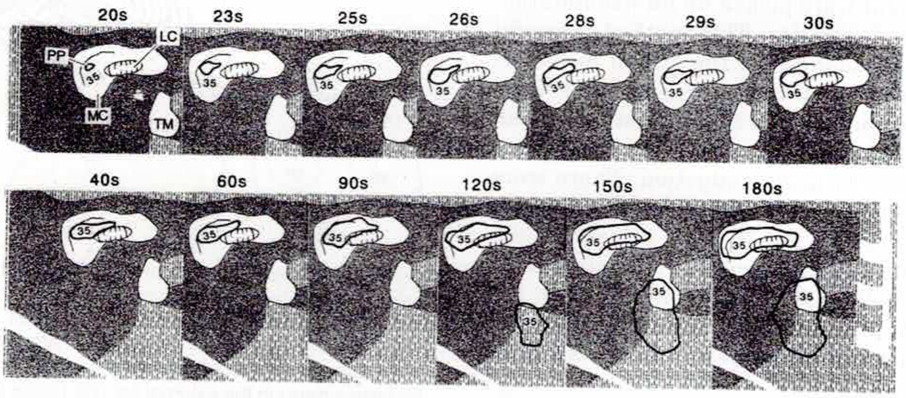

Fig. 4. Case 1. Changes in the isothermal line at 35°C by cold caloric stimulation of 20°C. The isothermal line starting from the posterior cranial fossa spreads with time in the direction of the attic beyond the lateral semicircular canal eminence in the mastoid cavity but does not reach the attic. The isothermal line 28 seconds after is partly diminished compared with that 26 seconds after.

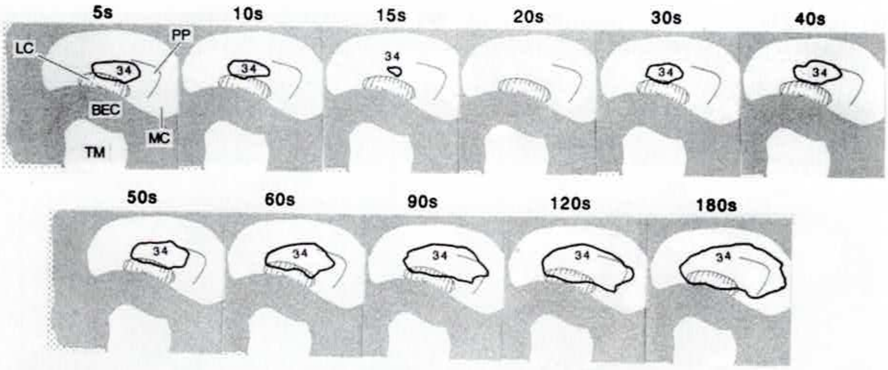

Fig. 5. Case 4. Changes with time in the isothermal line at 34°C by cold caloric stimulation of 20°C. The isothermal line diminished uniformly until 5, 10, and 15 seconds after stimulation from inception of cold caloric stimulation and disappeared at the end of the stimulation, but reappeared 10 seconds after the end of stimulation, or 30 seconds after, and continued to increase thereafter.

ducting bone parenchyma of the lateral semicircular canal. In either case, the recovery of temperature was made by heat conducted from the PP. It was not clear whether the cold caloric stimulation was conducted to the internal ear from the time at which the cold caloric stimulation of 20°C was started and the stimulation to the internal ear ended simultaneously with termination of the stimulation or whether the difference from the body temperature gave rise to a stimulus that was added to the internal ear. The results at surgery[1–3] could not be associated with those of experiments with the resected temporal bone.[4–6] Our experiment was the first to prove by images that the lateral semicircular canal is located between the isothermal region and stimulated region and that the temperature decreases because of the intensity of stimulation to the two regions, reaches equilibrium, and increases.

Formerly, the role of the posterior cranial fossa as an isothermal region having a large heat capacity was not known and was ignored. The tectorium of the internal ear in the temporal bone is the middle cranial fossa. Because it is located in the tangential direction, our present observation failed to determine its role, but it is supposed to play a similar role.

In the instance in which the mastoid cavity of the middle ear cavity was opened, several attempts[1–6] have been made to measure the temperature of the bony semicircular canal by heat stimulation. Temperature changes at a fixed point were picked up for examination as represented by a thermistor. This method is useful for recording absolute changes at the site of measurement but ignores the anatomical features and role of the surrounding area. In short, it can clarify that heat stimulation was conducted but cannot examine the "orientation and magnitude" of heat conduction. There were reports[3,4] on three thermistors used for the highest point of measurement, but the PP was not measured. Therefore, it was impossible to determine anatomically where the factor is to change caloric stimulation. In the present experiment, we were able to understand the move of a caloric distribution by caloric stimulation as the move of waves by using characteristics of thermoscanning with tracing of changes in the isothermal line. For illustration of our experiment, we have presented as many cases as possible.

The isothermal line of 34°C was chosen because the lowest temperature recorded in the areas around the lateral semicircular canal was 34°C and because the migration of the isothermal line configuration over tissue was interesting.

We selected four patients with cases of cholesteatoma requiring the opening of the mastoid cavity as the subjects, so our measurements may lack accuracy to some extent compared with measurements obtained in subjects with no impairment of the middle ear cavity. The cases of chronic otitis media are supposed to have heat conduction that is different from normal because the middle ear membrane becomes thick as a result of chronic inflammation and the tympanic membrane has perforation, in addition to the poor development of the air cells and high bone density. Furthermore, the lateral aspect of the temporal bone was excluded and the skin flap of the external canal was removed in the present observation, so the difference from normal in heat conduction in our experiment cannot

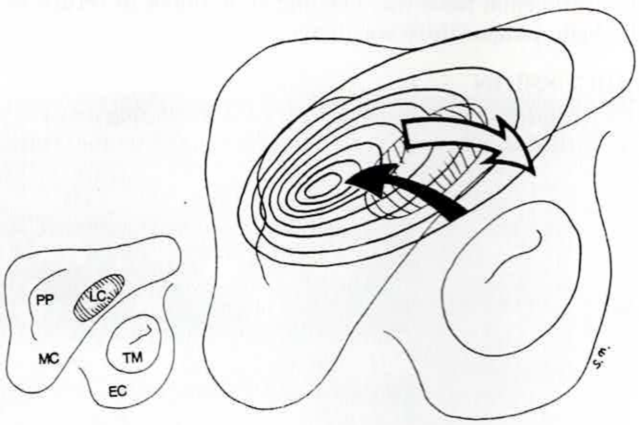

Fig. 6. An estimated diagram (right) showing propagation of cold caloric stimulation (dark arrow) and temperature recovery by body temperature conducted from the isothermal region of the posterior cranial fossa (white arrow) and its schematic diagram (left). Cold caloric stimulation goes through the middle ear and lateral semicircular canal eminence through the external ear and heads for the isothermal region of the posterior cranial fossa. The temperature is shown to recover in proportion to the order the cold caloric stimulation followed. The effect is similar to that of dropping a pebble into a pond.

be helped. However, to observe the whole, as in our experiment, is a new attempt. The rate of temperature changes differed from one case to another. Presumably, differences in bone density, size, and heat capacity of the PP in the mastoid cavity and the position of semicircular canal and sigmoid vein are mainly accountable for these differences.

CONCLUSION

The way in which the caloric stimulation was conducted and the way in which the temperature recovered were in the opposite direction.

Acknowledgments

The author thanks Kimitaka Kaga, Professor and Chairman, Department of Otolaryngology, University of Tokyo, and Shinobu Seki, and Takuzou Fujisawa, Department of Physiology, Bibai Rousai General Hospital.

BIBLIOGRAPHY

1. Cawthorne T, Cobb WA. Temperature changes in the perilymph space in response to caloric stimulation in man. *Acta Otolaryngol (Stockh)* 1954;44:580–588.
2. Kleinfeldt D, Dahl D. Die Temperaturveränderungen am horizontalen Bogengang des Menschen bei thermischen Vestibularisprüfungen. *Laryngol Rhinol Otol (Stuttg)* 1974;53:205–208.
3. Koide C. Temperature changes in the temporal bone caused by the conduction of thermal stimuli. *Equilibrium Res* 1993;52:504–512.
4. Harrington JW. Caloric stimulation of the labyrinth experimental observations. *Laryngoscope* 1969;79:777–793.
5. O'Neill G. The caloric stimulus: temperature generation within the temporal bone. *Acta Otolaryngol (Stockh)* 1987; 103:266–272.
6. Keck W, Thoma J. Conduction of thermal stimuli in the human temporal bone. *Arch Otorhinolaryngol* 1988;245: 335–339.