

VESTIBOLOGY

Caloric stimulation with near infrared radiation does not induce paradoxical nystagmus

La stimolazione calorica con radiazione a infrarossi vicini non induce nistagmo paradossoso

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SUMMARY

Near infrared radiation can be used for warm stimulation in caloric irrigation of the equilibrium organ. Aim of this study was to determine whether near infrared radiation offers effective stimulation of the vestibular organ, whether it is well tolerated by the patients and especially whether it is a viable alternative to warm air stimulation in patients with defects of the tympanic membrane and radical mastoid cavities. Patients with perforations of the tympanic membrane (n = 15) and with radical mastoid cavities (n = 13) were tested both with near infrared radiation and warm dry air. A caloric-induced nystagmus could be seen equally effectively and rapidly in all patients. Contrary to stimulation with warm dry air, no paradoxical nystagmus was observed following caloric irrigation with a warm stimulus (near infrared radiation). Results of a questionnaire showed excellent patient acceptance of near infrared stimulation with no arousal effects or unpleasant feeling. In conclusion, near infrared radiation proved to be an alternative method of caloric irrigation to warm dry air in patients with tympanic membrane defects and radical mastoid cavities. Near infrared radiation is pleasant, quick, contact free, sterile and quiet. With this method an effective caloric warm stimulus is available. If near infrared radiation is used for caloric stimulus no evaporative heat loss occurs.

KEY WORDS: Vertigo • Semicircular canals • Near infrared radiation • Caloric stimulation • Radical cavity

RIASSUNTO

La radiazione a infrarossi vicini può essere usata per stimolazione calda nei test calorici dell'equilibrio d'organo. Lo scopo di questo studio è stato di determinare se la radiazione a infrarossi vicini offre una stimolazione efficace dell'organo vestibolare, se è ben tollerata dai pazienti e specialmente se può rappresentare una valida alternativa alla stimolazione con aria calda nei pazienti con difetti della membrana timpanica. Un gruppo di 15 pazienti con perforazione della membrana timpanica e 13 pazienti con cavità mastoidea radicale sono stati sottoposti a stimolazione vestibolare sia con radiazione a infrarossi vicini che con aria calda. Un nistagmo è stato indotto con uguale efficacia e velocità in tutti i pazienti, ma al contrario della stimolazione con aria calda, non è stato osservato alcun nistagmo paradossoso dopo la stimolazione con radiazione a infrarossi vicini. I risultati di un questionario hanno mostrato un'accettazione eccellente della stimolazione con radiazione a infrarossi vicini senza effetti di eccitazione o sensazioni spiacevoli. In conclusione, la radiazione a infrarossi vicini si è dimostrata una valida alternativa alla stimolazione calorica con aria calda nei pazienti con difetti della membrana timpanica. Essa offre una stimolazione calorica calda veloce, senza contatto, sterile, senza rumori ed efficace.

PAROLE CHIAVE: Vertigini • Canali semicirculari • Radiazione a infrarossi vicini • Stimolazione calorica • Cavità di radicale

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Introduction

Caloric stimulation is one of the most important tests of vestibular diagnostics. Although it is a low frequency test, it provides information on the functional status particularly of both lateral semicircular canals by means of the vestibulo-ocular reflex (VOR), manifested in the type of nystagmus reaction induced¹⁻³. The classic caloric stimulation, described by Bárány in 1906, is conducted using water⁴. Cold and warm stimulation lead ultimately to a nystagmus reaction due to the temperature gradients on the semicircular canals⁴⁻⁸.

The use of water as a stimulation medium, for caloric irrigation, is contraindicated in cases of eardrum defects, radical mastoid cavities (open mastoid cavities) of the ear, inflammations, following paracentesis of the tympanic membrane and drainage as well as following surgical procedures on the middle ear. Stimulation with dry air is a possible alternative. Albeit, the heat capacity of dry air is much lower than that of water and the response to the stimulation is often too weak. A paradoxical type of VOR occurs in cases of eardrum defects and radical mastoid cavities during stimulation with dry air warmed to 44°C. Warm air stimulation induces, in the presence of middle

ear mucosa or secretion in the ear, a very fast drop in temperature to approximately 20 to 30°C due to evaporative heat loss thus resulting in a VOR as in cold stimulation⁹. Stimulation with air can also be very loud – indeed, measurements in the external auditory canal during air stimulation yielded noise levels of up to 125 dB (A)¹⁰.

Aim of the present investigation was to develop a caloric stimulation procedure offering the possibility of stimulation of the vestibular receptors using simple means and which is also rapid, quiet, sterile, not requiring physical contact and well accepted by the patient. The method should not cause any evaporative heat loss and should be suitable for use in patients with a radical mastoid cavity or with perforation of the tympanic membrane. Optical radiation, in the form of near infrared (NIR) radiation, offered a stimulation medium for these investigations. The idea of stimulating the vestibular organ alone with a radiant source had already been suggested by Stark (1978)¹¹.

Material and methods

Physical principles

The human skin represents a strong natural barrier to radiation damage. The depth of penetration of optical radiation depends upon the wavelength and for ultraviolet rays, for example, is only a few micrometers. The maximum depth of penetration of optical radiation into the tissues is achieved with NIR radiation. The NIR spectrum ranges from approximately 780 nm to 1400 nm and is invisible to our eyes. It lies near the long-wave, the red portion of visible electromagnetic waves¹². It is precisely within this spectral range (from approximately 900 to 1000 nm) that the depth of penetration of NIR radiation into human tissue, e.g. into the skin of the auditory canal, can reach several millimetres, depending on the optical power output. Here, the penetration is the deepest. For wavelengths ≥ 1000 nm and ≤ 900 nm, the depth of penetration de-

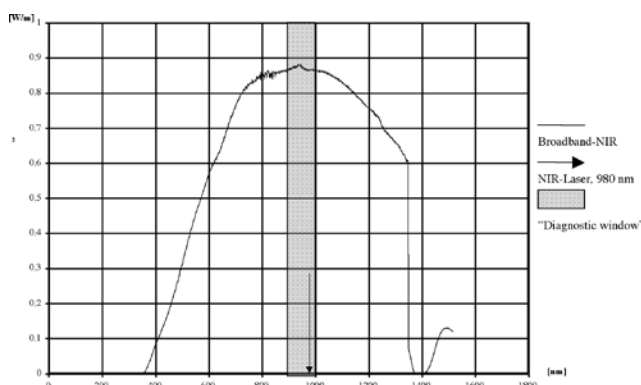


Fig. 1. Broadband and laser-NIR ranges. NIR-spectral ranges from approximately 780 nm to 1400 nm. Maximum depth of penetration of optical radiation into tissues is achieved with NIR radiation precisely within the near infrared spectral range from approximately 900 to 1000 nm ("diagnostic window").

creases (Fig. 1). The cause of this phenomenon is the limited absorption by tissue water and haemoglobin in this spectral range. Therefore, NIR radiation is more suitable than other media for the gentle application of large quantities of heat to the body.

In the present study, this approach has been exploited to construct a source of NIR radiation emitting in the range from 900 to 1000 nm using modified halogen radiators with a maximum broadband wavelength that virtually offers a quick, quiet and sterile warm stimulation of the vestibular organ and requires no physical contact. For the NIR source, a modified light source (KLQ 150, LOPTEK, Berlin, Germany), with a halogen lamp, with a rated power of 150 W that emits light at wavelengths between 350 and 2000 nm and an aluminium reflecting mirror was used (Fig. 2). The modified light source delivered



Fig. 2. Broadband NIR emitter. An ear speculum at the end of the fibre-optic cable aids in the application of NIR radiation in the auditory canal.



Fig. 3. Caloric stimulation with broadband NIR light source.

a broadband spectrum in the NIR range with a radiation maximum of about 950 nm. It was thus possible to apply radiation with an integral optical output of 2.5 W over a flexible fibre-optic bundle with an ear speculum attached to its end (Fig. 3).

Patients

Two test groups were formed for the comparison of caloric stimulation using NIR and warm air. Group A consisted of 15 patients with tympanic membrane defects (n = 15), divided into small perforations (smaller than one quadrant, n = 7) and large perforations (equal to or larger than one quadrant, n = 8). Group B consisted of 13 patients with a radical mastoid cavity (n = 13). In both groups, stimulation with broadband NIR radiation was followed by stimulation with warm dry air (44°, 5 lt/sec.). The maximum stimulation time, both with NIR radiation and with air, was 40 seconds. In all patients, the stimulation was interrupted with the onset of nystagmus or vertigo. NIR radiation stimulation was stopped, if no caloric reaction occurred after 40 seconds. The following parameters were recorded for each test performed: time elapsing from beginning of stimulation until onset of nystagmus; maximal slow-phase velocity of the nystagmus; type of nystagmus (regular or paradoxical); subjective sensation during testing.

For the evaluation of stimulus-induced local and general sensations, a survey was performed. In all the patients examined, Each subject was asked to categorize the general vertigo sensation and the local sensation after stimulation with NIR radiation and with warm dry air in the same ear. Vertigo was described as absent or minimal, moderate or significant. The local sensation was reported as non-existent, comfortable warm feeling or uncomfortable.

The recording and evaluation of eye movements were carried out using three-dimensional videonystagmography (3-D videonystagmography, Difra, Welkenraedt, Belgium). The data were analyzed using StatView 5.0 for Windows. Consent had been granted by the Ethics Committee to conduct the investigations.

Results

Using NIR, a regular nystagmus could be triggered in all patients. The stimulation with dry warm air produced a regular nystagmus in 7 patients (25%) and a paradoxical nystagmus in 17 patients (60.7%). One patient (3.6%) showed first a paradoxical nystagmus, which later became regular. In 3 patients (10.7%), no nystagmus was observed. The mean time of stimulation with NIR radiation before obtaining a nystagmus was 15.5 sec, SE 1.6 sec. The average maximal SPV was 9.4°/sec, SE 0.9°/sec. For warm air, the average stimulation time was 16.1 sec, SE 3.1 sec and the average maximal SPV was 19.6°/sec, SE 4.1°/sec. A comparison using the paired t-Test showed no

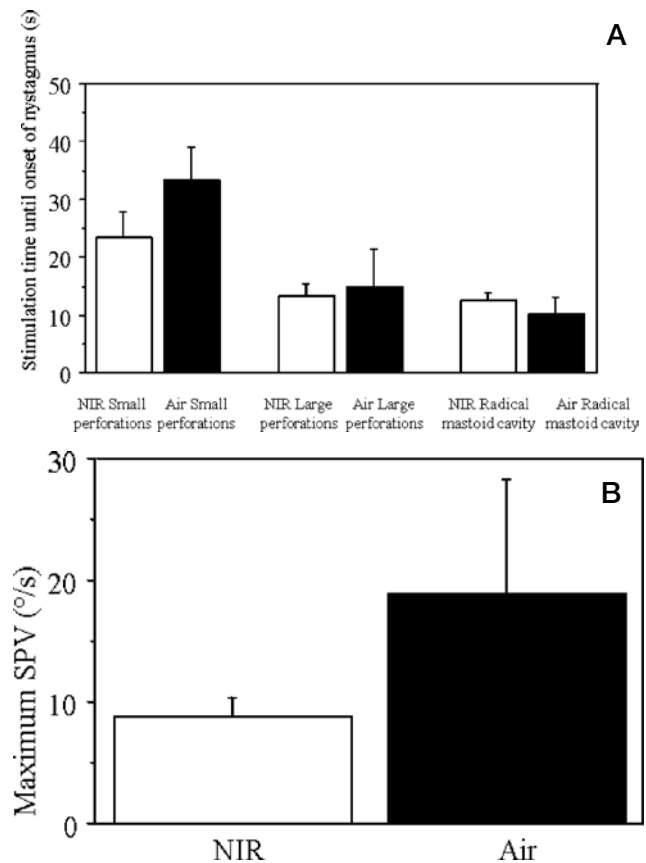


Fig. 4. Comparison of average stimulation time with NIR and air until onset of nystagmus (A) and of average maximal SPV using NIR and air excluding patients with paradoxical nystagmus (B).

statistically significant difference between the stimulation time for NIR radiation and for warm air, for all the patients, as well as within each group (Fig. 4A). For correct evaluation, the patients with paradoxical nystagmus were excluded from the statistical comparison of maximal SPV and, due to the small number of subjects with regular nystagmus (only 8), a t-Test was applied only for the 8 patients, but not for the Group A and Group B patients separately. Here again, no significant difference could be found between the maximal SPV after stimulation with NIR and with warm air (Fig. 4B).

The application of NIR radiation was very well tolerated by all patients. None complained of significant vertigo or of an uncomfortable local feeling, whereas the application of warm air resulted in an uncomfortable feeling in 89.3% of the patients and led to significant vertigo in 32.1%. The detailed results are shown in Table I.

Discussion

In this experimental study, a method of caloric stimulation of the vestibular organ using broadband NIR heat radiation was developed. Spectral investigations have shown that it is possible, by making specific changes in

Table I. Subjective vertigo and local sensation in patients with tympanic perforation and radical mastoid cavity during stimulation with NIR radiation and dry warm air (44°C).

| | NIR radiation | | | | Warm air | | | |
|--------------------------|-----------------------|------------------|---------------------|------------|-----------------------|------------------|---------------------|-------------|
| | No or minimal vertigo | Moderate vertigo | Significant vertigo | | No or minimal vertigo | Moderate vertigo | Significant vertigo | |
| No local feeling | 71.4 | 3.6 | 0 | 75 | 0 | 0 | 0 | 0 |
| Comfortable warm feeling | 10.7 | 14.3 | 0 | 25 | 10.7 | 0 | 0 | 10.7 |
| Uncomfortable feeling | 0 | 0 | 0 | 0 | 17.9 | 39.3 | 32.1 | 89.3 |
| | 82.1 | 17.9 | 0 | 100 | 28.6 | 39.3 | 32.1 | 100 |

the individual components (reflector, light conductor, heat protection filter) of a conventional light source and, with relatively simple technical approach, to create a modified light source featuring a broadband spectrum of optical radiation with portions of visible light and NIR radiation ($\lambda = 360 \text{ nm} - 1350 \text{ nm}$) with a wavelength maximum of about 950 nm. Based on the significantly higher spectral portion of NIR radiation, warm light halogen reflectors are better suited than the cold light reflectors intended for lighting purposes. By adhering to certain power and distance parameters, it was possible to safely use the device on test subjects and patients.

Experiments conducted on bone preparations showed that NIR radiation can heat bone tissue and penetrate almost instantly (with the speed of light) and deeply into bone tissue¹³. The factor of “heat radiation” takes on great significance with regard to heat diffusion in the petrous part of the temporal bone if NIR radiation is used to stimulate it. Applied through the auditory canal, NIR radiation penetrates deep into the bone tissue of the petrous part of the temporal bone, warms it quickly and effectively and triggers temperature changes in the vestibular organ. The maximum effect is achieved at a wavelength of about 900-1000 nm (“diagnostic window”)¹⁴. Convection and conduction are regarded as the main factors involved in caloric response, while heat radiation has been discussed as an additional factor. In our study, we showed that NIR heat radiation is

capable of generating nystagmus in test subjects, thus proving its essential role in the caloric response. The nystagmus triggered with NIR radiation corresponded in direction to that of warm stimulation. It is visible under Frenzel glasses and can be evaluated by means of both electronystagmography and video-oculography.

In healthy probands, a nystagmus reaction can be induced with broadband NIR radiation after a stimulation of at least 15 sec [9,13,14]. A further stimulation (30 sec, 45 sec) leads to a higher maximal slow phase velocity (SPV). In comparison to the caloric irrigation with warm water (44°, 50 ml in 30 sec) the maximal SPV using NIR radiation is lower ($> 15^\circ/\text{sec}$) to those with warm water ($> 30^\circ/\text{sec}$) (Fig. 5)⁹. Therefore, we chose, in this study, a maximal stimulation time of 40 sec in patients with defects of the tympanic membrane and radical mastoid cavities.

A statistical comparison showed that caloric stimulation with NIR radiation is equally effective to stimulation with dry warm air in patients with tympanic membrane defects. However, NIR radiation stimulation has some clear advantages over warm stimulation with air (Table II). A major advantage of NIR radiation is the administration of local, sub-epithelial heat stimulation in a measured manner and without physical contact. Thus heat stimulation occurs in the tissues of the auditory canal and is not transmitted from the surfaces of the auditory canal, as in conventional heat stimulation with water or air. In wet auditory canals or radical mastoid cavities of the ear, warm dry air stimulation produces evaporative heat loss, causing the temperature of the skin of the auditory canal to sink by about 7 to 9°C^{5,15}. With the application of NIR radiation to a non-ventilated, wet external auditory canal, the heat is generated deep into the tissues. Evaporation only takes place, if at all, to a very small extent^{9,15}. This has no influence on the normally generated nystagmus. No paradoxical nystagmus could be observed in NIR radiation stimulation. The method of broadband NIR radiation stimulation is, therefore, especially suited for patients with wet tympanic membrane defects and wet radical mastoid cavities, with infections of the eardrum and in the auditory canal, with drainage of the middle ear, as well as following surgery on the middle ear and after fractures of the otobasis. The

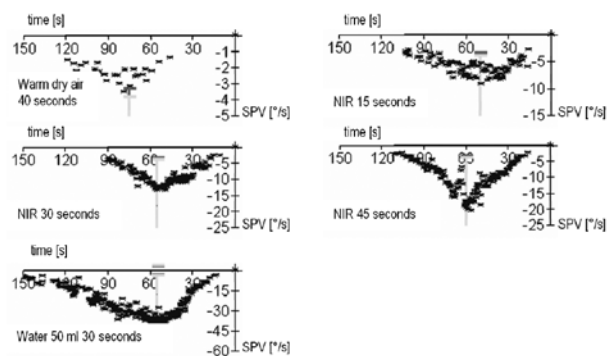
**Fig. 5.** Results (SPV) following dry warm air stimulation (40 sec), broadband NIR stimulation (15 seconds, 30 seconds and 45 seconds) and warm water stimulation (44°C) on the right.

Table. II. Advantages of stimulation of the vestibular organ with NIR radiation.**Advantages of NIR radiation stimulation**

| |
|-----------------------------------------------------|
| Contact-free application of stimulation |
| Sterile |
| Gentle application of stimulation |
| Comfortable, no arousal reaction |
| Very effective stimulation |
| Warm stimulation penetrates deep into tissues |
| No heat loss in the auditory canal |
| No paradoxical effects |
| Noise free |
| Can be performed at the bedside |
| Suitable for emergency diagnosis |
| Easily controlled |
| Targeted application possible (NIR radiation laser) |

questionnaire used in this study shows that NIR radiation stimulation is perceived as non-disturbing by patients, as opposed to warm air stimulation. In many cases, NIR radiation stimulation is not even perceived. Therefore, arousal reactions do not occur with NIR radiation stimulation.

The procedure of broadband NIR radiation stimulation is relatively easy to implement technically. It is also cost-effective. The application of broadband NIR radiation using an ear speculum enables a practicable warm stimulation

of the vestibular organ. Currently, because of the lack of visual control during the application of broadband NIR radiation, ensuring an exact distance from the radiated skin surface of the auditory canal is still problematic. Therefore, at this time, the method can only contribute to the qualitative evaluation of the caloric response to warm stimulation. Also, it is suitable as a screening test in clinical vestibular diagnostics. Further investigations and technological development are needed to confirm the NIR radiation method as an alternative warm stimulus and to measure the warm reaction to NIR radiation quantitatively for either side. At present, the method offers advantages in certain cases, if water irrigation is impossible and the stimulation with dry air might induce a paradoxical nystagmus as in patients with tympanic membrane defects or radical mastoid cavities (open mastoid cavities). A thermal equilibrium test with warm and cold stimulation is necessary for complete evaluation of peripheral vestibular function.

Outlook

Results of experimental investigations of stimulation of the vestibular organ with NIR radiation represent the basis for the development of a device¹⁶. A battery-operated, handheld device in the form of an otoscope that emits NIR radiation is conceivable¹⁷. Prerequisites are a contact-free distance measurement in the auditory canal and confirmation of the diagnostic value of warm stimulation as the sole stimulation method.

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