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ORIGINAL ARTICLE

Near-infrared spectroscopy in vegetables and humans

An observational study

Ronald A. Kahn and Anelechi Anyanwu

BACKGROUND Cerebral near-infrared spectroscopy (NIRS) of tissue oxygen saturation is claimed to be a surrogate marker for global cerebral perfusion. Increasingly, NIRS target-based therapy has been used during cardiac surgery in the hope of decreasing the incidence of adverse neurological outcome.

OBJECTIVES We report NIRS values for some common vegetables and faculty at a world-class medical institution.

DESIGN Observational nonblinded study.

SETTING Single tertiary care institution and local urban vegetable market.

PARTICIPANTS Five yams (*Dioscorea cayenensis*), five courgettes (*Cucurbita pepo*) and five butternut squashes (*Cucurbita moschata*) were studied. Five cardiothoracic surgeons and anaesthesiologists were the control group.

INTERVENTIONS None.

MAIN OUTCOME MEASURES NIRS value of each species.

RESULTS Mean NIRS value for the control group was 71% [95% confidence interval (CI) 68 to 74] and was similar to that of the yellow squashes [75% (95% CI 74 to 76)]. These values were significantly greater than the NIRS measurements of both the butternut squash and yam [63% (95% CI 62 to 64) and 64% (95% CI 63 to 65), respectively, $P < 0.01$].

CONCLUSION Commonly eaten vegetables have NIRS measurements similar to those seen in healthy humans.

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Introduction

Cerebral near-infrared spectroscopy (NIRS) of tissue oxygen saturation is claimed to be a surrogate marker for the adequacy of global cerebral perfusion during certain surgical procedures. Using optical spectroscopy, the degree of oxygen saturation may be estimated by measuring the difference in the intensity of a transmitted and received light at specific frequencies. If sensors are applied to the forehead, real-time measurements of cerebral oxygen saturation may be obtained.

Recent investigations have suggested that application of NIRS target-based therapy during cardiac surgery may decrease the incidence of adverse neurological outcome.[1] A comprehensive study to prove this point would require enormous effort and funding beyond the abilities of the authors. A simpler alternative test to assess the general applicability of this technology would be to measure baseline NIRS values in a few common vegetables and faculty members of a world-class medical institution.

Methods

The current study was approved by the institutional review board (IRB #17-01618, One Gustave L. Levy Place, Box 1081, NY, NY 10029, 212 824-8200. Approved April 2017). The study group consisted of vegetables we obtained from the local market. To avoid bias, the investigators were not allowed to cook or eat any of the study vegetables prior to conclusion of the study. The control group consisted of neurologically intact cardiothoracic surgeons and anaesthesiologists. The neurological function of the anaesthesiologists was defined as their ability to adjust the height or tilt of an operating room table or to find a 100 dollar banknote taped to the chest of a patient. For the surgeons, an intact spinal cord

From the Department of Anesthesiology, Perioperative, and Pain Medicine (RAK) and Department of Cardiovascular Surgery (AA), The Icahn School of Medicine at Mount Sinai, New York, New York, USA; and Division of Anesthesiology, Pain, and Intensive Care, Tel Aviv Medical Center, Israel (RAK)

Correspondence to Ronald A. Kahn, MD, Department of Anesthesiology, The Icahn School of Medicine at Mount Sinai, Box 1010, One Gustave L. Levy Place, New York, NY 10029, USA
Tel: +1 212 241 6366; e-mail: ron.kahn@mssm.edu

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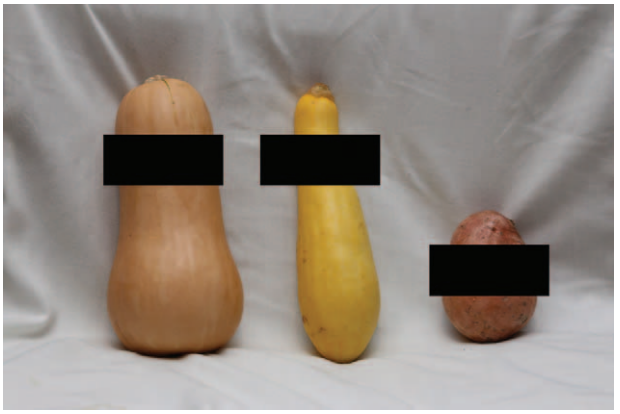
with spinal and brain-stem reflexes was regarded as being neurologically intact; higher brain function was desirable but not essential. No patients or vegetables were involved in the design of the research protocol which was explained to all subjects in the control group prior to obtaining NIRS measurements. Written informed consent was obtained.

A Fore-sight Elite Absolute Tissue Oximeter (Casmed, Branford, Connecticut, USA) was used for all measurements. As ripe mature vegetables were used in the current study, adult-sized oximetry probes were used (Fore-Sight Absolute tissue oximeter large sensor – Adult, Casmed). In an initial feasibility study, NIRS measurements of multiple vegetables were attempted, but NIRS signals could not be measured for Roma tomatoes (*Solanum lycopersicum*) or red peppers (*Capsicum annuum*). Stable oximetry signals were observed with yams (*Dioscorea cayenensis*), yellow (also known as golden) zucchini, variously known as courgettes and calcabin (*Cucurbita pepo*), and butternut squash (*Cucurbita moschata*); these vegetables were therefore chosen for further investigation (Fig. 1). Carrots (*Daucus carota*) were to be included for investigation, but some were consumed by one of the authors (RAK) prior to being studied; this was considered a protocol violation, so all carrots were excluded from further study.

Visibly dirty vegetables were prescrubbed using standard hospital equipment (Scrub Care Chlorohexidine Gluconate Solution 4% Surgical Hand Scrub with incorporated plastic scrub brush). Vegetables were washed with water; it was assumed that the control group had bathed at least once during the prior week, but we chose not to verify this to avoid self-incrimination. To ensure equal metabolic rate, all vegetables were allowed to reach room temperature (RT) after being removed from the refrigerator. Two oximetry probes were attached transversely around the largest portion of the vegetable. As in clinical practice, oximetry probes were placed next to each other with the oximetry sensors adjacent and the light emitting diodes laterally (Fig. 2). For the control group, the oximetry probes were attached to either side of the forehead. After a minute of stabilisation, baseline measurements were recorded. Subsequent oximetry measurements were recorded after 5 and 10 min. At completion of the experiment, all experimental subjects were euthanised. The yams and butternut squash were baked at 190 °C for 60 min, whereas the yellow zucchini were cut transversely and fried in hot vegetable oil with a small amount of salt and pepper. Members of the control group were allowed to return to their daily activities.

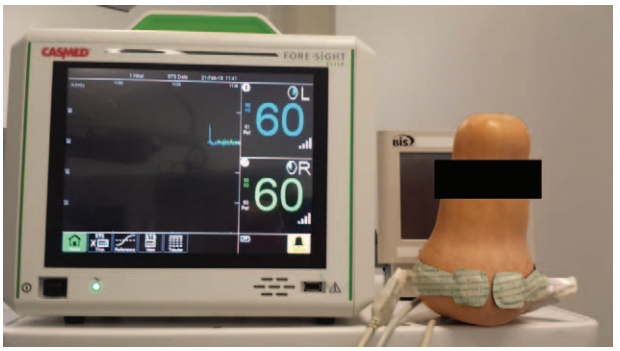
Study size was limited by the ability of one of the authors (RAK) to carry multiple sacks of vegetables from the market. The mean NIRS measurement for each subject during the study period was determined. The two right and left lateral simultaneous measurements were considered as two independent measurements. All measurements were reported as mean [95% confidence interval (CI)]. Differences in personal and NIRS variables among subject groups were determined by one-way analysis of variance. Post hoc analysis using Tukey's honest significant difference test was used to determine differences between groups.

Fig. 1



Subjects of the experimental group studied. From left to right butternut squash (*Cucurbita moschata*), yellow zucchini (*Cucurbita pepo*) and yams (*Dioscorea cayenensis*). The identity of subjects has been obscured.

Fig. 2



Experimental setup. A butternut squash is being studied. The oximetry probes are applied transversely at the widest level. The optical sensors are affixed side to side with the light emitting diodes positioned laterally. A portion of the subject was obscured to ensure anonymity.

Results

A total of 20 subjects were studied from February until April 2016: five physicians, five butternut squash, five yams and five yellow zucchini. Personal information is summarised in Table 1. The control group consisted of three women and two men; the sex of the vegetables could not be determined. As we 'are what we eat', to ensure a valid comparison among groups, none of the

Table 1 General characteristics

	Weight (g)	Length (cm)	BMI (kg m^{-2})
Control	63 200 (42 500 to 83 900)[a]	166 (145 to 187)[a]	22.5 (20.3 to 24.8)
Butternut squash	718 (592 to 845)[b]	18.9 (18.3 to 19.6)	20.1 (16.5 to 23.6)
Yam	219 (102 to 336)	10.4 (7.7 to 13.2)[b]	20.0 (15.3 to 24.8)
Yellow zucchini	200 (164 to 237)	19.1 (18.0 to 20.3)	5.4 (5.0 to 5.8)[c]

Mean (95% confidence interval). [a] Significantly different from vegetables ($P < 0.01$). [b] Significant difference among vegetables ($P < 0.01$). [c] Significantly different from both the control and other experimental groups.

members of the control group were vegans or fruitarians. The height and weight of the control group were significantly greater than those of the vegetables ($P < 0.01$). However, when adjusted for height, the BMI of the control group was not significantly different from the butternut squash or the yam. Although the butternut squash was significantly heavier than the yam and yellow zucchini at 718 g, (95% CI 592 to 844), 219 g (955 CI 102 to 336) and 200 g (95% CI 164 to 237), respectively ($P < 0.01$), the yams were significantly shorter than the butternut squash and yellow zucchini at 10.4 cm (95% CI 7.7 to 13.2), 18.9 cm (95% CI 18.3 to 19.6) and 19.1 cm (95% CI 18.0 to 20.3), respectively ($P < 0.01$). The BMI of the yellow zucchini was significantly less than the butternut squash, the yam and the control group at 5.4 kg m^{-2} (95% CI 5.0 to 5.8), versus 20.1 kg m^{-2} (95% CI 16.5 to 23.6), 20.0 kg m^{-2} (15.3 to 24.8) 22.5 kg m^{-2} (95% CI 20.3 to 24.7), respectively ($P < 0.0$).

The NIRS data are summarised in Table 2. The mean NIRS values for the control and yellow zucchini were 71% (95% CI 68 to 74) and 75% (95% CI 73 to 77), respectively; the difference was NS. The NIRS of the butternut squash and yam at 63% (95% CI 61 to 65) and 64% (95% CI 62 to 64), respectively, was significantly lower than the control group and the yellow zucchini.

Discussion

In the current study, we examined NIRS values of three varieties of common vegetables. The mean NIRS value of yellow zucchini was 75% (95% CI 73 to 77) which was not significantly different than the control group. This value was greater than both the butternut squash and yam at 63% (95% CI 61 to 65) and 64% (95% CI 62 to 64), respectively ($P < 0.01$). We feel that these species-specific data may be helpful in the establishment of a proper standard for NIRS values in common vegetables. Litscher and Schwarz[2] have previously reported NIRS values from a pumpkin (Styrian Cucurbita). Although that report was limited to a single subject in a single species, the current study provides a more robust picture of NIRS values of other vegetables. When combined with the data provided by MRI scanning of vegetables, our physiological observations are complemented by tremendous anatomical insights that may be the fruit for further investigation.[3]

Table 2 Near-infrared-spectroscopy-derived oximetric values

	Oximetry (%)
Control	71 (68 to 74)[a]
Butternut squash	63 (62 to 64)
Yam	64 (63 to 65)
Yellow zucchini	75 (74 to 76)[a]

Mean (95% confidence interval) is presented. [a] Significantly different than butternut squash and yam ($P < 0.01$).

Observational studies have suggested that a 20 to 30% decrease in cerebral oximetry may be associated with peri-operative cerebral injury.[4,5] When used as a trend monitor with a standard set of interventions, cerebral NIRS monitoring resulted in a lower incidence of adverse clinical events in patients undergoing coronary artery bypass surgery.[1] In contrast, other reports have suggested an absolute threshold for cerebral oximetry values as a predictor of adverse outcomes. Cerebral oxygen saturations less than 55 and 60% have been associated with neurological injury after aortic surgery,[6,7] but a meta-analysis suggested only low-level evidence linking cerebral oximetry with postoperative neurological outcome.[8] Taken together, current recommendations are for the maintenance of cerebral saturation either within 20 to 30% of baseline or greater than 55% during the perioperative period.

The authors feel that the recommendation to maintain cerebral oximetry greater than 55% may be too liberal. Based upon the current investigation, the authors suggest that minimum cerebral oximetry should be at least of the level of a yellow squash to ensure a satisfactory neurological outcome. However, if the patient is a politician, the maintenance of cerebral NIRS greater than a butternut squash or yam may be sufficient.

The current study has several limitations. All experimental group measurements were performed at RT. Had the measurements been performed at 37 °C, lower oximetry values may have been observed. Furthermore, some would argue that two of these species studied are not truly vegetables. According to botanical classification, a fruit is defined as a product of the fertilised ovary of the base of a flower and it contains the seeds of the plant. If these stricter definitions are considered, both the butternut squash and yellow zucchini would be classified as fruits. Even as fruits, however, the data from these species may be helpful for further investigation of psychiatric outcome after surgery. Legal precedent for the

consideration of these species as vegetables, however, does exist.[9] In 1886, to avoid paying the vegetable import tax, John Nix claimed that as a tomato is a fruit, it should be tax exempt. This argument was rejected by the United States Supreme Court in Nix v. Hedden. Chief Justice Gray wrote:

''Botanically speaking, tomatoes are the fruit of a vine, just as are cucumbers, squashes, beans, and peas. But in the common language of the people ... all these are vegetables..., usually served at dinner in, with, or after the soup, fish, or meats which constitute the principal part of the repast, and not, like fruits generally, as dessert.''

The authors feel that the result of this decision may be extrapolated to both butternut squash and yellow zucchini.

Finally, the choice of control groups may be criticised. Some might argue that many surgeons do not employ their brains on a daily basis, and some are often in a chronic state that mimics vegetation, as activity can be hard to detect. Because of difficulty in assessing brain function in surgeons, we used adequacy of spinal reflexes as a surrogate, as ability to perform the same reflex actions day after day seemed a constant characteristic of all surgeons. However, this surgical prejudice has been challenged. Barrett[10] observed that orthopaedic surgeons have significantly larger hand sizes than general surgeons. He concludes that although they are larger than their colleagues, ''orthopaedic surgeons, who under their larger exterior are deeply sensitive people who are kind to animals and help old ladies to cross the street. ...Orthopaedic surgeons are indeed large, but as Sir David Attenborough has pointed out, gorillas are among the most civilised and integrated species about.''

We felt though that inclusion of cardiac anaesthesiologists could bring some balance, provided they could show evidence of higher brain function, as adjusting an operating room table can be a very complex and intricate task. There is literature that does not support this higher intellectual function of anaesthesiologists compared with surgeons. In an article entitled 'Orthopaedic surgeons: as strong as an ox and almost twice as clever? Multicentre prospective comparative study', Subramanian *et al.*[11] suggested that male orthopaedic surgeons have greater intelligence and grip strength than their male anaesthetic colleagues. We believe that the inclusion of women in the current study provides the necessary balance.

In conclusion, this study has identified NIRS values for some common vegetables that are similar to cerebral NIRS in humans. Our data are a reminder that results of diagnostic tests may sometimes lack relevant clinical correlation. Test results should always be considered in the clinical context rather than in isolation. Our results suggest that predicting cerebral function from baseline NIRS data is a fraught exercise. In the wrong context, data are prone to misinform; although a cursory look at our data might suggest the contrary, we refute any suggestion that a yam or butternut squash is any more qualified a vegetable than a yellow zucchini, or indeed most of our control subjects.

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References

1 Murkin JM, Adams SJ, Novick RJ, *et al.* Monitoring brain oxygen saturation during coronary bypass surgery: a randomized, prospective study. *Anesth Analg* 2007; **104**:51–58.
2 Litscher G, Schwarz G. Transcranial cerebral oximetry – is it clinically useless at this moment to interpret absolute values obtained by the INVOS 3100 cerebral oximeter. *Biomed Tech (Berl)* 1997; **42**:74–77.
3 https://www.smithsonianmag.com/smart-news/these-mri-scanned-fruits-and-vegetables-unfold-alien-births-180951148/. [Accessed 5 March 2018].
4 Higami T, Kozawa S, Asada T, *et al.* Retrograde cerebral perfusion versus selective cerebral perfusion as evaluated by cerebral oxygen saturation during aortic arch reconstruction. *Ann Thorac Surg* 1999; **67**:1091–1096.
5 Samra SK, Dy EA, Welch K, *et al.* Evaluation of a cerebral oximeter as a monitor of cerebral ischemia during carotid endarterectomy. *Anesthesiology* 2000; **93**:964–970.
6 Fischer GW, Lin HM, Krol M, *et al.* Noninvasive cerebral oxygenation may predict outcome in patients undergoing aortic arch surgery. *J Thorac Cardiovasc Surg* 2011; **141**:815–821.
7 Orihashi K, Sueda T, Okada K, *et al.* Near-infrared spectroscopy for monitoring cerebral ischemia during selective cerebral perfusion. *Eur J Cardiothorac Surg* 2004; **26**:907–911.
8 Zheng F, Sheinberg R, Yee MS, *et al.* Cerebral near-infrared spectroscopy monitoring and neurologic outcomes in adult cardiac surgery patients: a systematic review. *Anesth Analg* 2013; **116**:663–676.
9 Nix v. Hedden 149 U.S. 304 (1893).
10 Barrett DS. Are orthopaedic surgeons gorillas? *BMJ* 1988; **297**:1638–1639.
11 Subramanian P, Kantharuban S, Subramanian V, *et al.* Orthopaedic surgeons: as strong as an ox and almost twice as clever? Multicentre prospective comparative Study. *BMJ* 2011; **343**:d7506.