

Original Article

Noninvasive thermographic visualization of the extent of carotid plaque distribution during carotid endarterectomy using an uncooled infrared camera

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Abstract

Background: Intraoperative thermographic confirmation of the extent of carotid plaque distribution using an uncooled infrared camera was assessed during carotid endarterectomy (CEA).

Methods: This camera was small, light, and provided high temperature resolution (<0.022 degrees), thus allowing detection of the changes in thermal radiation induced by surface temperature differences.

Results: Vascular flow of the artery appeared as a light color, and absence of flow as a dark color. Vascular re-flow was recognized as a bright color. Therefore, vascular flow could be evaluated using the uncooled infrared camera during CEA. The uncooled infrared camera offers real-time information on vascular patency and extent of plaque. Spatial resolution and image quality are satisfactory, and the procedure can be repeated easily and safely.

Conclusion: We have shown that the uncooled infrared camera could be a new and feasible technology for intraoperative imaging of the vascular flow, and is considered to be clinically useful during CEA.

Key Words: Carotid endarterectomy, intraoperative angiography, vascular flow

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INTRODUCTION

Carotid endarterectomy (CEA) is an effective surgical treatment for carotid stenosis, but the exact stenotic area and the shape of the associated plaque are important to be determined before arteriotomy. Table 1 compares the characteristics of the various methods used for assessment of blood flow during microneurosurgery. Conventional intraoperative assessment of blood flow has relied upon duplex sonography and indocyanine green (ICG) video

angiography. Duplex sonography is noninvasive and easily performed. However, the interpretation of microvascular Doppler signals is often difficult and remains subjective. Recently, ICG video angiography was proposed for the intraoperative assessment of the cerebral vascular flow,^[1-4] thus allowing intraoperative control of vessel patency during vascular surgery.^[5-7] This method is simple and offers real-time information on the patency of arterial and venous vessels of all relevant diameters. However, this method requires use of a microscope integrated with ICG

Table 1: Comparison of the characteristics of the methods for intraoperative angiography

	Preparation	Equipment	Cost	Invasiveness	Complication	Accuracy	Spatial resolution	Repeatable	Limitation
Intraoperative DSA	Difficult Hard	Large Expensive	High	More	Significant	Reliable	High	Possible	Significant
Duplex sonography	Easy Quick	Small	Low	Less	Slight	Reliable subjective	Low	Possible	Slight
ICG angiography	Easy	Integrated microscope	High	Less	Allergy	Reliable	High	Possible	Slight
Uncooled infrared camera (present study)	Easy Quick	Small	Low	None Non-contact	None	Reliable	Moderate	Possible	Slight

Intraoperative digital subtraction angiography (DSA) is invasive, with complication rates of 1% to 3% including permanent neurological deficits, and requires the use of ionizing radiation. In contrast, duplex sonography is easily performed, noninvasive, and low cost. However, the interpretation of microvascular Doppler signals remains subjective and insonation of small vessels may be difficult and unreliable. Indocyanine green (ICG) angiography is simple and offers real-time information on the patency of vessels. The spatial resolution and image quality are high. However, the views are restricted to the angle of the surgical approach. This method requires use of a microscope integrated with ICG angiography technology, and necessitates intravenous injection of ICG, which may result in allergic reaction. The uncooled infrared camera is a quick, reliable, cost-effective, and noninvasive method, which requires no use of ionizing radiation or ICG. In addition, there is no limitation of the microscope. The spatial resolution is excellent.

video angiography technology, and necessitates intravenous injection of ICG, which may result in allergic reaction, and delays repeat angiography until washout of the ICG.

Thermal radiometry, a technique that measures surface temperature distribution, is a non-contact and real-time monitoring method. An uncooled infrared camera can detect changes in the thermal radiation induced by differences in surface temperature. We previously evaluated the uncooled infrared camera and suggested that this modality may be suitable for assessing bypass patency.^[8] In the present study, we assessed the potential of the uncooled infrared camera for noninvasive visualization of vascular flow during CEA, and investigated this modality for assessing the extent of carotid plaque distribution during CEA.

MATERIALS AND METHODS

Preparation of the uncooled infrared camera

The infrared camera used in this study had two unique features: A wafer-level chip scale vacuum package with a 160 × 120 silicon-on-insulator-diode array providing a detectable wavelength range of 8-12 μm, and real-time signal correction capability with respect to the ambient temperature. This camera is small (42 × 56 × 43 mm), light (70.3 g), and has high temperature resolution (<0.022°). The output of the uncooled infrared camera was recorded with a digital video recorder.

Patient population

All clinical study protocols were approved by the medical human ethics committee of the National Defense Medical College. Written informed consent was obtained from all patients and/or responsible family members. The present study included five male patients aged from 46 to 78 years (mean age 68 years) who underwent CEA studied with an uncooled infrared camera at our hospital. Indications for CEA were based on the clinical history of ischemia and degree of stenosis of the carotid artery. We preoperatively

evaluated plaque distribution and characteristics using magnetic resonance imaging (MRI) and three-dimensional computed tomography angiography (3D-CTA). In addition, we usually checked the postoperative findings using 3D-CTA. We retrospectively reviewed the hospital records including medical charts, operative records, and radiological findings.

Study protocol

All patients were managed under the same protocol as follows. The extent of the plaque was assessed with the uncooled infrared camera before arterectomy. In addition, the vascular flow was assessed using intraoperative near-infrared video angiography after completion of the CEA. We used the internal shunt system in all patients during CEA. The vascular flow signal was visualized on the video screen in real time and recorded with a digital video recorder. The images could be reviewed and stored on the digital video camera or transferred to a personal computer. Postoperative findings of intraoperative near-infrared video angiography were validated by performing early 3D-CTA.

RESULTS

Intraoperative video angiography demonstrated the vascular flow of the artery appeared as bright color in all CEA procedures. Consequently, the uncooled infrared camera offered real-time information on the vascular patency during CEA in all five patients. The setup time ranged from 3 to 5 min, and the time required for investigation ranged from 1 to 3 min. No hardware failures occurred, and no side effects were observed after surgery. The spatial resolution and image quality were high enough to allow assessment of the carotid artery. The distal end and the proximal end of the carotid plaque could be identified in all cases. Improved findings were obtained in all five cases after CEA. The postoperative 3D-CTA findings corresponded to the

intraoperative near-infrared video angiography findings in all five patients.

Representative case

A 67-year-old man suffered a right hemispheric stroke 1 month before presentation. 3D-CTA revealed severe stenosis of the carotid artery [Figure 1a]. Carotid magnetic resonance angiography showed that the carotid plaque was unstable [Figure 1b]. The patient underwent a standard right CEA [Figure 1d and e]. The extent

of the plaque was assessed with the uncooled infrared camera before arterectomy [Figure 1c], especially on the distal side of the internal carotid artery. After completion of the CEA, vascular flow was assessed using intraoperative near-infrared video angiography [Figure 1f]. No complications, such as acute obstruction, occurred immediately after CEA [Figure 1g]. Postoperative 3D-CTA showed that the severe stenosis of the carotid artery had improved [Figure 1h].

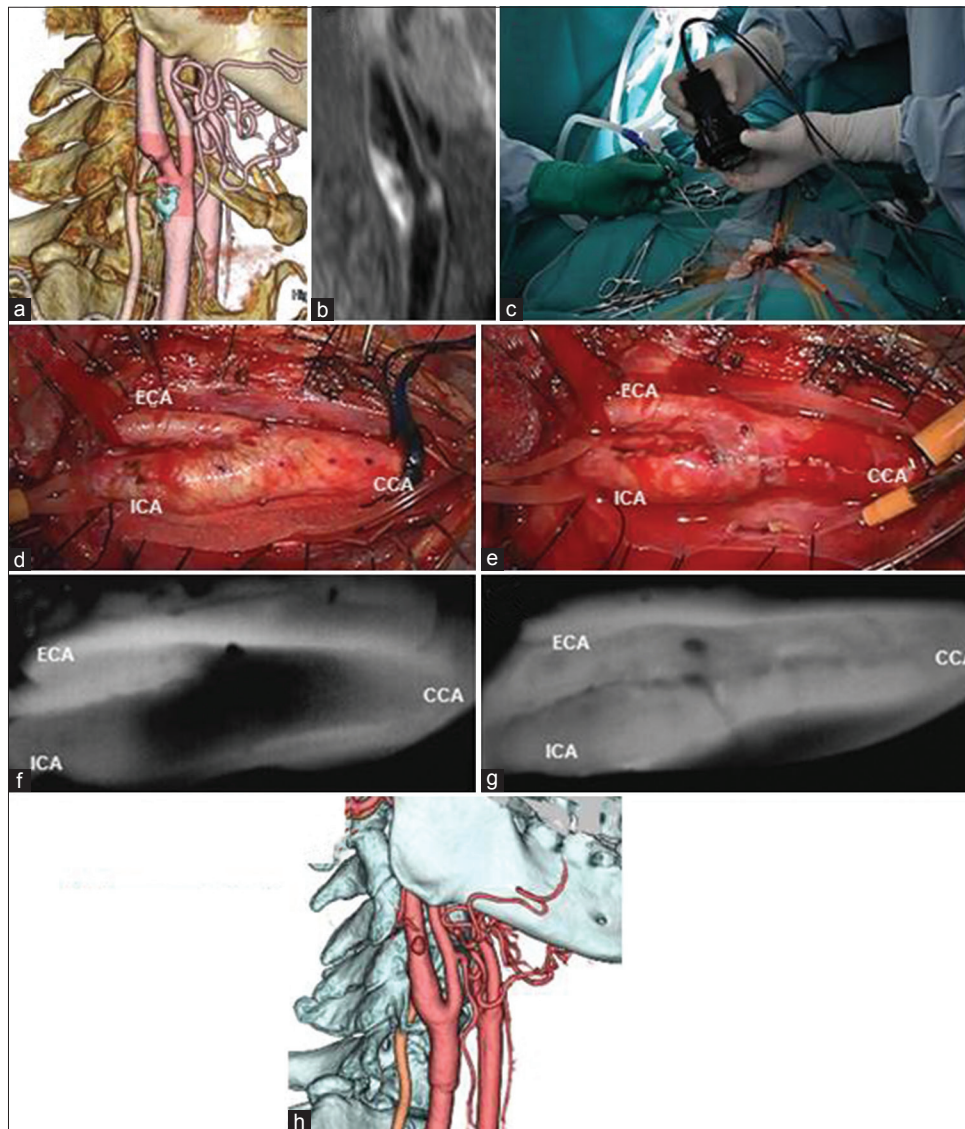


Figure 1: A 67-year-old man suffered a right hemispheric stroke 1 month before presentation. 3D-CTA revealed severe stenosis of the carotid artery (a). Magnetic resonance angiogram showed that the carotid plaque was unstable (b). The patient underwent a standard right CEA. Intraoperative findings before arterectomy (d) and after complete CEA (e) are shown. The extent of the plaque was assessed with the uncooled infrared camera before arterectomy (c), especially on the distal side of the internal carotid artery. After completion of the CEA, vascular flow was assessed using intraoperative near-infrared video angiography (f). The uncooled infrared camera equipped with optical fibers (not shown) was connected with the monitor. The device had two unique features: A wafer-level chip scale vacuum package with a 160×120 silicon-on-insulator-diode array providing a detectable wavelength range of 8-12 μm , and real-time signal correction capability with respect to the ambient temperature. The camera was small ($42 \times 56 \times 43$ mm), light (70.3 g), and had high temperature resolution ($<0.022^\circ$). The output of the uncooled infrared camera was recorded with a digital video recorder. No complications, such as acute obstruction, occurred immediately after CEA (g). Postoperative 3D-CTA showed that the severe carotid stenosis had improved (h). CCA: common carotid artery, ICA: internal carotid artery, ECA: external carotid artery

DISCUSSION

Thermal radiometry, a technique used for measurement of surface temperature distribution, is a non-contact and real-time monitoring method. Thermal radiation in the infrared range can be visualized by an infrared camera. Active research on remote sensing and security applications has developed smaller and lighter infrared cameras than the cameras used for conventional thermography. The present study used an uncooled infrared camera to assess blood flow during CEA. We found that the spatial resolution of the method was excellent. Moreover, there were no physical constraints related to the surgical and angiographic equipment. The present study demonstrated that the uncooled infrared camera provides a quick and reliable method for assessing blood flow in both large and small vessels. Further development will be needed to fit the uncooled infrared camera with an auto-focus motorized zoom lens onto the operating microscope, and to set the reference intensity based on the known temperature of an object placed in the microscope field of view to provide a simple technique for temperature compensation. The uncooled infrared camera, which represents a new technology for intraoperative imaging of the vascular flow, was clinically useful during cerebrovascular surgery, in particular for revascularization surgery, without requiring the use of ICG or an expensive, specially developed microscope.

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