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PATIENT FACING SYSTEMS

Design and evaluation of a novel and sustainable human-powered low-cost 3D printed thermal laryngoscope

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Introduction

Laryngoscopes are an essential and necessary piece of equipment used by anesthesiologist on a daily basis. Early designs of laryngoscopes date back as early as the 1700's, however, significant innovation and modifications began to take place in 1913 and have continued to the present day [1]. Critical to the operation of laryngoscopes is the requirement of a functional light source. While recent designs of laryngoscopes incorporate high efficiency Light Emitting Diodes (LED) as light sources, they still require power from a stored source that is either rechargeable or disposable. This can become a challenge in low resource settings where batteries or electricity are not readily accessible. An investigation of health facilities in 11 sub-Saharan African countries revealed that 26% of health facilities and 1% of hospitals had no access to electricity. Similarly, 6% of hospitals relied on generator-only power, and 66% of hospitals were classified as not having reliable access to electricity [2]. Furthermore, batteries are expensive, often difficult to acquire and their performance deteriorates over time. Batteries that are not properly recycled lead to toxic effects on the environment and potentially harmful consequences to the surrounding communities. In an effort to create a novel laryngoscope with a completely renewable energy source, we sought to design and evaluate a novel human-thermal powered laryngoscope based on the Seebeck effect.

The Seebeck effect describes a phenomenon where a magnetic field is generated from a temperature gradient through a semiconducting material (Fig. 1). Peltier tiles or thermoelectric generators are able to harness this thermal difference and produce a direct current. We hypothesized that embedding the Peltier tiles into the handle of a specially designed laryngoscope, the temperature change between the user's body surface temperature and room air can be converted to a current that powers the light source. This would completely eliminate the need for a battery since power would be reliably generated by the user at the time of intubation. Advantages of the solid-state, robust Peltiers tiles include no need for regular maintenance and the absence of consumable or moving components resulting in increased sustainability and reliability. Therefore, the aim of this research was to develop a low-cost 3D printed laryngoscope with a completely renewable light source that is powered only by thermal energy produced by the user's hand when holding the laryngoscope.

What is already known?
• Laryngoscopes are vital equipment for managing airways and the electrical or battery power to use them is not readily available in low-resource areas.
What is new?
• We describe the design, development and successful evaluation of novel sustainable human-powered low-cost 3D printed thermal laryngoscope

This article is part of the Topical Collection on *Patient Facing Systems*

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Materials and Methodology

Thermal electric generator (TEG)

An iterative approach was employed for prototype design and testing. In order to investigate the number of Peltier

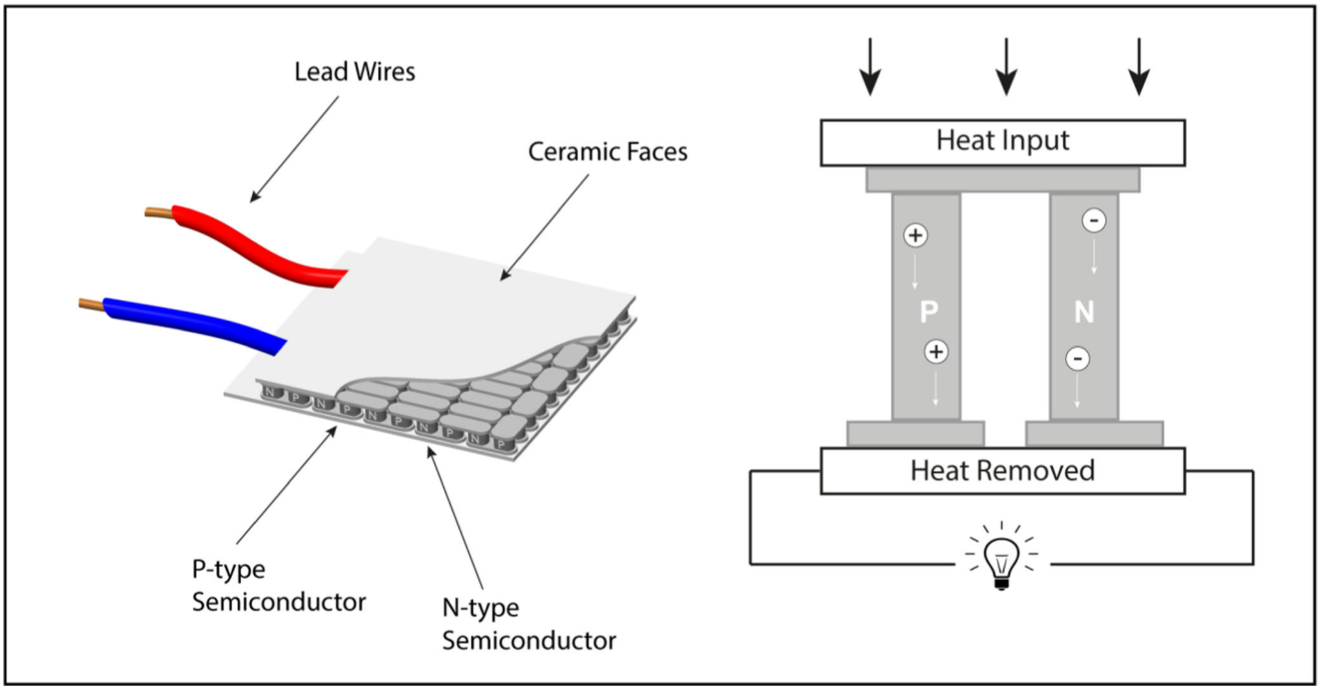

Fig. 1 Left - Thermoelectric Generator (Peltier Module) - Marlow Industries TG12–4-01LS (30x30x3.33 mm) Right - Schematic of the Seebeck Effect - a voltage or thermoelectric EMF is created in the presence of a temperature difference between 2 different semiconductors

tiles (TEGs) needed to effectively power the laryngoscope, tile dimensions and output were measured individually, and in groups of 2, 3, and 4 connected serially. The Peltier tiles (Marlow industries TG12–4-01LS Digikey 1681–1070-ND) were adhered to a specially designed aluminum heat sink (Advanced thermal solutions ATS-EXL63–300-R-Digikey ATS2189-ND) with thermal tape (t-Global technology 6.0 W/m-k DC0022/02-H48-6G-0.3-2A Digikey 1168–1829-ND). For each scenario, the leads from the tiles or tiles combinations were connected to the voltage booster or step up transformer (TXL W1210), which was then connected to the LED being tested. A light meter sensor (Testo 545 serial number 03077590) was mounted faced down on a retort stand at 20 mm directly above the LED [3]. In order to create a consistent temperature difference of approximately 10 degrees Celsius, the aluminum plate was first heated over a water bath for even heat distribution until the desired temperature was achieved. For each measurement, the temperatures of the aluminum plate surface, and tile surfaces were measured and recorded using a digital temperature reader (Mastercraft). The tiles were then placed faced down on the aluminum plate with slight pressure applied. For each scenario, 10 to 14 measurements were recorded. The lowest and highest temperature differences were discarded such that the means and standard deviation could be calculated for 10 data points. Temperatures on the tiles and heated surfaces ranged from 21.3 to 22.9 degrees Celsius, and 32.4 to 34.1 degrees Celsius respectively. The maximum brightness from the light meter was recorded subtracting the baseline brightness which was between 1 to 2 lx.

3D Printed Handle

The 3D printed handle was then designed to contain four thermoelectric generators (Peltier Tile) extending through an open portion of the exterior for direct contact with the user's hand in order to extract the maximum heat from the users left hand (Fig. 2). The inner surface of the thermoelectric generator is attached to an aluminum heat sink with multiple cooling channels in order to optimize the temperature gradient across the thermoelectric generator. Integrated circuitry consisting of a low-cost commercially available step-up transformer in direct electrical communication with both the thermoelectric generators and the light source are housed within the handle. A rounded rectangular shape was adopted over a traditionally cylindrical device in order to allow the Peltier tiles to be positioned as close as to the surface of the device as possible,

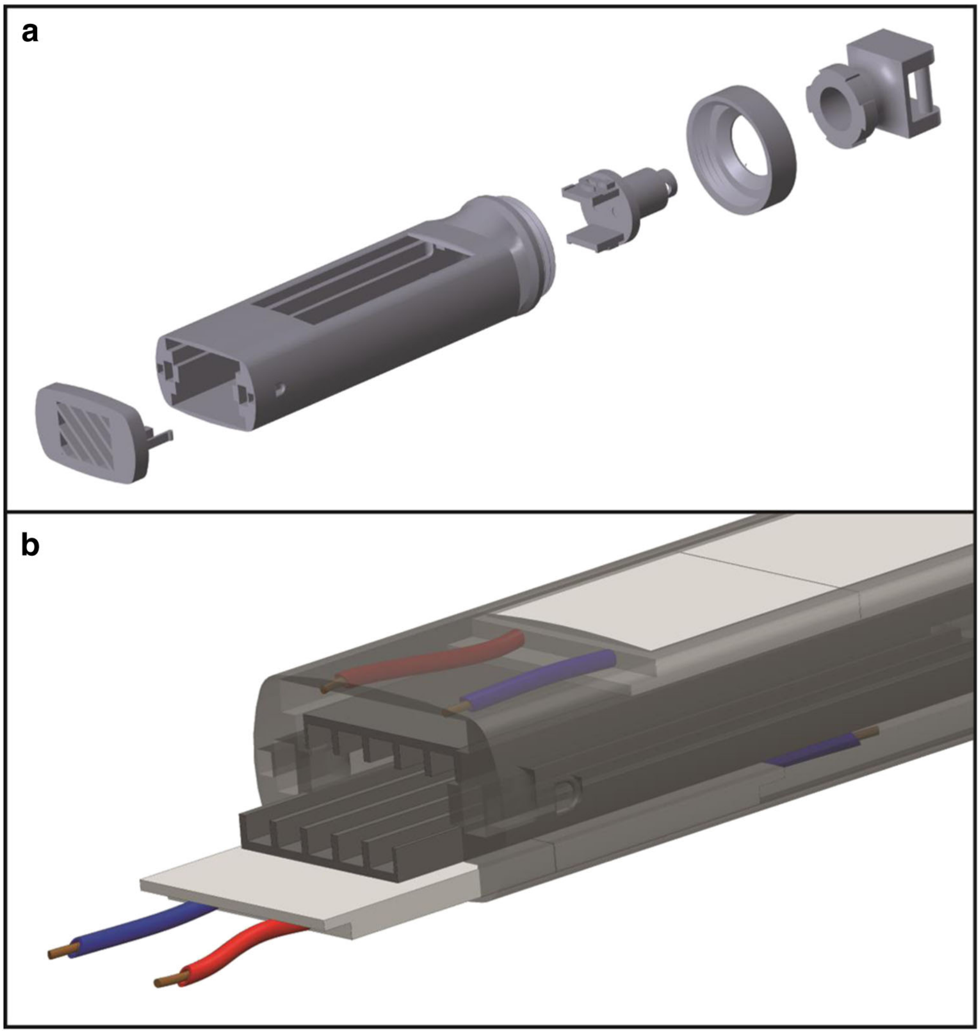

Fig. 2 Schematic of laryngoscope handle and heat sink. A) Device contains an external 3D printed shell designed to contain four thermoelectric generators (Peltier Tiles) through an open portion of the exterior for direct contact with the user's hand B) Schematic of completed design with the incorporation of Peltier tiles and aluminum heat sinks

maximizing skin contact with the operator's hand and heat transfer. The handle itself contains a large central channel with a venting port at the bottom. Since the electrical output the Peltier tiles is proportional to its internal heat gradient, an aluminum heat sink is used to dissipate heat on the cold side of the tile. This heat is directed towards a central channel on the device, which contains a venting port to communicate with room air, further dissipate heat, and reduce the internal heating of the Peltier tiles.

A light mount was used to hold the LED directly adjacent to the optic input of the laryngoscope blade. This direct proximity improved the functional intensity of light by minimizing distance between the light source and receiver. In traditional laryngoscopes, this is achieved using a metal spring. However, a similar design is not possible using stiff 3D-print materials such as ABS. These materials are not intrinsically elastic and often fracture with minimal strain. To address this, a design was created that could exhibit elastic properties even when composed of rigid ABS. This was achieved using two circular flexion points that radially distribute the elastic potential energy over a larger area (Fig. 3). Compression of this device acts similarly to a spring and causes a reduced vertical dimension. When the compressional force has been removed, this restorative force raises the light mount, bringing the LED nearly flush with the optic input of the laryngoscope blade. A prototype version can be seen in Fig. 4. Increasing the number of Peltier tiles connected serially effectively increased the light output (Table 1). In addition, comparison was made between two high powered LEDs. LED #1 (3.2 V, 320 mA) and LED #2 (2.5 V, 65 mA). By simply reducing the amount of current the LED required the brightness intensity was effectively doubled.

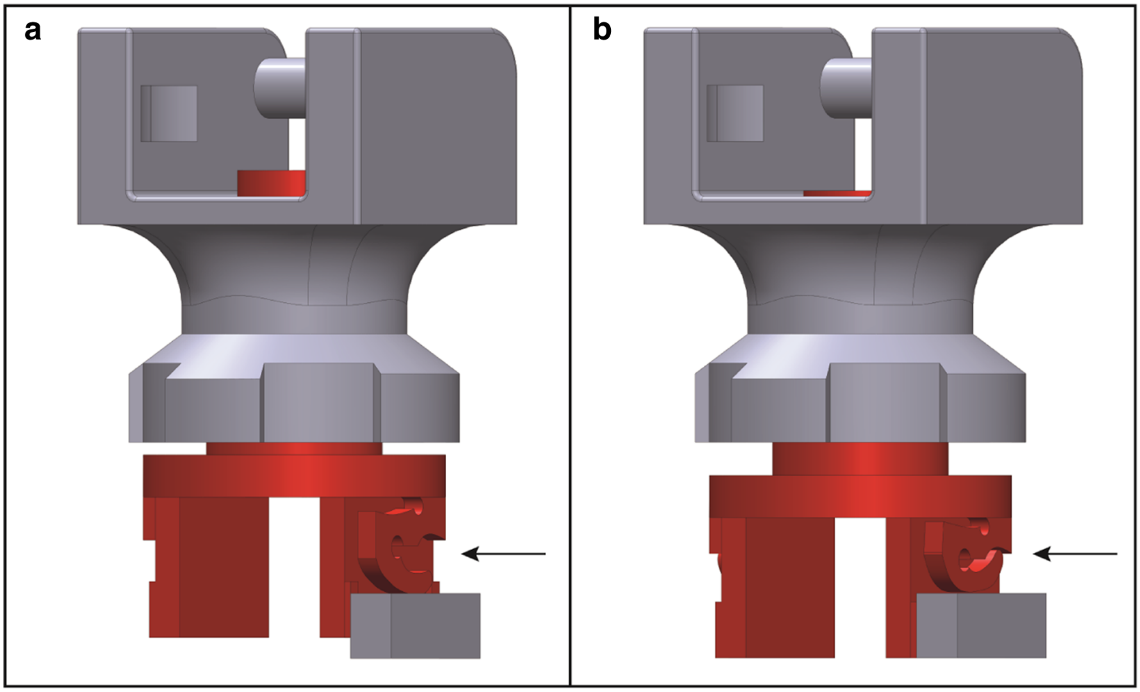

Fig. 3 Schematic of light mount with novel compression arm. A) Non-compressed before blade engagement. B) Compressed to allow for blade engagement

Fig. 4 Prototype version of thermal laryngoscope

Table 1 Number of Peltier Tiles vs Brightness at 10 °C Different

	LED #1		LED #2	
Tile(s)	ΔTemp *(°C)*	Brightness *(Lux)*	ΔTemp *(°C)*	Brightness *(Lux)*
1 Tile	10.7 ± 0.1	54.1 ± 6.7	10.7 ± 0.1	145 ± 20.1
2 Tiles	11.3 ± 0.5	80.2 ± 8.2	11.3 ± 0.3	185.9 ± 15.7
3 Tiles	11.4 ± 0.7	100.4 ± 8.9	11.3 ± 0.5	187.3 ± 27.9
4 Tiles	11.4 ± 0.6	91.5 ± 10.8	11.3 ± 0.4	204.1 ± 11.7

Data expressed as mean ± standard deviation. Comparison was made between two high powered LEDs. LED #1 (3.2 V, 320 mA), LED #2 (2.5 V, 65 mA). A temperature difference of approximately 10 degrees Celsius was generated by heating an aluminum plate over a heated water bath for even heat distribution. For each measurement, the temperatures of the aluminum plate surface, and tile surfaces were measured and recorded using a digital temperature reader. The tiles were then placed faced down on the aluminum plate with slight pressure applied before the brightness was measured and recorded

Results

The final 3D printed prototype incorporated 4 Peltier tiles in sequence and was able to achieve a mean (SD) maximum brightness of 204.1 (11.7) Lux using LED #2 (Fig. 5). The light immediately turns on once the user makes contact with the Peltier tiles embedded into the handle. Time decay was linear with the mean (SD) initial brightness of 193.8 (40.1) Lux decreasing to 142.3 (27.3) and 103.4 (20.7) at 60 s and 120 s respectively (Fig. 6).

Discussion

We have successfully demonstrated a proof-of-concept that a novel laryngoscope incorporating thermoelectric generators can effectively power a light source with only the heat from the user's hand. A maximum of approximately 200 Lux was achieved using 4 Peltier tiles at a 10 °C thermal difference. Although, a minimum illumination of 500 Lux for a duration of 10 min has been suggested by the International Organization for Standardization (ISO) for laryngoscopes, optimal brightness is variable between anesthesiologist and multiple studies have indicated that adequate brightness is obtained with levels far below 500 Lux [3, 4]. Some users have indication lower lux reduces glare on laryngoscopy providing for better lighting and viewing conditions The illumination decays by half at 2 min which would be more than sufficient for intubation conditions that have been shown to average 14 s in patients with normal anatomy [5].

Further optimization of heat sink, thermal adhesive material, handle design, tile placement and LED are required. In addition, as technology advances in the form of flexible and micro thermoelectric generators, the laryngoscope has the potential to meet and even surpass current ISO standards. Although the performance and feedback of the laryngoscope will need to be further tested on both manikins as well as healthy volunteers, this technology has the potential for substantial impact on the global stage.

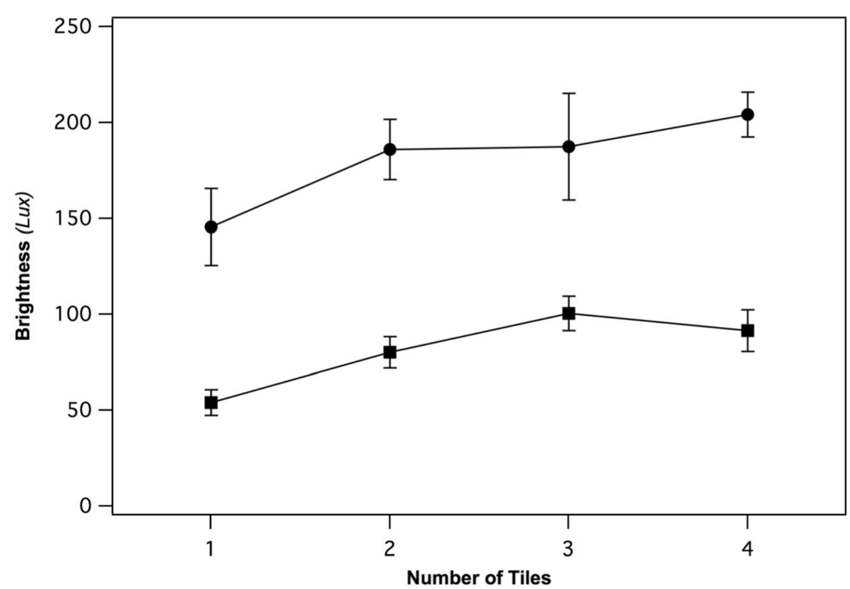

Fig. 5 Peltier tiles were adhered to the heat sink with thermal tape and measured individually, and in groups of 2, 3, and 4 tiles connected in series. A light meter sensor (Testo 545 - serial number 03077590) was mounted faced down on a retort stand at 20 mm directly above the LED. All measurements were performed with a baseline ambient brightness between 1 to 2 Lux. Data is expresses as mean ± standard deviation

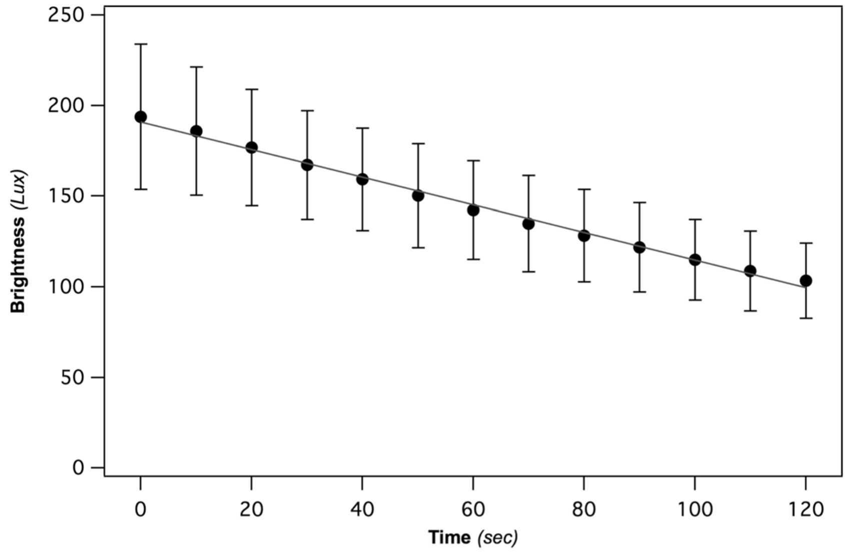

Fig. 6 Brightness decay with time. Data expressed as mean ± standard deviation using 4 tiles with an initial mean temperature gradient of 10.6 ± 0.6 °C

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Compliance with Ethical Standards

This work was presented in part as abstracts at Society for Technology Annual Meeting January 2018 – Miami Florida, United States and the Canadian Anesthesiology Society Annual Meeting June 2018 – Montreal, Quebec, Canada.

Conflict of Interest Clyde Matava declares that he has no conflict of interest. Michael Dinsmore declares that he no conflict of interest. Sachin Doshi declares that he has no conflict of interest. Vivian Sin declares that she has no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

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