Abstract— Dermatoscopes play a burgeoning role in dermatology, but are prohibitively expensive for non-dermatologists, especially medical undergraduates and generalists in resource-poor settings. A low-cost solution lies in developing a smartphone-adapted dermatoscope via three-dimensional printing, which further reduces cost with its affordable raw materials and self-assembly requirements. The prototype dermatoscope has fulfilled its low-cost appeal and trumps existing dermatoscopes in attaining instant and consistent image focus; the percentage of medical students keen on prototype ownership was manifold above commercial dermatoscope ownership rates. Future revisions of the prototype need to improve image resolution, enable smartphone model adaptability and simplify self-assembly to enhance actual ownership. It is a promising device in enhancing dermatological care spanning geographical boundaries and skill level.

Keywords—dermatoscope; low-cost; 3D-printing

I. INTRODUCTION

The dermatoscope, a lens with ten-times magnification, allows for visualisation of dermatologic details inaccessible to the unaided eye (1). Reliably correlated with histodermatopathology, dermoscopy enables quicker, more accurate and non-invasive diagnoses of cancerous and non-cancerous lesions, and is thus increasingly heralded as essential in general dermatology (2-5). However, dermatoscopes are expensive investments for non-dermatologists, especially medical students and medical professionals in a resource-poor setting. A basic handheld dermatoscope, such as the DermLite DL100, costs a prohibitive SGD 510, especially when setting. A basic handheld dermatoscope, such as the DermLite DL100, costs a prohibitive SGD 510, especially when compared to elemental medical instruments and educational materials.

Globally, the truncated undergraduate dermatology training is incommensurate with the dermatological patient load (6). Insufficient undergraduate clinical exposure leads to inept pattern recognition (7) – the foundational skill of dermatology. Undergraduate dermoscopic training has proven to be an effective intervention with sustained skill retention (8); unfortunately, few medical students own a personal dermatoscope, presumably deterred by cost.

Resource-poor settings are constrained by inadequate manpower and insufficient funding. Access to specialists is low; generalists are the norm. Telemedicine has increasingly bridged the geographical and knowledge gap between specialist and rural generalist. The ubiquity of smartphones and extensive mobile phone network coverage (9) allows the smartphone to double as a teleconsultation nexus and data collection device; its built-in camera builds itself a strategic niche in teledermatology where visual assessment is crucial for an accurate remote diagnosis. However, the smartphone’s camera has inadequate magnification and illumination to facilitate clinically useful dermoscopy.

The solution for both groups is a low-cost, compact dermatoscope. The pervasiveness of smartphones and the advent of clip-on smartphone camera macro lenses make a smartphone-enabled dermatoscope a compelling combination. While the clip-on lens is cost-effective at SGD 5, it lacks the full functions of a proper dermatoscope, especially polarised non-immersion dermoscopy to reduce the epidermal glare for visualisation of dermal structures. Compared to handheld dermatoscopes, a smartphone-enabled dermatoscope is also more portable, facilitates image archiving (10) and collaborative learning over online platforms. While smartphone-enabled dermatoscopes are already commercially available, some of which are paired with an application for store-and-forward teledermatology (11), cost remains prohibitive (12).

Thus, there remains a need to develop a cost-efficient but functional dermatoscope. With a stereolithography (STL) file of a basic dermatoscope and assembly instructions provided for free online, three-dimensional (3D) printing of a dermatoscope is the welcome solution with its relative affordability and cost savings from self-assembly, and transcendence of geographical boundaries in limiting rural access to medical equipment.

II. METHODS

A. Prototype Design

The prototype was designed on an online computer-aided design software (123D Design; Autodesk Inc., Sanfael, CA, USA) based on iPhone 6s dimensions and produced with a three-dimensional (3D) printer (Cubicon Style; Hyvision System, Gyenggi-do, Korea) using acrylonitrile butadiene styrene (ABS).

B. Quantification and Comparison of Prototype Specifications

Quantitative comparisons were made between the prototype (P), native iPhone 6s camera (N), iPhone 6s camera with clip-on macro lens only (L) and the commercial handheld dermatoscope (HEINE Delta 20 T Dermatoscope, HEINE Optotechnik GmbH & Co., Herrsching, Germany) with and without polariser (DP and DN respectively). The smartphone was placed at the minimum focusing distance (MFD) using a
tripod at 6cm from image for the N, rested on the removable reflector at 1.6cm from image for P and L, and with the smartphone camera adherent to the viewing aperture of the dermatoscope for DP and DN. All photos were taken after autofocus was achieved under ambient light.

Non-contact dermoscopy was employed when the polariser was not used (DN), as the polarising filters were attached to the same removable component containing a flushed glass board for contact dermoscopy.

As the field of view of PP was partially obscured by the LED hoods, all images were magnified by 50% on the iPhone screen prior to image capture.

1) Colour Reproduction
3 primary colours, 3 secondary colours, and the two extremes of the grayscale provided – off-white and dark grey – from the ColorChecker (13) chart were chosen. Comparisons were made both across camera combinations and across colours.

2) Image Area and Distortion
Graph paper of 11x11mm for a 10x10 square was imaged. The number of squares visible in the image determined the image area. Image distortion was qualitatively compared.

3) Illumination and Contrast
A variety of vascular, pigmented, inflammatory and hyperkeratotic lesions were imaged. Illumination was qualitatively compared with regards to (a) general intensity (b) homogeneity of illumination, and (c) contrast. Contrast was described using the lesion with a perifollicular hyperpigmentation with a central hypopigmentation, as the hyperpigmentation is mild compared to the subject’s skin colour.

4) Resolution
The USAF 1951 IX Edmund Resolution Test Pattern was imaged. The resolution values were determined from the smallest resolvable longitudinal and horizontal patterns.

C. Qualitative Usability Study
Purposive sampling of medical students who had completed their dermatology posting was essential in obtaining an accurate assessment of medical education needs. Nineteen Year 4 medical students from the Lee Kong Chian School of Medicine were randomly surveyed.

The study aims were explained and a demonstration comparing the native iPhone camera with the prototype was done on a skin lesion on the respondent using white light. The students then tested out the prototype before completing the online survey.

The usability survey consisted of both quantitative and qualitative questions on medical students’ perceptions of a dermatoscope and their impressions on the prototype on its usability and marketability. Open-ended answers were analysed using thematic content analysis (14).

III. RESULTS

A. Prototype Design

1) Prototype Components
The prototype components include – (a) a smartphone casing, with a holed hood for LED leads, and an aperture for the camera sensor, (b) a light reflector to concentrate and even the spread of illumination, (c) a lens holder press-fitted anterior to the lens.

The lens was taken from a clip-on smartphone macro lens (SGD 5). The polarised filter was affixed posterior to the lens holder from a pair of polarised 3D glasses.

4 LED bulbs of the following wavelengths were chosen, guided by the DermLite II’s LED colour spectrum (15): white (primary peak at 445nm, secondary peak at 550nm), blue (463nm), yellow (566nm) and red (629nm). The wavelengths were determined using a spectrometer (OOLBase32; Ocean Optics Inc., Dunedin, FL, USA). The bulbs were connected in parallel to a 3V button battery, each controlled by a dedicated slide switch.

2) Improvements from existing dermatoscopes

<table>
<thead>
<tr>
<th>Point of reference</th>
<th>Problems overcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial dermatoscope (handheld or smartphone-enabled)</td>
<td>1. Cost</td>
</tr>
<tr>
<td></td>
<td>2. Intermittent focusing</td>
</tr>
<tr>
<td>Clip-on macro lens</td>
<td>1. Instable smartphone attachment</td>
</tr>
<tr>
<td></td>
<td>2. No polariser</td>
</tr>
<tr>
<td></td>
<td>3. No multispectral option</td>
</tr>
<tr>
<td></td>
<td>4. Intermittent focusing</td>
</tr>
</tbody>
</table>
The prototype’s production cost of SGD 10 is 98% cheaper than the cheapest commercial dermatoscope available, the DermLite DL100 (16).

A key feature exclusive to P is the instant and sustained focussing enabled by the light reflector. With a height identical to the lens’ minimal focusing distance, the user need only rest the device via the light reflector on the patient’s skin and the lesion comes into immediate focus; further magnification via the smartphone’s LED screen inevitably causes micro-movements in the device; this is countered by a firm anchor on the patient’s skin and maintains the lesion in focus.

The additional SGD 5 over the cost of a clip-on lens has allowed for polarised dermoscopy and tetra-spectral imaging – a feature unique to advanced dermatoscopes.

Its rectangular, 4-walled hard casing design, however, makes it exclusively iPhone 6s compatible.

Full feature comparison is shown in Table 1.

### B. Quantitative Comparison of Prototype and Existing Dermatoscopes

1) Colour Reproducibility
Refer to Appendix A for a visual comparison of colour reproducibility.

N, DP and DN most closely reproduced the colours in the standard, although N was superior to DP and DN in reproducing grayscale colours. DN produced a “cross-sign” if the lesion is in full contact with the lens case, due to the brightness of the 4 circumferential LEDs that cast a shadow where the lesion is misaligned with their axes of illumination. L produced washed-out colours. P produced a brighter circular area on the bottom right corner of each image, reflecting the position of the white LED.

The grayscale colours were generally poorly reproduced compared to the primary and secondary colours across all combinations – dark grey is reproduced in a lighter shade and vice-versa for off-white.

2) Image Size, Magnification And Distortion

<p>| TABLE II. IMAG E SIZE DETERMINATION AND D ISTANCE COMPARISON USING MILLIMETER PAPER |</p>
<table>
<thead>
<tr>
<th>N</th>
<th>P</th>
<th>DP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Image size</td>
<td>50.6x66.0mm</td>
<td>7.7x9.9mm</td>
</tr>
<tr>
<td>Magnification</td>
<td>1.17x</td>
<td>7.66x</td>
</tr>
</tbody>
</table>

From Figure 2, P achieved greatest magnification; without 50% smartphone magnification, images by P remain 3.78x magnified.

N showed minimal barrel and pin-cushion distortion; P, DP and DN showed slight pin-cushion distortion without barrel distortion.

3) Illumination and Contrast
Refer to Appendix B for the lesion profiles.

At 50% magnification, the illumination was significantly more homogenous in images taken by P than when taken at no magnification, but incomparable to the homogeneity of illumination by DP and DN. As expected, pictures taken by DN had a darker hue than those taken by DP.

Referring to Appendix A Image D, DP achieved the greatest image contrast, with the scattered hypopigmentation in greatest detail. In P and DN, the pigmented areas were more obvious than the non-pigmented areas.

4) Image Resolution
DP and DN had the highest resolutions at 57.0 line pairs per millimetre (lp/mm), followed by P and L at 32.0 lp/mm and N at 4.0 lp/mm.

### C. Usability Study

1) Background Knowledge and Usage Of Dermoscopy
21.1% of Year 4 medical students did not know what a dermatoscope was. After a brief explanation of dermoscopy, 57.9% of students were keen on purchasing their own dermatoscope for clinical use. Cost was the most frequently-cited factor (87.5%) for barriers to ownership.

2) Usability of Prototype
Ease of use had the highest composite score (4.53/5), but 52.6% of respondents rated aesthetic appeal only average (3/5), with the lowest composite score of 3.11/5. Intuitiveness of use (26.3%) was the most desired area for improvement, such as a casing that has a “more secure fit on the phone to allow for one-handed use”, and “label”(ed) switches.

3) Marketability of Prototype
The significant cost savings made 100% of respondents keen on procuring the prototype, but only 78.9% were willing to self-assemble the dermatoscope.

All students were willing to carry this low-cost dermatoscope during their clinical attachments, with only 21.1% willing to carry it throughout all postings. Portability was the most frequently-cited facilitating factor (75%), followed by ease of use (50%). Interestingly, one respondent recognised that the low-cost dermatoscope enabled holistic patient evaluation, placing students in a “better position” to investigate “potentially serious … conditions”. The remaining 78.9% were only keen on doing so during their dermatology posting. The low yield of a dermoscopic exam in non-dermatological postings was the most frequently-cited barrier.

IV. DISCUSSION

That dermatoscopes were unheard of to 78.9% of students, despite having completed their dermatology posting, reflects the under-emphasis of dermoscopic examination in undergraduate training[8] and the potential for a low-cost dermatoscope to enhance dermatology education.

The prototype achieved superior magnification relative to the commercial dermatoscope, but only 60% of its resolution. The magnification-resolution balance is thus not optimal compared to the commercial dermatoscope, where superior image clarity is achieved at a clinically sufficient magnification. However, achieving instant and constant image focus is emblematic of the prototype.

Doubts about the durability of the device might be due to unawareness of the lifespan of ABS, or confused with flimsiness inherent in the thinness of the case. ABS, however, is more durable and stronger than other mainstream thermoplastic 3D printing materials[17].

Self-assembly remains a hurdle to ownership. The need for soldering skills, assembly time and obtaining electrical components are potentially the greatest barriers. Having to print the prototype via a third party would further raise costs.

For future iterations of the prototype, internalising the electronic circuit components would enhance its aesthetic appeal. Intuitiveness of use would be improved using a clamp mechanism for the main casing that both allows secure attachment for single-handed use, and adaptability to all smartphone models regardless of gadget thickness. The prototype may be strengthened with a thicker casing. To further simplify self-assembly, the battery-powered lighting system could be replaced with a passive LED light guide transmitting the smartphone’s native light source to surround the camera sensor.

V. CONCLUSION

Medical students’ likelihood and willingness to perform a holistic clinical skin examination has been enhanced by the prototype’s low cost, portability and ease of use. With future refinements and input from resource-poor generalists, the 3D-printed prototype remains a promising device with multiplying effects on healthcare delivery globally.

REFERENCES


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## APPENDIX A – COLOUR REPRODUCIBILITY COMPARISON BASED ON COLORCHECKER CHART

<table>
<thead>
<tr>
<th>ColorChecker Standard</th>
<th>N</th>
<th>L</th>
<th>P</th>
<th>DP</th>
<th>DN</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="ColorChecker Standard" /></td>
<td><img src="image2" alt="N" /></td>
<td><img src="image3" alt="L" /></td>
<td><img src="image4" alt="P" /></td>
<td><img src="image5" alt="DP" /></td>
<td><img src="image6" alt="DN" /></td>
</tr>
</tbody>
</table>

[Image 1: ColorChecker Standard](image1)
[Image 2: N](image2)
[Image 3: L](image3)
[Image 4: P](image4)
[Image 5: DP](image5)
[Image 6: DN](image6)
<table>
<thead>
<tr>
<th></th>
<th>P</th>
<th>DP</th>
<th>DN</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A) Melanocytic nevus</td>
<td><img src="image1" alt="Melanocytic nevus" /></td>
<td><img src="image2" alt="Melanocytic nevus" /></td>
<td><img src="image3" alt="Melanocytic nevus" /></td>
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<tr>
<td>(B) Campbell de Morgan spot (2)</td>
<td><img src="image4" alt="Campbell de Morgan spot" /></td>
<td><img src="image5" alt="Campbell de Morgan spot" /></td>
<td><img src="image6" alt="Campbell de Morgan spot" /></td>
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<tr>
<td>(C) Eschar</td>
<td><img src="image7" alt="Eschar" /></td>
<td><img src="image8" alt="Eschar" /></td>
<td><img src="image9" alt="Eschar" /></td>
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