Lasers in Surgery and Medicine

# The Impact of Color Fidelity on Evaluation of Patients in the Outpatient Dermatologic Setting

**Margit Juhasz,** MD, MSc,[1*] **Christine Pham,** BS,[2] **Ryan Allen,** BS,[3] **Andrew Harper,** BS,[3] **Michael Siminovitch,** PhD,[3] **Wendell Brase,** MS,[4] **Kenneth Linden,** MD, PhD,[1] **Christopher Zachary,** MBBS, FRCP,[1] **and Natasha Atanaskova Mesinkovska,** MD, PhD[1]
[1]*Department of Dermatology, University of California, Irvine, Irvine, California*
[2]*School of Medicine, University of California, Irvine, Irvine, California*
[3]*California Lighting Technology Center, University of California, Davis, Davis, California*
[4]*Department of Sustainability, University of California, Irvine, Irvine, California*

**Background and Objectives:** To demonstrate that high color fidelity light-emitting diode (LED) sources are preferred by dermatologists for the evaluation of patients during standard-of-care, outpatient visits when compared to low color fidelity LED sources similar to fluorescent lighting.
**Study Design/Materials and Methods:** Three different LED sources were installed in exam rooms at a single, academic, medical institution (low color fidelity [82 color rendering index (CRI)] similar to fluorescent lighting, and high color fidelity [97 CRI and 96+red CRI]). A cross-sectional survey study was conducted in three parts. Naturalness (*i.e.* ability to reproduce natural, daylight conditions), effectiveness, color contrast, comfort, and overall performance of each LED source were rated on a 5-point scale from 0 to 4 with 0 being the worse, and 4 being the best. The first part included a survey of board-certified dermatologists ($n = 3$) assessing their visual experience while clinically evaluating a subset of patients during standard-of-care outpatient visits. The second survey was completed by dermatologic medical providers ($n = 55$) at three separate monthly departmental Grand Rounds sessions in which standardized patients were evaluated with the LED sources. Lastly, patients ($n = 75$) finished a survey assessing the comfort level of the LED sources.
**Results:** In the first part of the study, all dermatologists significantly preferred the high color fidelity sources over low color fidelity sources based on all five evaluation criteria, with two preferring the 97 CRI LED source overall, while the third dermatologist favored 96+red CRI. Assessments provided by the 55 participants at Grand Rounds demonstrated that the 97 CRI was most "liked." Patients also preferred the high color fidelity LED source, reporting the 96+red CRI source was the "most comfortable."
**Conclusion:** Dermatologists, dermatologists-in-training and mid-level providers significantly prefer high color fidelity LED sources for outpatient evaluation of dermatologist patients in enclosed spaces, rating them the more natural, effective, comfortable, and providing superior color contrast than low color sources. Patients also favor high color fidelity LED sources as being the most comfortable in the clinic room. Lasers Surg. Med. © 2020 Wiley Periodicals LLC

**Key words:** skin; dermatology; color fidelity; variable color rendering

## INTRODUCTION

Color fidelity is defined as a light source's ability to most accurately reproduce color obtained under natural, daylight conditions in an enclosed space. Sources with the highest color fidelity are those that produce a spectrum of light most congruent with sunlight [1]. Linear fluorescent light fixtures are a common light source type in commercial buildings, including medical facilities, and primarily feature low color fidelity sources. In highly visual medical specialties, such as dermatology, color fidelity is especially important for the characterization and diagnosis of cutaneous disorders such as skin cancer or exanthems (colloquially "rashes"). Just as art museums choose lighting which best reflects the original conditions in which a masterpiece was created, medical practitioners, especially those specializing in dermatology, should strive for lighting conditions which best highlight natural skin tones, as well as contrasts between healthy and pathologic states.

In an era concerned with energy consumption, it is important that hospitals, medical centers, and outpatient clinics are conscious regarding their choices for energy usage. Traditionally, many facilities opt for linear fluorescent lighting; linear fluorescent lamps are low-cost and

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*Correspondence to: Margit Juhasz, MD, MSc, Department of Dermatology, University of California, Irvine, 118 Med Surge I, Irvine, CA 92697. E-mail: mjuhasz@uci.edu

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rely on gas-discharge to create ultraviolet radiation which is converted to visible light by a phosphor coating on the inside of the lamp [2]. Although fluorescent light sources are thought to use 25% less energy than the now antiquated incandescent light sources, innovations have led to even more energy-efficient options such as light-emitting diodes (LEDs) [3].

LEDs are an energy-efficient light source, and they are replacing traditional linear fluorescent lighting used in the outpatient clinic setting. LEDs rely on electrical current passed through a semiconductor (such as silicon or selenium) to create visible light. In addition to their ability to produce the entire spectrum of visible light without ultraviolet conversion, LED sources to use about half the energy of linear fluorescent light sources [4], and require a fraction of the power needed by linear fluorescent lighting. For instance, in this study, the LED luminaires examined use 31.0–49.1 W, while linear fluorescent lighting with three 4-foot long fluorescent T8 lamps uses 66–96 W [5]. Furthermore, linear LEDs, luminaires, and retrofit kits have an extremely long lifespan of 50,000–100,000 hours, as compared with 20,000–36,000 hours with linear fluorescent lamps.

By definition, linear fluorescent light sources are low color fidelity. Although standard in the office setting, fluorescent lights are not ideal for the characterization of cutaneous disease. LED sources may be an energy-efficient solution for producing light with high color fidelity in the medical setting. This pilot study was designed to test the hypothesis that high color fidelity LED light sources are perceived as more natural, effective, and comfortable than low color quality light settings for outpatient dermatologic evaluation.

## MATERIALS AND METHODS

### Ethical Review

This study was considered exempt by the University of California, Irvine Institutional Review Board.

### Study Design

New luminaries containing three LED sources were installed in the ceiling of exam rooms at a single, tertiary, academic center dermatologic practice (Fig. 1)—a low color fidelity [82 colour rendering index (CRI)] LED source, a high color fidelity source (97 CRI), and a high color fidelity LED source with additional red spectrum light (96+red CRI). The 82 CRI source was chosen as a reference with similar performance to fluorescent lighting. The power requirements for the 82, 97, and 96+red CRI LED luminaires were 31.0, 38.5, and 49.1 W, respectively. Prior to use at the dermatologic practice, the LED sources were tested at the California Lighting Technology Center at the University of California, Davis (Davis, CA) to determine each sources' spectral distribution (SPD), and normalize the phototopic light output of all three sources. Each LED source was calibrated to have the same correlated color temperature.

This pilot study was designed as three cross-sectional surveys: (i) in which academic, board-certified dermatologists assessed the three LED sources for the evaluation of a subset of their patients receiving standard-of-care at outpatient clinic visits, (ii) in which dermatologic practitioners of varying educational status (from medical student to board-certified dermatologist, and mid-level providers including nurse practitioners and physician assistants) appraised the same LED sources for the evaluation of six patients during three monthly departmental Grand Round Conferences (two patients per occasion), and (iii) in which patients were surveyed regarding their impression of the same LED sources during their standard-of-care outpatient clinic visits. Medical practitioners and patients were surveyed by two trained, unblinded, test administrators (MJ and CP) to ensure that a repeatable procedure regarding LED setting control was followed. Before evaluation of each LED source, a 30- or 5-second adaptation period was required to allow for the medical practitioners' or patients' eyes to adjust to the new SPD. The order in which the LED sources were surveyed was randomly generated for each encounter; medical practitioners and patients remained blinded to which light setting they were evaluating.

### Surveys

Basic demographic questions were asked of medical practitioners (age, gender, educational level, wearing of glasses or correctional lenses, and history of color blindness), as well as patients (age, gender, wearing of glasses or correctional lenses, and history of color blindness). In the first part of the study, board-certified dermatologists were given a 30-second adaptation period and asked to assess the three LED sources based on naturalness (i.e., ability to reproduce natural, daylight conditions), effectiveness, color contrast, comfort, as well as overall performance in the outpatient clinic setting. Each quality was rated on a 5-point scale from 0 to 4 with 0 being the worst, and 4 being the best; overall performance was also rated on a 5-point scale with 0 being "dislike" and 4 being "like." In the second part, medical practitioners were asked to evaluate the LED sources based on the same five categories above with 30-second adaptation periods. The LED sources were then switched rapidly (5-second adaptation period) in sequence and medical practitioners were asked to rank the sources on effectiveness and overall preference. In the third, and final, arm of the study, patients were asked to evaluate the LED sources based solely on comfort. Statistical analyses of survey answers were performed using parametric methods with significance set to $P < 0.05$.

## RESULTS

### Part 1

Three, board-certified dermatologists (1 woman, 2 men; age range: 41–69 years) were asked to evaluate the three LED sources while conducting standard-of-care outpatient visits over the course of 5 months. Two derma-


Fig. 1. Example of the (**A**) LED luminaire used, (**B**) installed in the ceiling of an exam room at a single, tertiary, academic dermatologic practice, and (**C**) photographs of normal skin under lighting provided by the three LED sources studied.

tologists required glasses/correctional lenses, but none had a history of color blindness. In total, all three dermatologists evaluated 60 patients. The most common chief complaints for outpatient visit were hair loss ($n = 12$), acne, actinic keratosis, cosmetic consult, and rosacea ($n = 5$ each), as well as dermatitis, moles, and skin cancer ($n = 4$ each), among others. All three dermatologists could tell the difference between the three LED sources, and preferred the high color fidelity settings (97 CRI and 96+red CRI) over the low color fidelity (82 CRI) in all domains of the survey (naturalness, effectiveness, color contrast, and comfort; $P < 0.0001$). Two dermatologists preferred 97 CRI (78.2% and 52.6% of encounters) while the third dermatologist narrowly preferred the 96+red CRI LED source (52.9%). Overall, all dermatologists significantly preferred high color fidelity LED sources ($P < 0.0001$); there was no encounter in which dermatologists preferred the low color fidelity 82 CRI setting.

Subgroup analysis of survey responses based on the coloration of skin lesions demonstrated that dermatologists significantly preferred the high color fidelity settings ($P < 0.0001$), with 50% of encounters favoring 97 CRI for the evaluation of erythematous lesions (including but not limited to precancerous skin lesions, atopic dermatitis, and rosacea; $n = 40$) and 50% preferring 96+red CRI for brown (including but not limited to benign nevi, melasma, and post-inflammatory hyperpigmentation; $n = 12$). Only lesions in which dermatologists specifically noted their color of lesions (erythematous or brown) while they were evaluating the different LED sources were included in this analysis. High color fidelity settings were significantly preferred for the evaluation of both light (Fitzpatrick I–III; $n = 40$) and dark (Fitzpatrick IV–VI; $n = 15$)

skin phototypes with 42.5% of encounters preferring 97 CRI, and 60% 96+red CRI, respectively ($P < 0.0001$). Five patients did not have a Fitzpatrick skin phototype recorded (Fig. 2).

### Part 2

The dermatologic conditions evaluated during three, separate, monthly Grand Round Conferences included atopic dermatitis, psoriasis, alopecia areata, and cosmetic consults for brown lesions (melasma, solar lentigines, and ephelides). Fifty-five medical practitioners participated. The majority of participants were female (70.9%), wore glasses or correctional lens during daily activities (60%), and had an average age of $35.2 \pm 10.8$ years; one participant was color-blind. The highest proportion of practitioners were post-graduate trainees (including interns, fellows, and residents; 56.4%), followed by board-certified dermatologists (29.1%), medical students, and others (self-identified as physician assistants) (7.3% each).

Medical practitioners were given a 30-second adaptation period between LED sources. Just as before, the high color fidelity settings 97 CRI and 96+red CRI were significantly favored in all domains of the survey (naturalness, effectiveness, color contrast, and comfort; $P = 0.018$). However, only 58.2% of practitioners reported noting a difference between the LED sources. When asked which light they preferred overall, the high color fidelity 97 CRI (32.7%), was closely followed by the 82 CRI (20%) and the 96+red CRI (18.2%). In contrast, a shorter adaptation period of 5 -seconds dramatically changed their preference

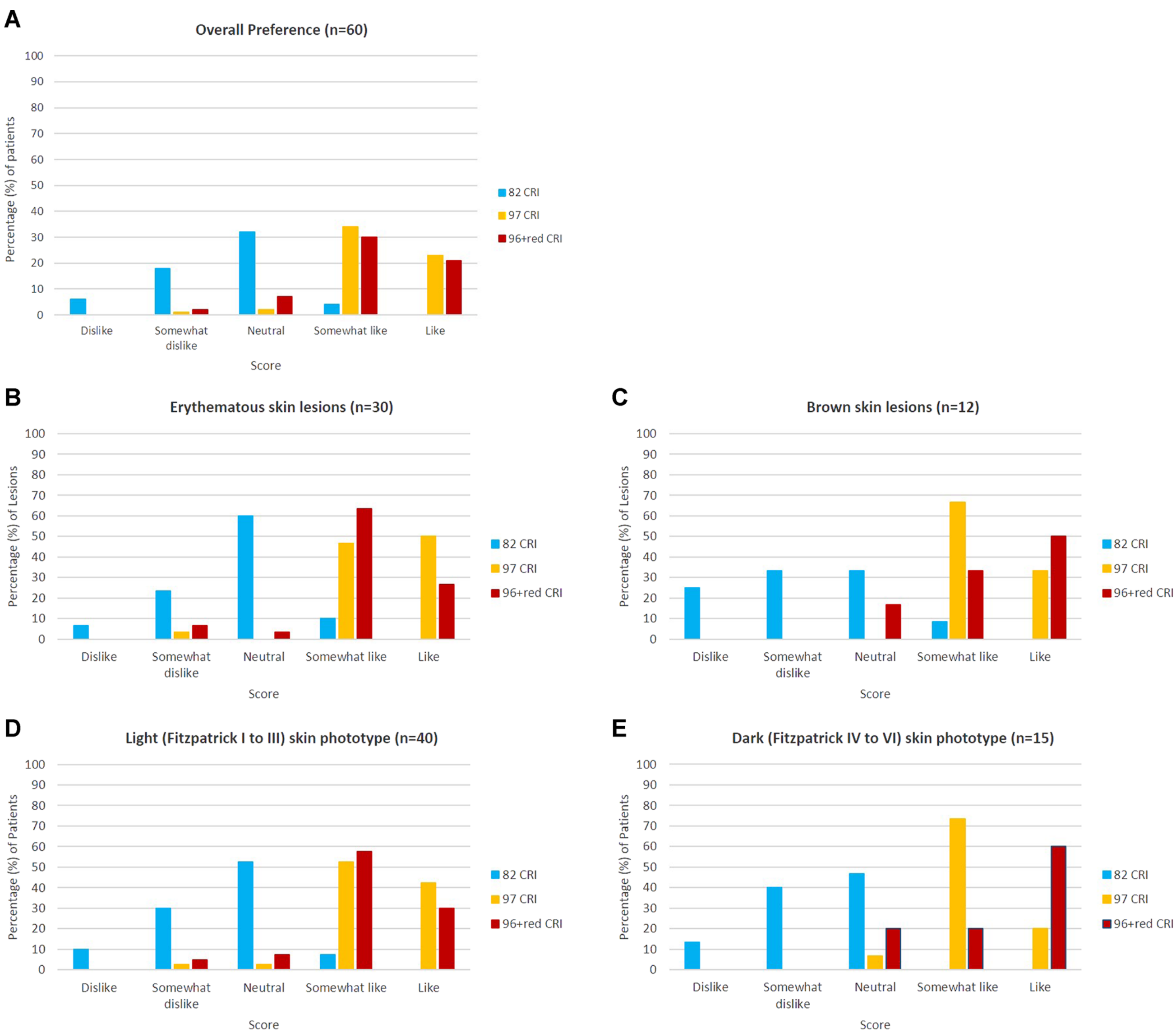


Fig. 2. (**A**) **B**oard-certified dermatologists overall prefer high color fidelity settings (97 CRI and 96+red CRI), as well as for the evaluation of (**B**) erythematous and (**C**) brown lesions, and in both (**D**) light (Fitzpatrick I–III) and (**E**) dark (Fitzpatrick IV–VI) skin phototype ($P < 0.0001$).

with 49.1% preferring the high color fidelity 97 CRI, followed by 29.1% for the high color fidelity 96+red CRI, and 5.5% for the low color fidelity 82 CRI ($P < 0.0001$).

### Part 3

Over the course of 5 months, 75 dermatology patients (64% female; average age 48.8 ± 19.2 years) were surveyed. Fifty-three percent reported they require glasses or correctional lens, and two patients were color-blind. Sixty-five patients fully completed the survey regarding the comfort level; 35.4% reported the 96+red CRI LED source was the “most comfortable,” followed by the 82 CRI at 33.8% and the 97 CRI at 32.3%, however, these findings were not significant ($P = 0.14$) (Fig. 3).

## DISCUSSION

In medical specialties that rely heavily on visual input to make appropriate diagnoses, finding light sources that maintain high color fidelity are important. In dermatology, subtle changes in skin color and texture are often clues to cutaneous disease. In this study, we tested three LED sources, one low color fidelity (82 CRI) to mimic “normal” linear fluorescent medical office lighting and two high color fidelity (97 CRI and 96+red CRI), with board-certified dermatologists, dermatologists-in-training, mid-level providers, as well as patients to determine which light source was preferred in the outpatient setting. As we move to more energy conscious choices, it is necessary to ensure that our choices do not sacrifice visual quality during outpatient clinic visits.

The board-certified dermatologists who participated in the first part of the study significantly ranked the two high fidelity LED sources higher as their preference overall for the evaluation of all skin phototypes, erythematous lesions, and brown lesions. Furthermore, patients agreed that high fidelity sources were the most comfortable in the exam room setting, however, these results were non-significant. Based on the findings in this study, it was decided to permanently outfit all outpatient exam rooms with the 97 CRI light source.

In both the Grand Rounds survey, with multiple training levels of medical providers, and the patient survey the three LED sources were ranked closer together based on likability and comfort level, respectively, compared with the board-certified dermatologists. This may suggest that with further medical training, board-certified dermatologists become more sensitive to changes in the light spectrum produced by sources in a clinic room, and this affects the perception of the natural coloration and texture of their patients’ skin. The Purkinje effect describes the phenomenon in which the eyes’ perception of color changes with different lighting conditions. It is hypothesized that an adaptation period of 30 to 60 seconds is required for our eyes to adjust after a light source is changed. When the adaptation period is shortened, differences in color perception between lighting sources can be accentuated. During our study it was noted that with a 30- second adaptation period, dermatology practitioners ranked the three LED sources closely together; however, when the adaptation period was shortened to 5 seconds, their preference for high fidelity sources was highlighted.

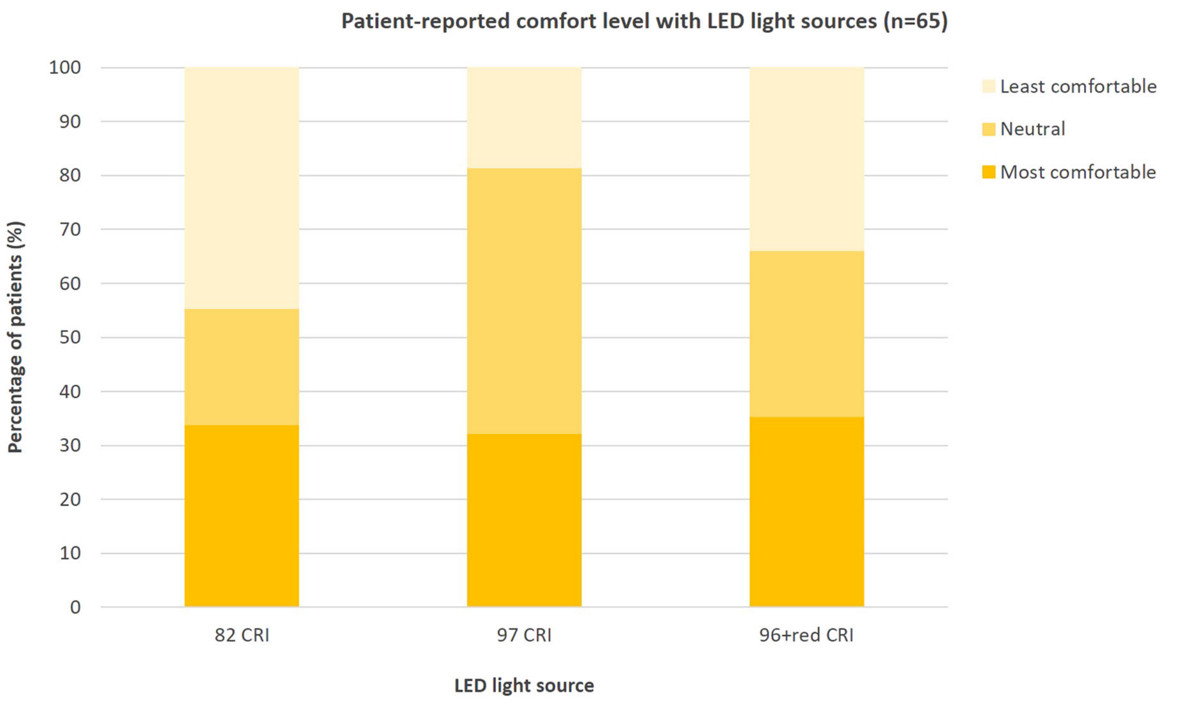


Fig. 3. Patients find high fidelity light sources (97 CRI and 96+red CRI) more comfortable in the outpatient clinic room, however, these results are not significant ($P = 0.14$).

Although dermatologists often rely on dermatoscopes with their own light sources for magnified inspection of skin lesions, it is not known if ambient clinic lighting would affect such evaluation. In this study, we did not record if dermatoscopes were used to inspect erythematous or brown lesions while assessing the various LED sources. It is possible that as ambient light plays a role in the detection of suspicious skin lesions based on gross clinical appearance, there is also a role in dermoscopic evaluation. Further studies will need to be completed to determine if ambient light does affect dermoscopy.

Limitations of this study include its conduct at a single department in an academic center and its relatively small sample size. In the future, studies may compare commonly installed fluorescent lighting to the high color fidelity LED sources to discern if there is a preference amongst medical practitioners in other healthcare applications.

## CONCLUSIONS

Practicing board-certified dermatologists, dermatologists-in-training and mid-level providers significantly prefer high color fidelity LED sources for dermatologic evaluation of patients in the outpatient setting in all domains of the survey (naturalness, effectiveness, color contrast, and comfort). Patients also report that high fidelity LED sources are more comfortable in the clinic room. LED sources 97 CRI and 96+red CRI may be energy efficient options for medical practice lighting and could possibly replace fluorescent sources, as the 97 CRI has already done in our academic practice. Further tests will need to be completed in specialized medical settings, such as the operating room, to determine if other medical providers prefer high color fidelity LED sources for the performance of detailed procedures and find these sources comfortable for long durations.

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