

Research Article

Optimal Lighting of Optical Devices for Oral Cavity

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Oral surgery mainly provides surgical scope illumination by doctors wearing headlamps, but there are still clinical restrictions on use. The limitations are (1) due to the angle of the head swing and the shadow of the visual field during the operation and (2) due to projection of the light source being worn on the doctor's head and the length of the wire, and the fiber-optic wire will affect the relative position of the surgical instrument and limit the scope of the doctor's activity. This study will focus on the development of oral lighting optical microstructure devices to solve and improve the abovementioned clinical use limitations. The production method is to make an oral lighting mold by 3D printing technology and use the polydimethylsiloxane (PDMS) of liquid silicone material to make an oral lighting device with mold casting technology. The results show that the optical simulation achieves the target light distribution by optimizing the three geometric reflection surfaces combined with the lens design by the optimization method, and the maximum illumination value can reach 5102 lux. According to the measurement results of mold casting technology, the average errors of the profile of the 3D printing finished product and the PDMS finished product of the oral device structure are about 1.4% and 16.9%, respectively. Because the contour of the PDMS finished product's error caused the light to shift by 0.5~3 mm distance, the light is still concentrated in the range of the tonsils, so this study can be defined as within the acceptable range of within 16.9% of the intra lighting error. The development of oral lighting devices in this study will reduce the burden on physicians in nonprofessional fields, reduce the time of surgery for patients to maintain the health of doctors, and rise the level of medical equipment to increase surgical safety.

1. Introduction

As the society's awareness of medical health, medical rehabilitation, green environmental protection, and energy conservation rises, the LED industry has become the focus of various professional fields. Among them, the LED light source is suitable for medical illumination because it meets the requirements of high reliability, long life, and low cost and is the best solid light source to replace the current halogen lamp, mercury lamp, and xenon lamp. In addition, the LED is small enough in size to form any geometric shape and any size of point, line, and surface. The light source can also be miniaturized. The LED is very suitable for medical lighting, and domestic LED medical lighting is becoming

more common. It can be used in a wide range of applications, such as combining LED with surgical equipment in various operating rooms to develop its operating room-specific lighting devices, which is why LED lighting is expected to be widely used in the medical field.

This study is aimed at the illumination of the scope of the internal part of the oral cavity. At present, the surgical illumination of the internal oral cavity is mainly provided by the surgeon wearing a fiber-optic projection lamp, but there are still clinical restrictions on use. The main limitation is the scope of surgery. Lighting needs to be oscillated by the doctor's head to achieve better illumination range. The physician must focus on the surgical procedure and also control the angle of the light source. Therefore, the shadow

obstacle caused by the poor swing angle of the head or the dead angle of the visual field is often caused by the poor illumination of the surgical area, and the interference affects the operation. At present, most of the literature or patents focus on single use. According to the results of the literature, there are many methods for discussing oral lighting. For example, when using the principle of geometric reflection combined with photodynamic therapy (PDT) to treat the oral cavity, it is not necessary to cover the entire oral cavity to make the oral cavity evenly illuminated. The average illuminance produced was 50 mW/cm [1].

Another option is to use an oral lighting patch. One side of the patch is a light-transmissive layer, and the other side is viscous for fixing. There are two cavities between the two sides. The cavity was filled with a chemical substance, and the space in between has two chambers that need to be folded before use. The substance produces a chemical reaction that excites a chemical photoreaction and is emitted by the light-transmissive layer to achieve the function of oral lighting. However, this patent has safety concerns about the luminescence persistence being low and the chemical being at risk of leaking [2]. Part of the light generated by the light source illuminates the surface of the tooth by means of an optical conduit, and the other part of the light is guided by the reflector to a predetermined place. When the light is reflected from the surface of the tooth, the reflected light is received to form a shadow. However, the patent is more suitable for use in taking images. When used in surgery, the doctor needs to take the surgical instrument in one hand, and the other hand takes the product, which is inconvenient, and the product is large in size and easily interferes with the operation when used [3].

When an external light source is directed onto the light guide metal plate, the light is reflected inside the oral cavity to achieve the function of illumination. The disadvantages of this research device are poor light source efficiency and poor lighting performance [4]. The structure is designed as a U-shaped sheet, and a rectangular portion is, respectively, arranged on each of two ends of the U-shaped sheet; a plurality of LEDs are arranged on the side of each rectangular portion, and a power supply line is arranged at the closed end of the U-shaped sheet. This illuminating device has flexibility and also has the function of a mouth opener. This patent can be used for tonsillectomy, but the light supply is insufficient, the surgical field of view is reduced, and it does not provide tongue protection [5]. The oral lighting device developed by Isoite Medical Company from the United States can be used for illumination during dental examinations. However, if it is applied to the removal of tonsils, it will obscure the area of the tonsils inside the mouth and affect the operation. Therefore, it is not applicable [6]. The product launched by American Medical Company eBite, the buccal oral lighting device, has the function of illumination and can be used for illumination in dental and laryngological examinations. However, if used in tonsillectomy, the physician must hold the illumination device and the tongue fixation tool simultaneously. The appliance not only causes difficulty in operation but also affects the surgical field of view and thus is not suitable for use in oral surgery [7].

Based on the patents' literature above, it is found that the problem of obscuring shadows caused by the poor head swing angle or dead angle of view is seldom discussed. In view of this, the research will be discussed for the oral cavity with innovative design and optical simulation software analysis to develop oral lighting devices with high illumination.

With the development of various miniaturized processing technologies, in recent years, in addition to the requirements of high electro-optical transmission rate, high brightness, and longevity, the development of various optoelectronic device products also has the goal of power saving, energy saving, and miniaturization. Under this trend, the development of optical devices is also moving toward miniaturization, array, and integration, and low cost and high efficiency have become one of the research goals in this field. In order to achieve miniaturization of the system, micro-optical devices have become indispensable, and the importance of micro-optical systems has gradually increased, hoping to improve what conventional optical devices cannot achieve.

In terms of mass production of optical devices, the main production technology is mold casting, which can be used to manufacture glass and plastic materials. However, due to the low cost of plastic materials, the ease of processing complex devices, and the short processing time, many photovoltaic devices have been gradually replaced by plastic materials such as imaging lenses, illumination devices, projection lenses, and lens arrays. Different process methods will affect the structural characteristics of the entire microlens, which will affect its optical quality. For example, the radius of curvature of the lens will affect the size and dimension; the surface roughness will affect the quality of the entire optical output.

This study will combine 3D printing technology with mold casting technology, hoping to use this novel process to partially replace the previous micro-optical device manufacturing technology. Among them, polydimethylsiloxane (PDMS) of liquid silicone material is often used to fabricate the micro-optical structure. In 2014, Liu et al. [8] produced a microlens array by a lithography process combined with a mold turning technique and a hot pressing method. The circular groove is made by the photoresist. The upper PDMS is formed into a circular arc surface by suction, and the UV glue is copied to form a convex spherical shape mold. The UV plastic mold is turned into a concave spherical surface with PDMS as a material, and finally a microlens array of a PC substrate is produced by hot pressing of PDMS. The situation in which the PDMS forms a concave curved surface is calculated and controlled in an analog manner. In 2007, Yang et al. [9] used a lithography process and combined it with microfluidic technology to make a cylindrical shape with double exposure, and then PDMS was used to spin coat the PDMS-tunable thin film wafer. The pressure that causes film undulation to change the contact angle was measured. The volume of the injected liquid and the measurement of the contact angle result are controlled, and the effect of changing the lens to the curvature is easily controlled. In 2006, Ren et al. [10] used PDMS polymer plastic

material as the elastic film, and rubber was used to seal the fluid. The pressure was applied to the rubber from the outside to make the upper PDMS film convex into a lens shape, and the change of the contour and the focal length was observed. In 2004, Jeong et al. [11] produced a curved lens that can be biconvex or biconcave with a lithography process and used PDMS rolled mold to obtain a microlens with a fixed curvature on one side; they completed the PDMS lens with one side curved and the other side swirled. A layer of PDMS film is applied to change the surface of the lens to a meniscus or biconvex shape by changing the volume of the liquid in the liquid lens. In 2003, Chronis et al. [12] used a lithography process to form a photoresist into a cylindrical shape and then flipped the PDMS microlens film. The microfluidic injection liquid filled the PDMS film, changing the volume of the hydraulic fluid to fine-tune the focal length using ANSYS software. The film was subjected to force deformation analysis to observe the shape change of the PDMS film and to explore the relationship between pressure, radius of curvature, and focal length.

According to the above literature, PDMS is a thermo-setting elastomer material due to its material property, which has good tactile sensation and does not cause harm to the human body. It has better translucency, replication, and flexibility than general polymer thermoplastic polymerization. The product has better stability and heat resistance and has gradually become an indispensable material in medical supplies, diving equipment, and automobile and motorcycle industries. Therefore, this study uses PDMS as materials for oral lighting structural devices. The advantages of this process can reduce cost and production time, replacing expensive equipment, and mass production constraints. Therefore, measurement and experimentation are used to explore process results in this research process.

There are currently two types of 3D printed biocompatible materials on the market: Stratasys MED610 and Formlabs Form 2 Dental SG. These two materials are widely used in clinical medicine, but the two materials harden due to chemical reactions after molding and solidifying, which do not meet the design requirements of this study. Therefore, this study did not directly use 3D printed products to put into the oral cavity. In view of this, this research uses reverse engineering technology to make molds, pours PDMS materials into the molds, and finally obtains the finished product. Polydimethylsiloxane (PDMS) is a kind of high-molecular organosilicon compound, usually called organosilicon, which is inert, nontoxic, and nonflammable. PDMS is the most widely used silicon-based organic polymer material, which is used in microfluidic systems, caulks, lubricants, and contact lenses in biological microelectromechanical systems. PDMS in solid form is a silicone, nontoxic, hydrophobic, inert, nonflammable, and transparent elastomer. The manufacturing process of PDMS is simple and fast, the material cost is much lower than that of silicon wafers, and it has good light transmission, good biocompatibility, easy to join with many materials at room temperature, and structural flexibility caused by low Young's modulus. PDMS is a very safe substance. It does not react to the immune system and is not swallowed by cells. It does not

breed bacteria or react with chemicals, so there are no commonly believed side effects. This safety data can be obtained from various manufacturers. At the same time, silicone rubber can be developed and produced for skin wounds, which can be used to protect wounds. It is a very safe material and is licensed by health authorities in various countries.

The original design of this study is mainly for the surgical auxiliary lighting of the tonsils to solve clinical problems, and it is not necessary to adjust the angle of the light while performing surgery. It is not intended to replace all headlights, but to design from the perspective of "auxiliary lighting." In addition to the auxiliary lighting for tonsil surgery, the auxiliary lighting device developed in this research can also be used in the following occasions: (1) operating room where headlights cannot be adjusted by hand and is susceptible to interference. (2) When the oral surgery is deep, the oropharynx and hypopharynx will have dead corners if the spreader cannot be opened enough. (3) Where the oral cavity has undergone radiation therapy or suffers from oral submucosal fibrosis, which prevents the oral cavity from opening.

2. Materials and Methods

The limitation of the research scope will be mainly for the removal of inflammation of the tonsils in the oral cavity. The main research focus is to design the oral lighting devices, explore the illuminance by optical simulation analysis, and obtain the prototype design parameters of the lighting devices to facilitate the subsequent process production, measurement analysis, and verification. The oral lighting device design and optical simulation analysis of the tonsil removal procedure are as follows: first, the oral lighting devices are constructed. Second, defining the relative position of the oral tonsil gland and the oral lighting element. Third, using optical simulation analysis to design high-illumination oral lighting devices. Fourth, the process of making the oral lighting devices and measurement verification.

2.1. Oral Lighting Structure Design. The structural design requirements of this study are based on the current state of clinical surgery and are set to meet the following requirements: (1) open the mouth to facilitate the doctor to perform surgery; (2) fix the tongue in order to avoid it interfering with the operation because if the tongue is lifted, it will block the sight; (3) add lighting function to help doctors avoid the lack of light during surgery; and (4) reduce the equipment required before surgery, such as oral spreaders, lighting equipment, tongue depressors, and other medical equipment. The oral lighting structure designed in this study (see Figure 1).

2.2. Define the Relative Position of the Tonsil and the Oral Lighting Devices. Figure 2 clearly shows the relative position of the tonsils and uvula in the oral cavity, that is, the lymphoid tissues located on both sides of the oropharynx. The most common medical problems encountered are

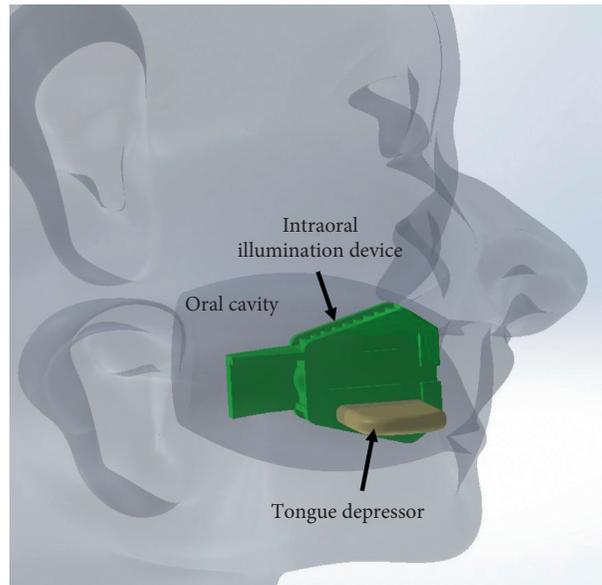


FIGURE 1: Oral lighting structure design schematic diagram.

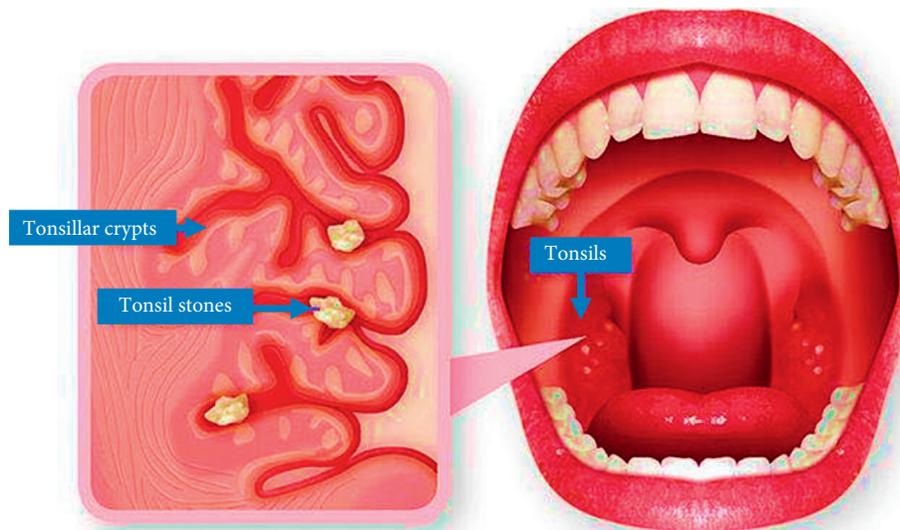


FIGURE 2: Location of the tonsil in the oral cavity.

obstructive hypertrophy or infection. Hypertrophy of the tonsils is often caused by increased immune activity. Hypertrophy itself is not a disease, but when the tonsils are obviously too large, it will lead to obstructive respiratory arrest; the surface of the tonsils can easily hide food debris, pathogenic bacteria, and so on, due to many glandular fossae that may cause infections. Generally, antibiotics will be used first. If there is a recurrent tonsil inflammatory disease, further surgery will be considered. In this study, the relative positional dimension of the light surface of the tonsil and the oral lighting structure is $20\text{ mm} \times 15\text{ mm} \times 30\text{ mm}$ (front \times height \times width) (see Figures 3 and 4). Focusing the light source on the tonsils, with cross emission provided by light sources on the left and right side of the tonsils, can prevent the doctor from reducing the brightness by blocking the light

source during the operation. The definition of the relative position of the optical simulation in the oral cavity is as follows (see Figure 5).

2.3. Oral Illumination Specification. Illuminance is the luminous flux of visible light absorbed per unit area of the surface of the object, and the light used for the incident surface is in Lux. Every place with a different purpose of use should have its appropriate illumination to match the actual needs. This study will use the two commercially available products as a reference to set the illuminance target value. The first is ebite2 for dentistry, and the second is for surgical headless lamps. According to the two products, the first commercial product ebite2 [7] has an illumination range of

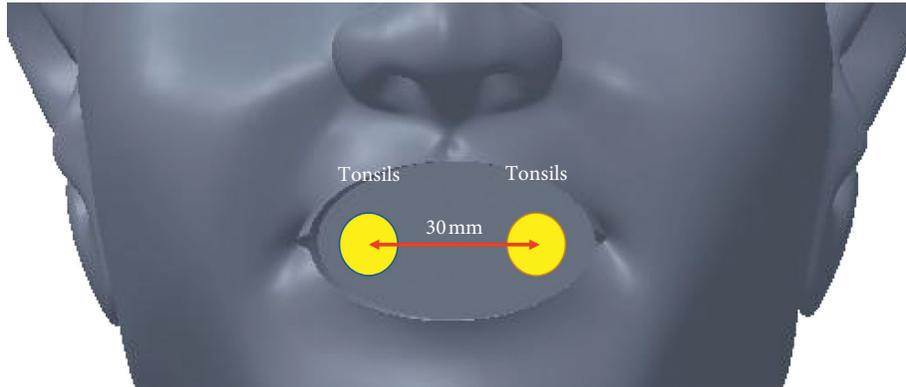


FIGURE 3: Schematic diagram of the definition of the tonsil in the oral cavity.

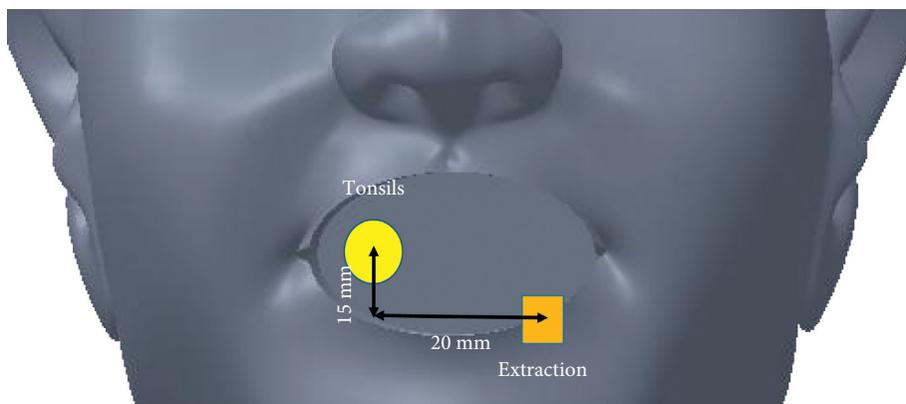


FIGURE 4: Schematic diagram of the relative position of the tonsil gland and the illuminating surface.

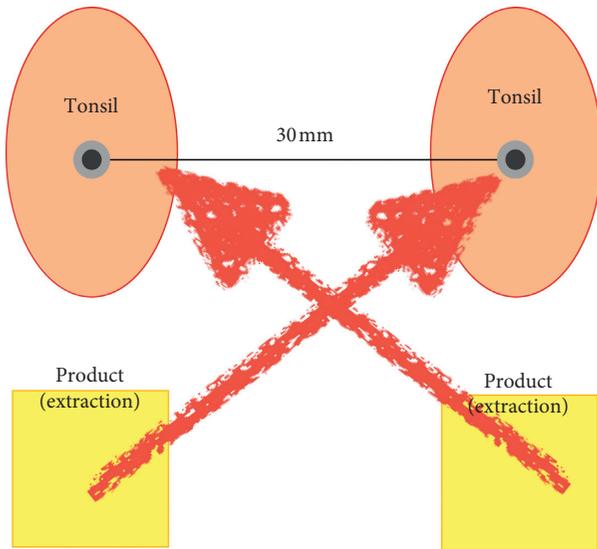


FIGURE 5: Relative position definition of oral optical simulation.

4200 lux to 9000 lux and is used to illuminate the entire mouth. This study is only for the tonsils, but this lighting interval is still available as a reference interval. The second headless lamp illumination [13] is as high as 50000 lux, but the working distance is 250 mm. The distance between the study products is 25 mm from the tonsil, the working

distance is 10 times that. The calculation is based on the ratio and shows the illumination target is 5000 lux. The lighting range of 5000 is also met in the first item ebite2. Therefore, after the literature patent basis and after discussion with the clinician, the target illuminance was confirmed to be 5000 lux.

3. Simulation Results

In order to illuminate the obliquely diagonal area of the tonsil, it was necessary to refract the light. Therefore, a lens was designed to concentrate on the light source. After the experiment, we found that the geometric refraction surface was divided into three segments. It would achieve the optimization of the current illumination, so we divided the refraction angle into three refraction surfaces, which made the best use of the light in each segment and achieved the light intensity required for tonsil surgery. The structure is shown (see Figure 6).

3.1. Simulation Results of Oral Lighting Reflective Surface Design. The design of the single-angle reflecting surface reveals that the light cannot be completely projected onto the receiving surface (the area of the tonsil). This study is going to talk about the change to three angular reflecting surface design structures (see Figure 7). From the simulation results

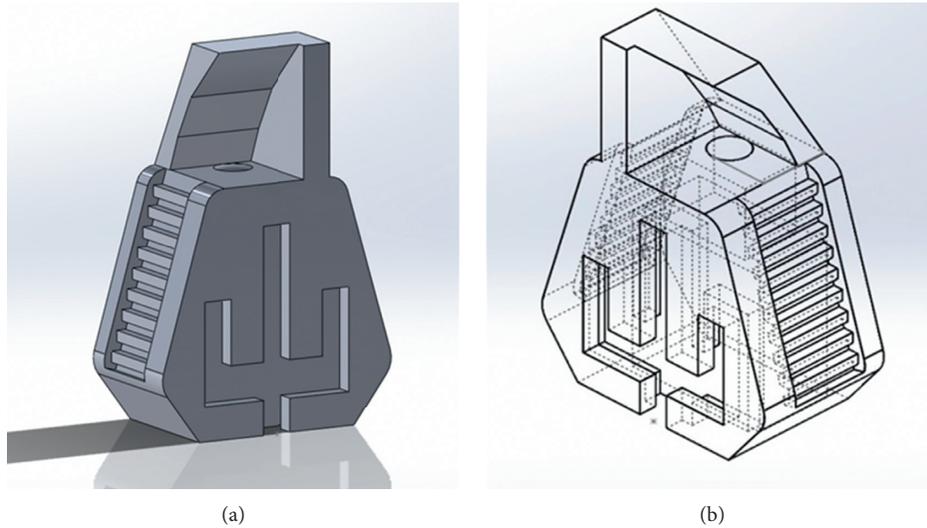


FIGURE 6: Schematic diagram of oral lighting structure.

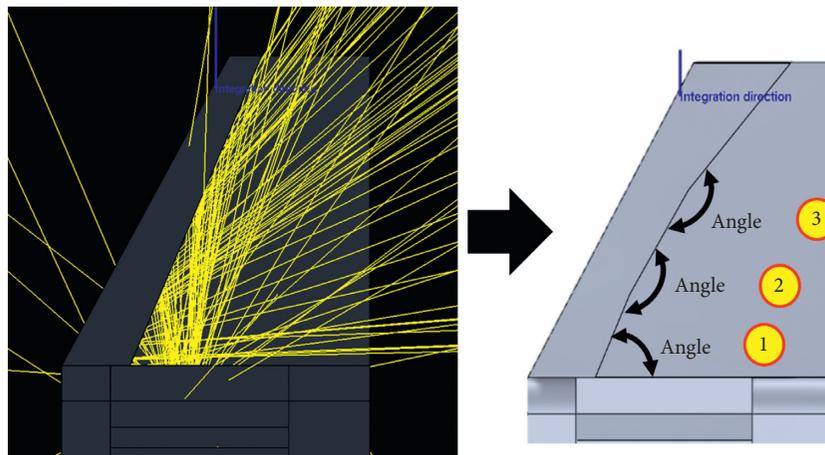


FIGURE 7: Schematic diagram of the geometric bevel angle of the oral lighting structure.

of the reflection surface angle 1, it can be found that the maximum simulated illumination value can reach 1419 lux when the angle is 67 degrees (see Figure 8). The simulation results of the angle of reflection 2 show that the maximum simulated illumination value can reach 4066 lux at an angle of 173 degrees (see Figure 9). The simulation results of the angle of the reflection surface 3 show that the highest simulated illumination value can reach 5029.19 lux when the angle is 171 degrees (see Table 1 and Figures 10 and 11).

3.2. Simulation Results of Oral Lighting Lens Design. The structural design of the lens is mainly to completely collect the LED light, improve the light utilization rate, and obtain various results with the different curvature radius of the lens. Figure 12 shows the light intensity result obtained by the actual simulation, which clearly shows that the optimum radius of curvature is 41 degrees, and the illuminance can reach 5102 lux. It can be seen from

Figure 13 that the light has been clearly focused on the opposite receiver, and the target value of the oral lighting has been reached.

4. Manufacturing Process and Measurement

The mold is designed according to the optimal simulation design structure parameter value, the complex prototype mold is quickly printed by 3D printing technology, and then the oral lighting devices is transformed by reverse engineering and mold casting technology. Finally, the mold dimensions and optical characteristics are measured. The production process is shown in Figure 14.

4.1. Mold Design and 3D Printing. Subverting the traditional mold precision mechanical production method to adopt 3D printing technology to make the mold core, the model of this research has high complex characteristics, which is one of

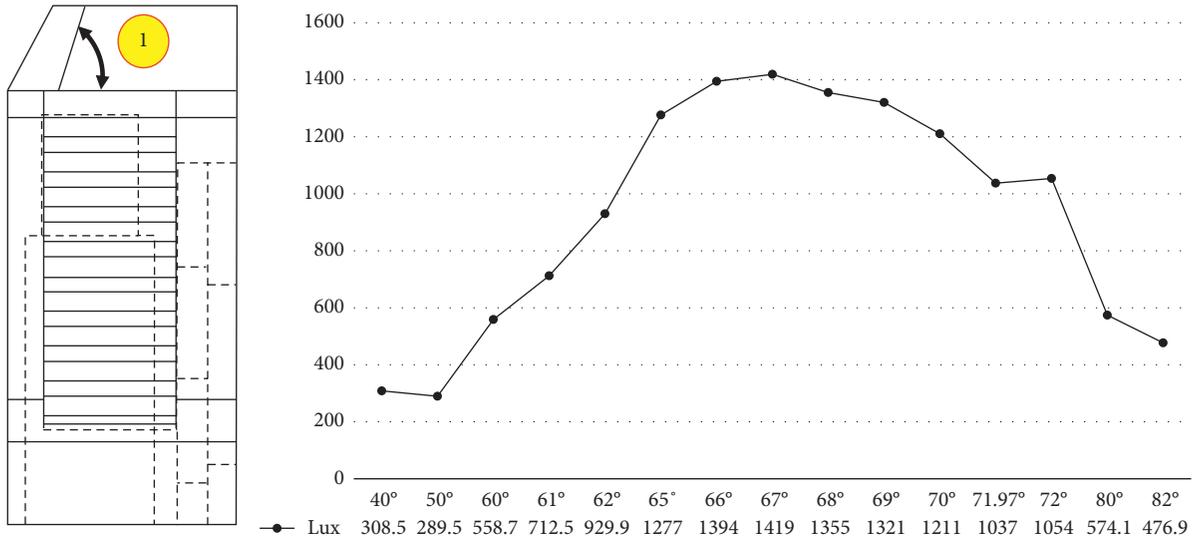


FIGURE 8: Schematic diagram of geometric level angle 1 and optical simulation results.

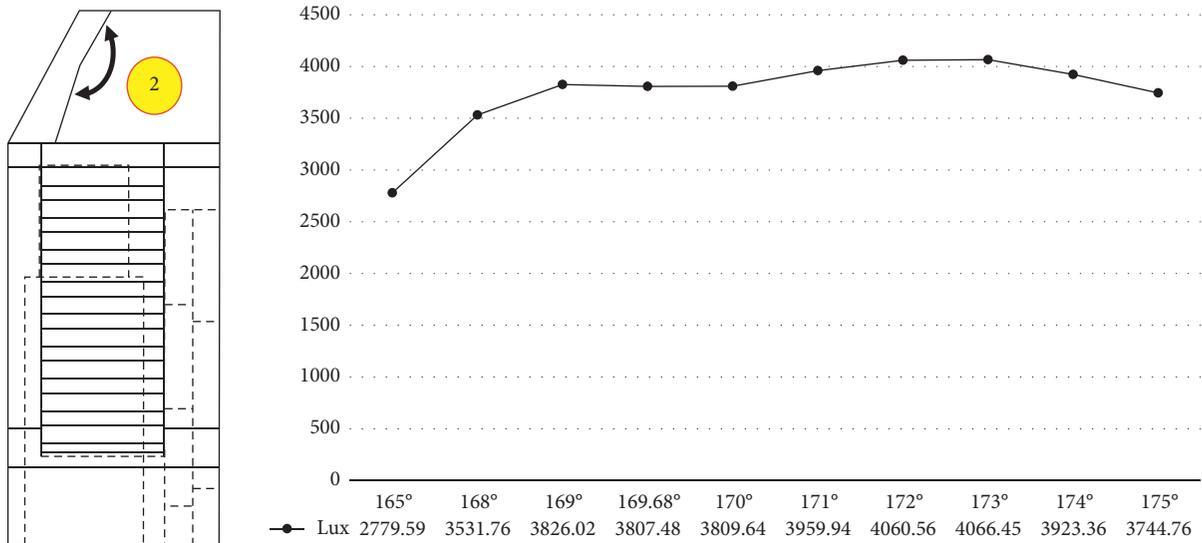


FIGURE 9: Schematic diagram of geometric level angle 2 and optical simulation results.

TABLE 1: Optical analog measurement value of geometric level angle 3.

Area	Shape	Parameters	Magnitude	Measure	Value
Area_1	Rectangle	(0; 0) (5; 5)	Illuminance	Average	5029.19 lx

the advantages of 3D printing. The parting line is the maximum appearance of the product in the drafting direction. The parting surface is the contact surface of the male and female mold blocks which can be produced by the mold. The relationship between the parting line and the parting surface can be stated as follows: the contour line which is the intersection of the parting surface and the product surface is a parting line. In the design of the mold, the parting line is judged to be completed, and the next step is to form the parting surface by extending the parting line in the most

suitable direction (see Figure 15). The parting surface is judged by the drawing direction of the molding product. Assuming that a plane perpendicular to the direction is the judgment basic plane, the maximum range of the appearance surface of the molding product projected onto the plane is its parting line. According to the parting line, the appropriate extension is the parting surface. The parting surface can be simple on only one plane, that is, the parting line of the molded product is on the same plane; it can also be complex, irregular, or stepped.

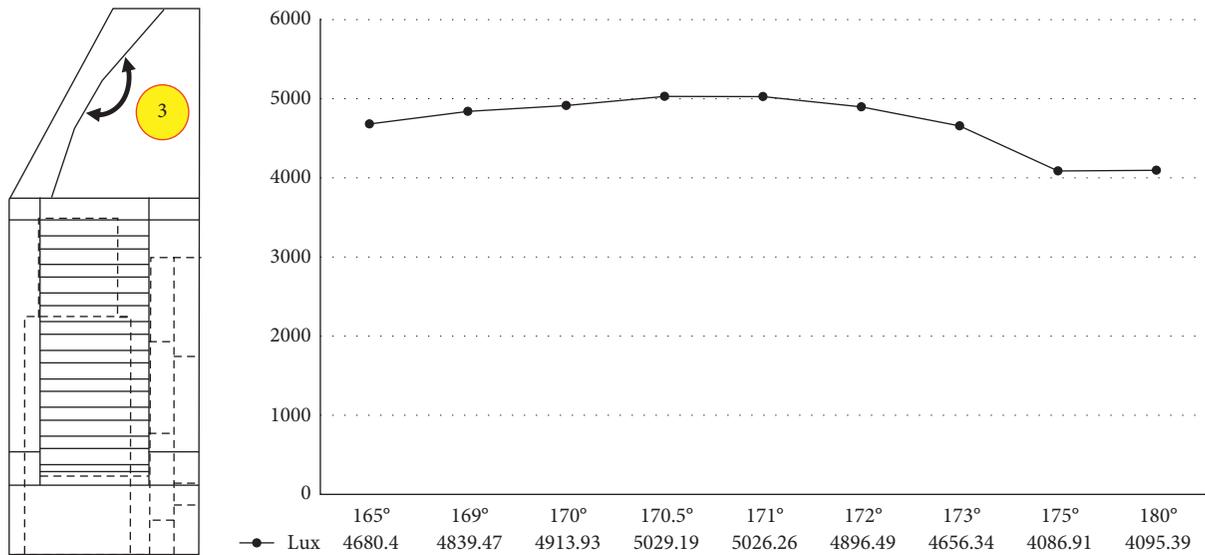


FIGURE 10: Schematic diagram of geometric bevel angle 3 and optical simulation results.

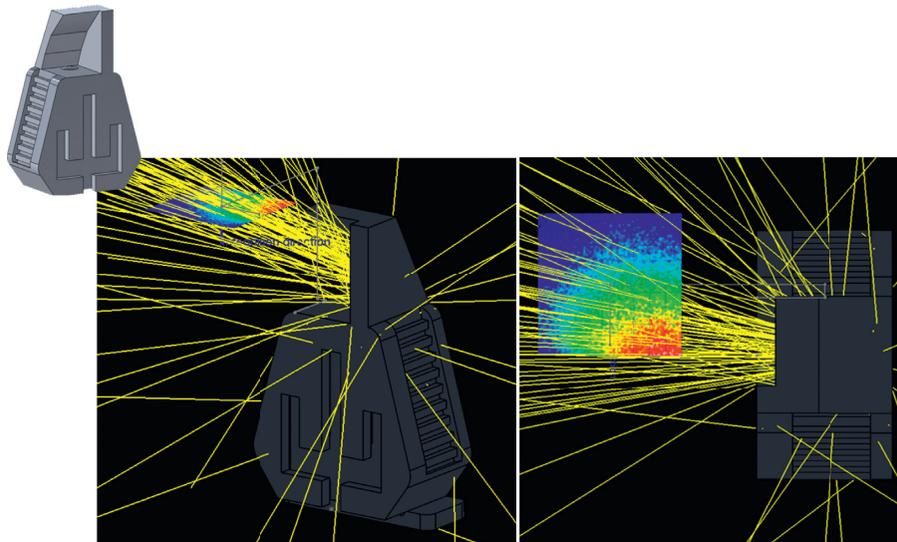


FIGURE 11: Optical analog light trace of geometric bevel angle 3.

In order to make the structure of the mold simple and reduce the manufacturing cost, the mold design surface is generally designed as a single plane, that is, a plane perpendicular to the drawing direction. In the mold design, the nonflat single-plane parting surface is chosen, that is, the design of the parting surface composed of several surfaces should be avoided. This is because there would be additional processing and appearance and dimensional tolerance problems for subsequent contact surfaces between the blocks. However, in the current industry, due to demand and saving subsequent processing costs, complex parting surface products account for a relatively large number. The mold of this study was split into three devices according to the parting line (plane) design (see Figure 16).

The 3D printing technology is based on the assistance of Computer Aided Design (CAD) software. The 3D CAD

model is cut into thin layers, and the process of decomposing 3D data into 2D data is performed. According to the layered 2D data, the manufacturing method is used to produce the same thickness as the data layer. The process of each layer of sheets overlapping forms a 3D solid object. 3D printing mold has three-device finished products (see Figure 17).

4.2. Mold Casting Process. PDMS is the most widely used polymer biomedical material known at present. The cost of the material is much lower than that of strontium and quartz glass. The process is simple and rapid, the light transmittance and biocompatibility are good, and it is easy to combine with various materials at room temperature. It is a porous absorbent for oxygen and carbon dioxide and has been widely

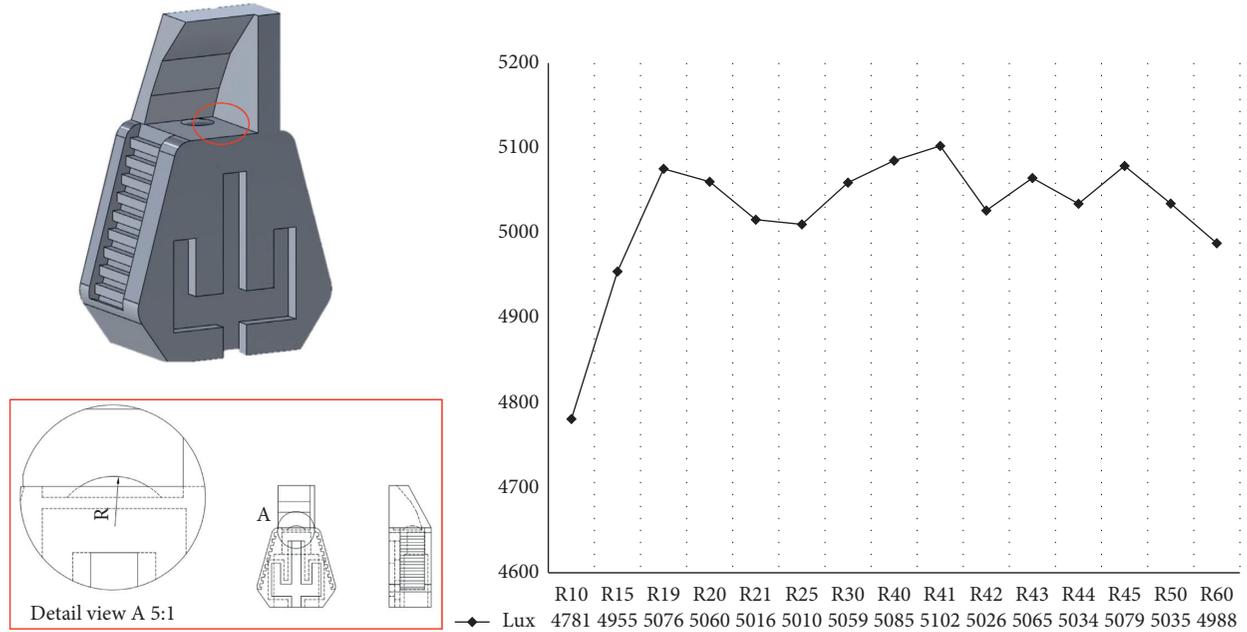


FIGURE 12: Simulation results of lens curvature radius design.

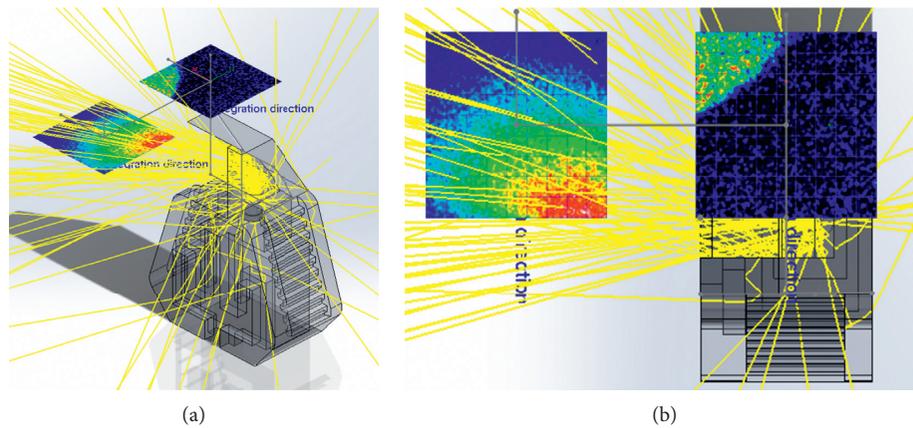


FIGURE 13: Simulation results of oral lighting optical microstructure device design.

used in various biomedical research. The polydimethylsiloxane (PDMS) used in this study was produced by Sil-More Industrial Ltd. The main agent SYLGUARD-184A and the hardener SYLGUARD-184B were uniformly mixed at a mass ratio of 10:1. Mixed by vacuuming, the bubbles in the liquid are deformed and then left to stand or heat to form.

The mold is made by using a 3D printing machine. When the two molds are combined, the positioning pins, and the clamps, bolts, and nuts are used to fix the four corners of the mold. The mold casting is used to complete the PDMS mold. During the mold casting, in order to smoothly let the air discharge so that it does not remain in the flow channel and affect the forming, a utility knife can be used at the bottom of the flow channel to scrape a little knife mark, and the air is discharged along the direction of the tool mark. The PDMS casting finished product is shown (see Figure 18).

4.3. Finished Product Measurement

4.3.1. Finished Product Shape Profile Inspection. Comparing the difference between the size of the mold and the 3D printing mold after PDMS mold casting, the completed PDMS finished product is measured under Computer Aided Verification (CAV) two-dimensional image measuring results (see Figure 19). The data shows the 3D printing finished product of the oral device structure, and the average error of the profile of the PDMS-finished product is about 1.4% and 16.9%, respectively. Contrasting the PDMS mold after casting with the 3D printing mold shows that there is shrinkage. The reason causing the results might be the shrinkage due to temperature of the wax mold. The further shrinkage occurs when contacting with the heated mold.

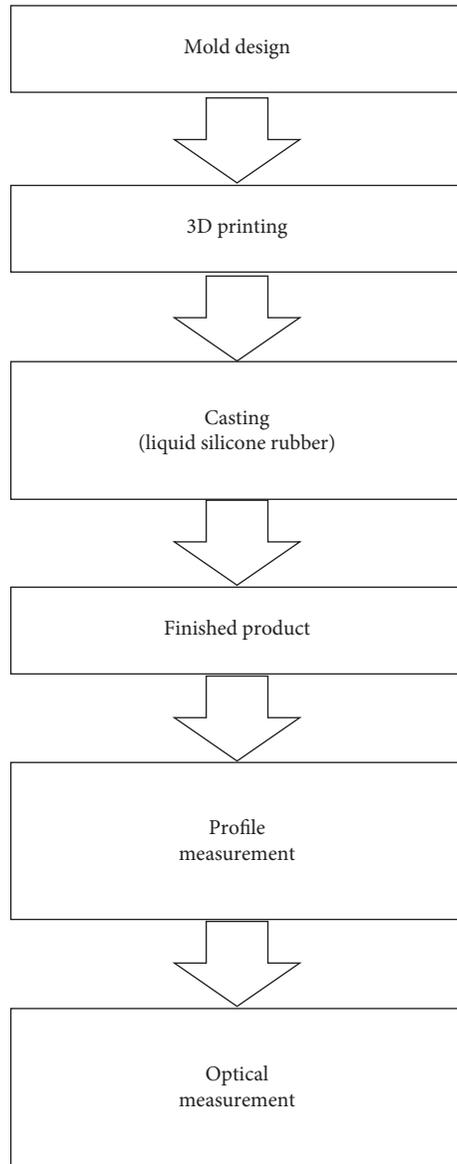


FIGURE 14: Schematic diagram of the mold structure production process.

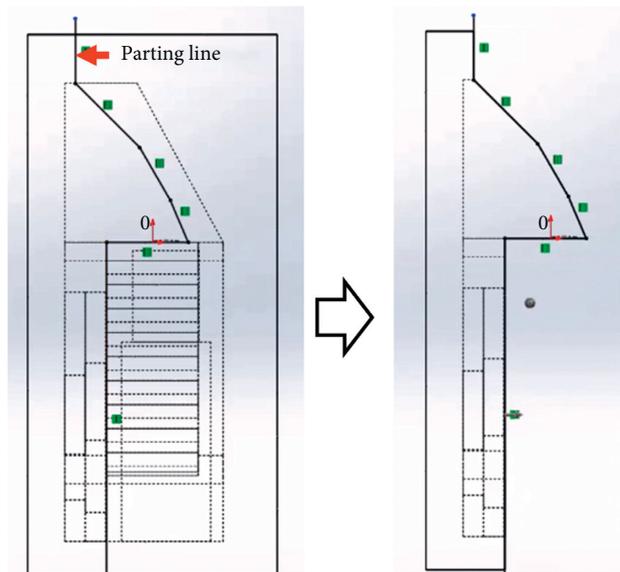


FIGURE 15: Schematic diagram of the parting line of the mold design.

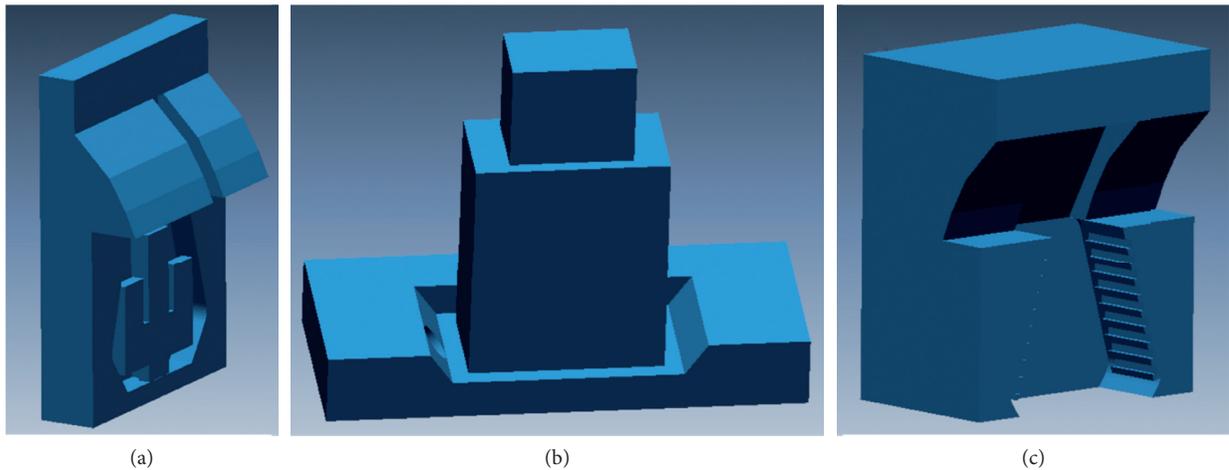


FIGURE 16: Computer aided mold design.

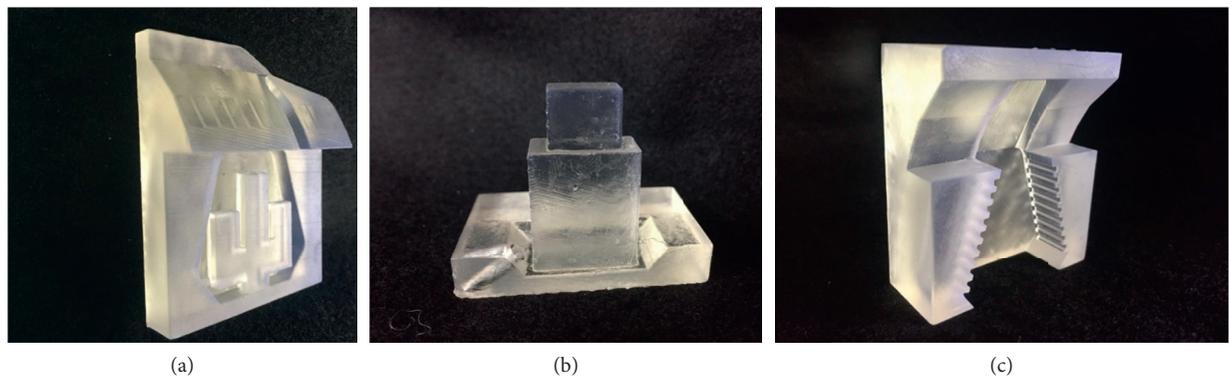


FIGURE 17: 3D printing finished product.



FIGURE 18: PDMS casting finished product.

4.3.2. *Oral Lighting Optical Microstructure Device Light Distribution Detection.* The luminance optical properties were measured by using a conoscope machine. Figure 20 shows the light distribution was attached to a micro-optical element. Light was scattered from the center to the left and right sides, thus proving that the optical element can

generate one side perspectives. The distance of the measured light deviation is 0.5~3 mm due to the contour error of the finished PDMS (see Figure 20), but the light is still concentrated in the range of the tonsils. Therefore, this result can be defined as an acceptable range within 16.9% of the intra lighting error.

illumination by optical simulation analysis, and designing the illumination component with high illumination. The oral lighting device is produced for actual photometric measurement. The successful development of a low-cost and easy-to-assemble high-illumination oral lighting devices facilitates mass production in the future. The results of the study met the original design goals: (1) to open the mouth to facilitate the doctor's surgery; (2) to fix the tongue in order to avoid it interfering with the operation, because if the tongue is lifted, it will block the sight; (3) add lighting function to help the doctor during the operation to avoid the lack of light; and (4) reduce the number of tools required before surgery, such as oral spreaders, lighting equipment, tongue depressors, and other medical equipment. This study would solve the problem of clinicians having to wear a fiber-optic projection lamp due to poor head swing angle or visual field blindness, reduce the burden of physicians in nonprofessional fields, reduce the operation time of patients to maintain the health quality of doctors, and further advance the medical equipment standards to improve surgical safety.

Data Availability

The processed data required to reproduce these findings cannot be shared at this time as the data also form part of an ongoing study.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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