Modern Medical Beauty Instruments: A Study of The Principles Behind Four Common Techniques

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Abstract. In recent years, with the rapid socioeconomic development, and the ongoing upgrading of beauty equipment, medical beauty has become a new fad. In its wake, with the advent of technology come laser, ultrasonic, photon and radio frequency beauty instruments, which are employed in their respective field of application. It is worth acknowledging that the emergence and development of these instruments have provided people with more diversified and personalized beauty choices. Nevertheless, as skin type and demand for beauty care differs from one person to another, it is of particular importance to choose the right instrument and treatment. In this paper, modern medical beauty instruments are compared for discussion based on four mainstream technical principles, followed by an analysis of their respective efficacy as well as their future development. In addition, this paper also notes several possible technical limitations and details corresponding recommendations, in hopes of bringing consumers a better skincare and cosmetic experience, and providing some reference for the technical development of such instruments in future.

Keywords: Beauty instrument; laser; photon; ultrasound; radio frequency.

1. Introduction

With the rapid social and economic development, people’s quality of life is also improving. In recent years, there has been a significant increase in the demand for aesthetic and cosmetic treatments among beauty lovers. Globally, the medical beauty industry has become the third largest industry only next to aerospace and the automotive industry. According to the International Society of Aesthetic Plastic Surgery (ISAPA), on average, more than 10 million surgical procedures were performed annually from 2013 to 2016, and nearly 12 million non-surgical procedures were performed during the same period [1]. A recent report by ISAPA shows that the total number of surgical procedures increased by 9% from 2015 to 2016. Furthermore, a report by Grand View Research Inc. indicates that the global medical market for aesthetics is expected to reach $11.9 billion by 2022 [1]. It is a fact that the global medical beauty market is growing rapidly, and the industry of equipment used for aesthetic purposes is especially prominent. In 2009, the global market for medical beauty instruments generated total sales revenues of $1.8 billion. In 2010, this figure stood at $2 billion, of which the United States accounted for approximately 60% [2]. According to Frost & Sullivan, an international market research organization, the global market for medical beauty instruments is expected to reach $4.9 billion in sales revenue in 2016 [2]. The medical beauty industry was born in the 1990s [3] and is based on the expansion in relevant fields of medicine, optics, electricity and chemistry. Medical beauty instruments, as part and parcel of the industry, are devices applying different technologies to regulate body and facial features and functions on the basis of human physiology, though the main role is to regulate the surface skin of human body. As far as their technical principles are concerned, they can be broadly categorized as ones of acoustic wave technology, ionic conduction technology, LED light and micro-currents, while their development history can be traced back to the early 20th century [4].

In recent years, small or miniature household beauty instruments are favored by the majority of consumers. For beauty service organizations, it is also mainly instrument-based, with manual assistance. Compared with traditional manual skin care, beauty instruments using a variety of technologies can act directly on the deep layers of human skin, so as to achieve the desired effect. Among a wide selection of such devices, those featuring laser, ultrasound, photons and radio frequency are products of rapid technical development, each with its own characteristic and application scenario. It is true that these devices provide people with more diversified and personalized beauty choices. However, since skin types and needs differ from one to another, it is especially critical to choose the right instrument and treatment for oneself. In addition, despite the rapid development of various cosmetic technologies, some problems still exist, such as safe operation and equipment failure. In this paper, we will study the four mainstream technologies behind modern medical beauty instruments along with a discussion of their development trends.

2. Beauty Instruments Shining with Technology

With the industrial development as well as people's enhanced aesthetic sense, a wide range of beauty instruments are pushing the boundaries. Among the various types, the ones that have received more attention are those of lasers, RF, IPL, and photos. Through this paper, the specific use of lasers, ultrasound, photons, and radio frequency in beauty instruments is discussed and analyzed.

2.1. Historical and Technical Analysis of Laser Beauty Instruments

Starting from 1917, when Einstein proposed the quantum theory of radiation, to 1958, when Towns and Schalow, the fathers of lasers, brought forward the technology of microwave radiation, and then on to 1960, when Maiman invented the ruby laser, the boundaries of medical application of lasers were being pushed [5].

In recent years, a variety of high-precision laser cosmetic instruments have come out, boasting such advantages as less time consumption, less pain, better effect, and no recurrence. Lasers are used in medical cosmetology mainly through photothermal action, photodynamic response, and photostimulation [6]. And the solution to existing skin problems is achieved by inducing freezing, cutting, peeling and tightening of skin tissues. It acts on human tissues by means of high-energy, precise, monochromatic light with a certain penetrating power, thus generating high heat locally to remove or destroy target tissues. Noteworthy are lasers of different wavelengths for the treatment of different vascular dermatoses and hyperpigmentation problems [7].

In the past, accidents occurred in the procedure due to improper operation or instrument failure, and the specificity of treatment. Referring to laser instrument faults, it was found that Li Hongzhen et al. proposed a fuzzy logic-based automatic fault diagnosis method [6], which, as its name suggests, constructs fuzzy diagnostic rules based on fuzzy logic in order to accomplish automatic fault diagnoses. Specifically, the method comprises three steps: first, fault monitoring signal acquisition and processing; second, quantification of fault characteristics; and third, automatic fault diagnosis. Laser surgery can cause skin burns due to occasional improper temperature control. In the literature, it is mentioned that laser is transmitted in skin tissues, and the technology used is infrared temperature measurement. Complex Programmable Logic Device (cpld) enables temperature control and accurate judgmental processing of specific conditions, thus increasing safety and avoiding accidental burns [8].

Laser beauty instruments can be divided into two categories, Q-switched lasers and fractional pixel lasers, depending on their light-emitting principle. Commonly used lasers are CO2 laser, infrared laser and so on. In actual use, poor ventilation, strong electromagnetic interference or instrument impact may lead to their failure. If any abnormality occurs, the mild impact is having the desired effect discounted, while the more serious outcome is certain components can be disabled, resulting in unserviceable instruments [6]. New laser beauty instruments use super-pulsed CO2 lasers to cut the epidermal layer of the skin with the help of computerized image scanning generator. With a cutting thickness of less than 100μm, it affects no deeper tissues, while new collagenous fibroblasts grow out to achieve the effect of wrinkle rejuvenation [8]. The advantage of such a technique over surgical and chemical methods is that it does not leave scars, thus greatly satisfying the needs of aesthetic women. Figure 1 showed the demonstration of CO2 fractional laser advantages.

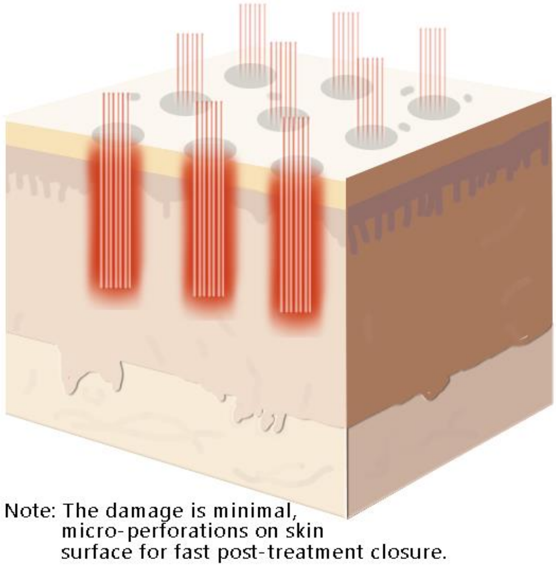

Fig. 1 Demonstration of CO2 fractional laser advantages (Photo credited: Original)

2.2. Historical and Technical Analysis of Ultrasonic Beauty Instruments

As early as 1880, the French Curie brothers discovered the piezoelectric effect, providing a theoretical basis for ultrasonic probe emission and reception; in 1928, a French company granted a patent on ultrasound for its treatment of diseases; in 1980, the first ultrasonic scalpel was developed by Cooper LaserSonics Inc. in the United States and was listed among major inventions of the time [9].

An ultrasonic beauty instrument relies on mechanical wave vibration above 20,000Hz as its principle and through ultrasonic penetration acts upon the subcutaneous 4-6mm layer. Due to its energy and permeability, it can not only lighten up skin but help to accelerate blood and lymph circulation, promote cellular metabolism, and make skin more radiant and silkier.

Through literature sorting, a certain ultrasonic beauty instrument is designed by using a built-in low-power-consumption and high-reliability microprocessor chip PIC. Its circuit is streamlined and performance reliable, and the ultrasonic spray is both fine and even, delivering a more remarkable result [10]. Its basic functions are as follows. One is ultrasonic spray; the second is to act the ultrasonic waves generated by the massage probe directly on human skin. That is, the device, by virtue of the mechanical, thermal, physical and chemical properties of ultrasound, acts on the skin. The core composition of an ultrasonic instrument is what’s called a single chip microprocessor, running on Reduced Instruction Set Computing (RISC). All operation commands are entered by keyboard, including ultrasonic circuit startup, ultrasonic timing, ultrasonic spray and massage probe switching, and ultrasonic amplitude control. The oscillation generating circuit operates under the control of micro-controller PIC16C58A, in which ultrasonic waves are emitted at a frequency of 1 to 1.1 MHz, with power of 30 to 40 W. Adjustment of the power level is done by software. Figure 2 showed the ion export schematic, and Figure 3 showed the ion import schematic.

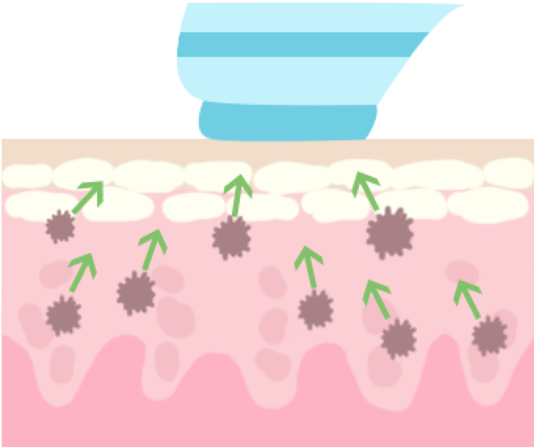

Fig. 2 Ion export schematic (Photo credited: Original)

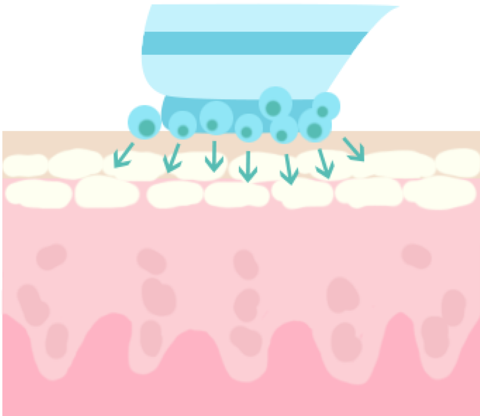

Fig. 3 Ion import schematic (Photo credited: Original)

As for efficacy, ultrasonic beauty instruments excel in skin cleansing, nutritional introduction, pore care, spot fading and brightening, detoxification and anti-aging [4]. Worthy of mention is plasma beauty instruments, a new type gaining in popularity nowadays. With such advantages as sterilization, mite removal, skin rejuvenation, anti-aging, whitening and spot fading, it is well liked by women. With the further development of technology, ultrasonic beauty instruments will be increasingly compact and more convenient to carry around, with better skincare effect.

2.3. Historical and Technical Analysis of Photonic Beauty Instruments

In 1993, the U.S. company Lumenis invented the technology of Intense Pulsed Light, referred to as IPL. In 1995, still the company produced the world's first FDA-approved photo-rejuvenation instrument. In 2003, the traditional IPL technology was improved and upgraded in U.S. for enhanced safety and efficacy of treatment, initiating the era of perfect IPL.

Photonic beauty instruments are widely applicable for treatment of various skin ailments, bringing about obvious therapeutic improvement, and are preferred and essential instruments for the dermatology department of each hospital and beauty salons. Photons are usually categorized as LED light, intense pulsed light, red light, blue light, and green light, while the very essence of photonic beauty instruments is to strike a person's face with intense pulsed light, so as to rejuvenate the skin. Intense pulsed light is an intense beam of a specific wavelength and generally can be acquired by filtration through a wave filter. It promotes collagen synthesis and accelerates blood circulation, which helps to fade melanin, improve skin laxity, soothe wrinkles, and leave skin glowing with radiance. Figure 4 showed the photonic operation schematic.

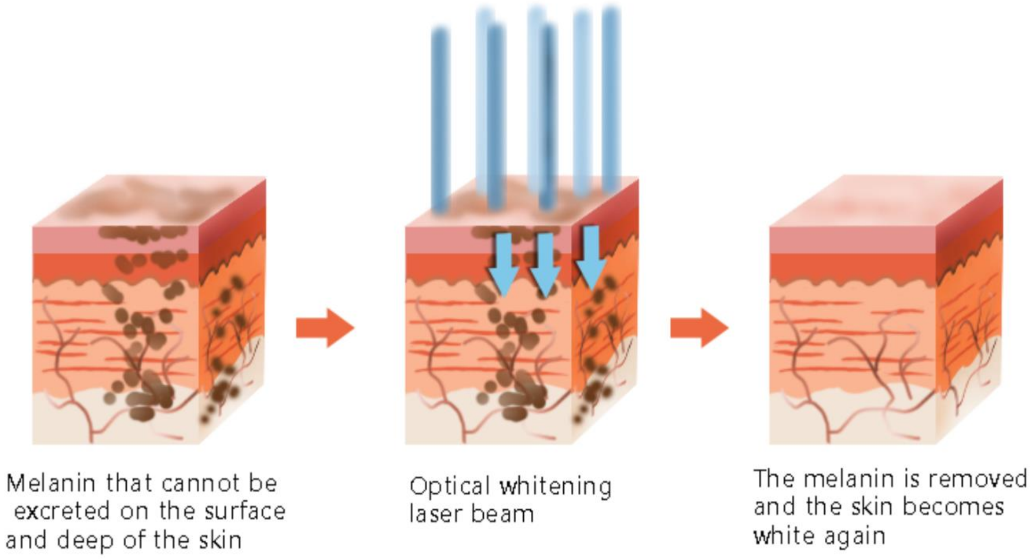

Fig. 4 Photonic operation schematic (Photo credited: Original)

Certain researchers, with a research background in semiconductor light-emitting diodes, starting from the mechanism of interaction between LED and biological tissues, found that LED light sources helped improve skin texture under certain conditions. They even designed their own structure and hardware and software system for an LED cosmetic device, and tested its stability, which was shown to be of particular efficacy [11]. Some others experimented with cells that were irradiated with light waves of different wavelengths of 670nm, 728nm and 880nm, with an irradiation wave dose of 4J/m2, and found that these light waves could speed up cell reproduction and have a promotional effect on their growth. The principle is that light of this nature can quickly penetrate into deeper layers of skin before the effective decomposition of pigments, thus achieving rapid and precise cosmetic care. Advantages of this type are safety and reliability, environmental friendliness and energy efficiency, wide wavelength range, spectral purity, and compact size, etc. [11]

2.4. Historical and Technical Analysis of Radio Frequency-based Beauty Instruments

RF electromagnetic fields at frequencies between 300kHz and 300GHz release biological effects and are becoming a hot spot of research interest [7]. Nowadays, RF electromagnetic fields are widely used in medical treatment, communication and identification. Common RF cosmetic technology, tumor ablation surgery, and mobile communication base stations, etc. all resort to RF frequency.

One of the earliest signs of facial aging is the gradual degradation of collagen and elastin, leading to skin laxity. Due to iterative technical innovation, the cosmetic surgery technique is now in its fourth generation. The first generation is based on physical and chemical techniques; the second generation features traumatizing laser cosmetic technology; and the third generation is built on non-invasive pulsed intense light. As these three generations of technology are limited to the epidermis of skin, it is difficult to penetrate the dermis for treatment. In response to this sore point, the fourth generation of RF cosmetic technology was born, arguably the best choice for skin tightening.

He Bingbing et al. had studied bipolar radio frequency with electromechanical parameters in the field of subcutaneous temperature control, and, using self-researched electrode-spaced bipolar RF cosmetic instruments and by setting frequencies and duty cycles of different output RF signals, carried out heating experiments on isolated pigskin [12]. The technology was found to be a stunning solution for anti-wrinkle cosmetic treatment. It is the use of alternating current to generate an electric field between the two electrodes that attracts and repels electrons and ions charged in the deeper tissues of the skin. Accelerated motion and collision generate heat, which is then transferred to the target tissue to combat wrinkles and add elasticity to skin. The RF electrode does not generate heat itself, and the converted heat acts upon internal tissues [13]. It was found in many experiments that its scope of action is the lower half of the circle with the midpoint between the positive and negative electrodes as center and the spacing between the two electrodes as diameter. To expand the heating area, three or more electrodes can be put in place for better heat transfer and subsequently a better anti-wrinkle effect. Figure 5 showed schematic of subcutaneous heating Center under bipolar RF, and Figure 6 showed the electrode distribution for the three strobe modes.

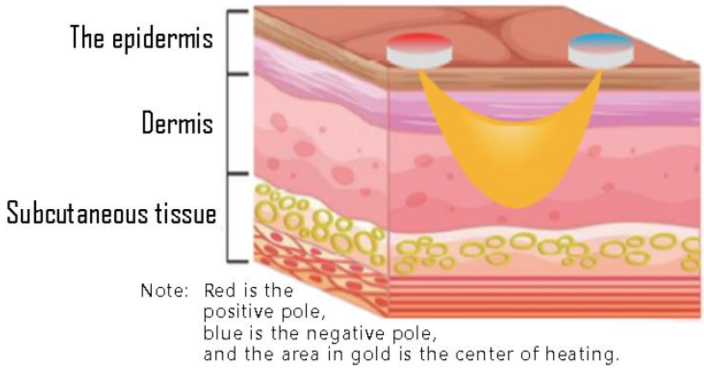

Fig. 5 Schematic of subcutaneous heating center under bipolar RF [13]

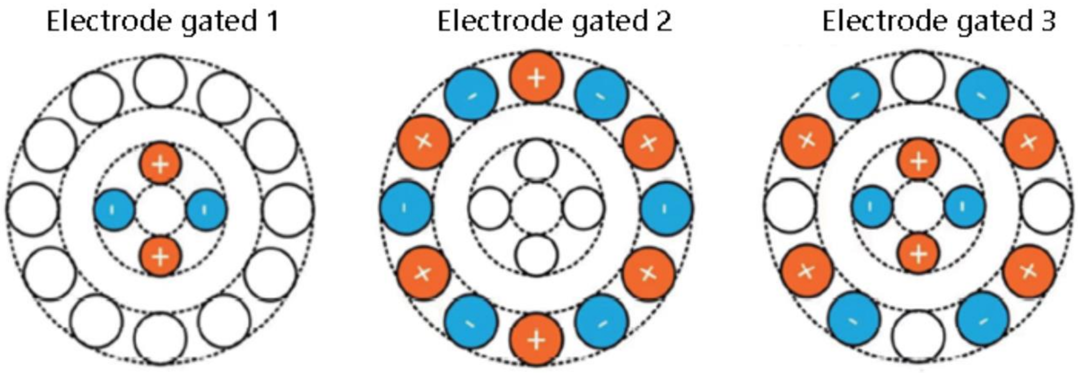

Fig. 6 Electrode distribution for the three strobe modes [13]

3. Analysis of Future Development Trends of Beauty Instruments

3.1. Discussion and Analysis of Future Development Trends of Beauty Instruments

3.1.1 Laser technology

Among the many cosmetic instruments, it is the laser category that leads the world in both number and sales. There are lasers of different wavelengths to treat various vascular skin diseases and pigmentation [7]. Laser cosmetic treatments include painless cleansing of tattooed eyebrows, eyeliners, and body tattoos, removal of bright red moles, freckles, and age spots, as well as amelioration of dilated capillaries, to name a few.

Precision skin care is an inevitable trend in the development of home beauty equipment. That is, consumers are no longer content with basic skin care, but to pursue a more accurate, personalized skin care experience. Skin varies from person to person, and skin problems can hardly be solved in a single way. Therefore, artificial intelligence can be incorporated into laser-based instruments with a large skin database imported, based on which products for precise skin care can be rolled out to meet consumer demand. As per actual demand, hair, wrinkle and acne removal with lasers and laser-based dental scaling are introduced, further widening its cosmetic application. Worth mentioning is the fact that hair transplantation can also be made possible with the help of lasers, a new highlight to cater to niche market need.

3.1.2 Ultrasonic technology

Ultrasonic beauty instruments with cleaning and skin care as the dominant function will have a promising prospect. With sci-tech progress as a response to upgraded consumer demand, ultrasonic beauty instruments will continue to be invested with new technologies and new functions. On the one hand, such efficacy as spot fading, skin rejuvenation, anti-aging and sterilization will be taken to extremes; on the other hand, a safer, more efficient and more comfortable beauty experience are made possible. Foreseeably, there will emerge a number of compact ultrasonic beauty instruments for home use, making skin care easier and more convenient.

On the subject of its development, firstly, ultrasonic beauty instruments, with artificial intelligence and big data incorporated, can be made more intelligent to provide customized or personalized skincare solutions. Secondly, nanotechnology allows for deeper skin cleansing, such as precise targeting and effective release of active ingredients to provide better skin care. Thirdly, the field of application can be further explored. For instance, its combination with micro-needling technology is expected to round out the skin diagnostic and repair effect.

In short, ultrasonic beauty instruments in future are expected to be more intelligent, more personalized and more diverse.

3.1.3 Photonic technology

With consumers' increased attention to environment, nature and health, photonic beauty instruments need to be given a new concept, that is, repair from the inside to nourish healthy skin. Let's say, advancing research and development of photoelectric technology, deepening research on wavelength and dosage, and rolling out a more comprehensive and innovative skincare model. All serve to meet individualized skincare needs.

For light waves generated by general electronic probes, both their singularity and stability are poor. The result is incomplete removal of spots and possible skin damage. In contrast, photonic crystal instruments are based on the transmission matrix method. Through MAtlab programming simulation, the appropriate photonic crystal medium material, as well as its period and thickness, can be selected to determine the coating structure. In this way, it makes up for the problems that exist in general cosmetic instruments and improves safety and stability. And light waves are fast and deep into skin, disintegrating pigment cells and shortening time needed for treatment [14].

In addition, its environmental philosophy can also be a highlight. Together with the new experience of sci-tech skincare, it is expected to become a new breakthrough and a new fashion.

3.1.4 RF beauty instrument

In March 2022, RF beauty instruments were included in the catalog of Class III medical instruments and the following month of the same year, they were categorized as household handheld devices, from which it can be seen future RF beauty instruments will tend to be more and more compact. This aside, there is still room for continual product quality and safety improvement, for example, registering products as state-approved devices for medical use, dispelling consumer misgivings and increasing product credibility and reputability. With the emergence of new materials and technologies, in order to improve the anti-aging effect, the heating area can be effectively enlarged by heating dermal tissues at different subcutaneous depths and in uniform layers [13]. Technically, both electrodes spacing, and the frequencies of different output RF signals are adjustable to control heating depth; reasonable duty cycles can also be set to determine the time of heating up. Through these improvements, a more ideal RF instrument is designed [12]. Notably, the performance and safety of such instruments need further enhancing in future, bringing potential risks close to zero.

3.2. Limitations, Intensity Analysis and Recommendations

3.2.1 Possible limitations

Favored by consumers, laser, ultrasonic, photonic and RF beauty instruments enjoy an arguably good prospect for development, but not without limitations. Firstly, the intensity and scope of application vary among different technologies. For example, laser beauty equipment is primarily targeted at specific skin problems, such as pigmented lesions and vascular lesions, but its operation requires a higher level of known-how, accompanied by potential risks. Ultrasonic beauty instruments are limited by energy transfer efficiency and penetration depth inadequacy. Photonic beauty instruments are safe but too mild and multiple treatments are needed before expected results are achieved. Finally, RF beauty instruments excel at skin tightening and wrinkle reduction, but with disproportionately varying effects on different skin types.

3.2.2 Suggestions for Four Common Beauty Instruments in Future Development

1) Technical innovation: New technologies need to be developed continually to improve the penetration depth and energy transfer efficiency of beauty instruments for a more accurate and efficacious therapeutic effect.

2) Personalized customization: By using artificial intelligence and big data technology, personalized beauty solutions are developed as per individual skin type and need, thus improving treatment effects and user satisfaction.

3) Safety guarantee: Research on and monitoring of product safety need strengthening to ensure both safety and reliability of beauty equipment and also for reduced potential risks and side effects.

4) Interdisciplinary collaboration: Cooperation with such fields as medicine, biology and material science is needed to jointly promote innovation in and development of the industry.

4. Conclusion

Overall, laser beauty instruments can help to achieve precise removal of spots, moles and wrinkles as well as skin tightening, etc., and are trustworthy. These instruments top the global sales of beauty devices. Ultrasonic beauty instruments feature distinctive whitening and skin rejuvenation, cleansing and nutrition, sterilization and anti-aging effects. The equipment is simple to operate, easy to carry, and safe in its circuitry, and is intelligent and efficient as well. For photonic beauty instruments, energy can be quickly transmitted to deep layers of the skin, effectively breaking down pigments. Fast and precise in a true sense, it is also an environmentally friendly and energy-saving product. RF instruments are of particular benefit in non-invasive and anti-wrinkle application, and electrodes may be employed to increase skin elasticity for an extended duration.

However, with consumers' ongoing quest for beauty and iterative upgrading of new technologies, it still leaves much room for breakthroughs in technical limitations before a safer, more effective and personalized beauty effect is achieved. With the concept of human-centered product innovation in mind, we need to embrace technical innovation, personification and customization in order for these instruments to meet diversified needs and provide consumers with a better skincare experience. It is believed that the future market of beauty instruments will be replete with opportunities and hopes.

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