Laser Tattoo Removal
Communication Skills 1 – Assignment 2

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Nowadays, the tattoo industry is undergoing sustained growth. According to Ipsos news, about 21% of Americans had at least one tattoo in 2012, and this number increased to 30% in 2019. This rise of the tattoo industry also leads to a growth in the tattoo removal industry. In fact, according to The Harris Poll and The Detroit News, about 14% of tattooed Americans had regrets about at least one of their tattoos in 2012, and this number has risen to 25% in 2019. In addition, reports from The American Society of Dermatologic Surgery show that around 86 thousand tattoo removal procedures were carried out in 2010, and 100 thousand procedures in 2011 (a rise of 16%). The tattoo removal market is projected to surpass 27 billion USD worth in 2023, which is more than the double from its 11.6 billion USD value in 2016.

There are several different ways to remove tattoos (e.g., skin excision, abrasion or tattoo removal creams), but our focus will be laser tattoo removal, which is the most widely used method in the industry due to its effectiveness, safety and relatively low invasiveness compared to other methods. Different types of lasers are used to remove black and different color tattoos. Even though the market is growing, there is still room for improvement in results after the removal, and this results in opportunities to do research and development in this field.

In order to explain tattoo removal, we must first describe how tattoos are placed into the skin. To create a tattoo, tattoo artists can hand-poke or use a machine. For both methods, the results are similar if the tattoo is done by a professional artist and the difference between them is mostly about the time taken for the process. The two most common machine types are rotary and coil. Both of them fulfill the same purpose, which is moving the needle at a certain speed. There are many types of needles that have different numbers of ends, ranging from 3 ends to 25. The needles with fewer ends serve for outlining, while the needles with more ends serve for shading or coloring. Tattoo colorants are usually made from pigments, which are made out of metallic compounds, and they serve to reflect light without any chemical reaction with body cells.

The tattoo artist pierces the skin with the machine at a frequency of 50 to 3000 times per minute. The needle with ink pierces the skin to get to the dermis layer of the skin, which is the layer under the epidermis (the outer layer of the skin). After the injection of the ink, for each wound, the immune system is alerted and white blood cells called macrophages are sent to remove the incoming strange particles. These macrophages should remove the injected ink and close the wound. Some particles are small enough, so the macrophages carry these particles to the liver to excrete them. Bigger particles cannot be carried away by macrophages and therefore, the cells carry the particles and stay in the same place, keeping the ink visible, thus making the tattoo permanent.

Historically used techniques for tattoo removal were often invasive and consisted of non-selective destruction. Such methods include dermabrasion (wearing away of the most superficial layers of skin with strong abrasive devices such as sandpaper, diamond wheels, wire brushes, etc.), cryosurgery (application of liquid nitrogen to the skin in order to freeze it) and surgical excision (removal of skin with a blade and posterior skin grafting for wound closure). Procedures performed with these methods often result in incomplete removal, and varying degrees of scarring and dyspigmentation. The introduction of Quality-switched (QS) laser into tattoo removal marked the beginning of a new era in the industry by offering patients more effective, less invasive and safer procedures.

Q-switching consists of producing pulsed output laser beams, which results in pulses with much higher peak power than the one produced by the same laser operating in continuous waves (lasers with average power below 1 W can reach peak powers of several KW with Q-S technology). When these high intensity short pulses are applied to an ink pigment, tissue absorbs photons, causing a rapid heating of the pigment, which may lead to fragmentation of the pigment due to large thermal transients which cause mechanical damage in the pigment. The fragmentation is referred to as selective photothermolysis and it depends on certain conditions being met during the laser application process. The damage mechanism consists of formation of stresses of sufficient magnitude to produce a rupture in the pigment. These stresses are a result of a very high temperature gradient in the pigment, which is a consequence of partially submitting the pigment surface to a very intense heat source for a period of time shorter than the thermal relaxation time of the pigment (Time taken for a particle to dissipate about 50% of the incident thermal energy. It is related to the diameter of the pigment and its thermal diffusivity coefficient. It typically takes values of a few nanoseconds). Since ink pigments are particles of very reduced size and, as a consequence, have very short associated thermal relaxation times, the laser impulse must have durations in the nanosecond or even picosecond range, with the second option being the most effective but also the most expensive. Depending on the wavelength of the laser, the applied thermal energy will be absorbed by particles with specific optical properties, which are related to the color of the particles. By manipulating the laser wavelength, pigments of specific colors can be effectively selected, hence destroying targeted ink pigments and leaving surrounding tissue unharmed. Selective photothermolysis is a complex process and when applied to tattoo removal procedures, there are a number of factors that must be taken into account in order to have optimal results and minimum risks for patients. The variables that affect the effectiveness of tattoo removal procedures can be classified into three main categories: Laser-dependent, tattoo-dependent, and host-dependent.

Laser-dependent factors include the spot size or beam diameter of the laser (increasing the diameter decreases the scattering of the beam and improves penetration), pulse duration (nanoseconds to picoseconds range), wavelength of the laser in relation to tattoo color (affects the pigments' absorption of the thermal energy applied), and the peak power of the beam. It is worth noting that there is still room for improvement in this aspect since there are many colors for which the ideal wavelength is not yet known, despite all the research that has been done in the field.

The tattoo itself introduces several variables into the process. Ink particles have a maximum diameter of approximately 6 µm, while the maximum particle diameter that can be absorbed by the lymphatic system is of around 0.4 µm. The size of the particles controls their thermal relaxation time and heat absorption rate (larger particles reach higher temperatures, which gives them a higher chance of fragmentation against smaller ones). The color of the pigments is also a highly influential variable, since dark colors generally have a better response to QS laser than bright colors due to higher heat absorption. The location of the ink in the skin defines the depth to which the laser must penetrate: professional tattoos are usually located in the upper to mid-dermis region, while amateur tattoos tend to be more superficial, which makes the former more difficult to remove (15-20 sessions for professional tattoos and 5-10 sessions for amateur tattoos). Additionally, the chemical composition of the ink can affect the predictability of the process results, since the exact composition of the pigments is rarely known and it can include a wide variety of components, including heavy metals.

Results are also affected by several variables introduced by the host (patient). The amount of energy scattered highly depends on the skin tissue of the patient. Energy which does not reach the target (ink pigment) may damage surrounding skin tissue or be reflected by the epidermis. This effect may be reduced by manipulating the laser-tissue interface by applying substances such as hyperosmotic solutions (e.g., sucrose, glycerol and water-soluble gels) or clearing agents (e.g., polypropylene glycol or polyethylene glycol) on the epidermis, which reduces the surface scatter from incident light. Other options include employing a pulsed laser to remove the epidermis, eliminating epidermal diffraction and scatter.

Other host-dependent factors are related to the patient's immune system response to the treatment. QS laser procedures merely cause the fragmentation of ink particles and it is the tissue response that handles phagocytosis and expulsion of the tattoo. Therefore, healing quality can be severely affected in patients suffering immunosuppression (i.e. via chemotherapy, drug induced or a medical condition) and ink retention after procedures may occur. Herpes infections, keloidal tendencies and sun exposure habits are also important variables in the final result.

Currently, laser tattoo removal is still in a developing stage. For example, constant efforts are being made to reduce pulse duration in QS laser and to create tattoo ink that is more responsive to laser (microencapsulation of water-soluble dye which can be removed by targeting the shell instead of disrupting the entire pigment particle). Nonetheless, it is still a flawed and costly process, which can be avoided by simply making responsible decisions when choosing to get a tattoo.

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