LiteCure
Lasers for Life

Laser Therapy Scientific Background

Introduction

Therapeutic lasers have been used around the world for over twenty years, yet only recently has this technology been widely integrated into mainstream medical practice. Technology and manufacturing advancements now allow laser units to be affordable and to have adequate output power to perform comprehensive treatments in a reasonable time. As more studies are being completed, we are finding that therapeutic lasers are effective for many everyday disorders. It is important to understand the basic mechanisms of laser therapy in order to use this versatile tool properly for appropriate applications. This understanding will allow the clinician to use lasers as a stand-alone therapy, or as an adjunct to other treatments.

Photochemical effects occur when laser light is absorbed by chromophores (the light absorbing part of a molecule) within a target cell, and biochemical change is inspired. Photo-biomodulation, which is the term science and industry agree is most descriptive, is an example of a photochemical process in which photons from a laser source interact with target cells and cause stimulatory or inhibitory biochemical change.

There are over 3,000 published studies on non-ablative laser therapy. Many of these studies have been done on cells in vitro and have shown excellent results of laser light's effect on various types of cells. These studies have shown increases of angiogenesis, neurite extension, normalization of ion channels, stabilization of the cellular membrane and many other cellular changes.

The exact mechanism of action for photo-biomodulation is still being debated in the scientific community. It is likely that several mechanisms are involved, depending on the type of cell being stimulated. The most supported mechanism to date is that cytochrome c, which is found within the intercellular membrane of the mitochondria, acts as a photoreceptor. Cytochrome c absorbs light from 500 nm to 1100 nm due to specific properties of this large molecule. Once light is absorbed, cytochrome c is excited and can more readily bond with oxygen and become cytochrome c oxidase, a compound critical to the formation of ATP. ATP is the activated carrier of energy in the cell, and facilitates a host of biologic responses or secondary mechanisms. This cellular mechanism initiates the reduction of pain, the reduction of inflammation and the healing of tissue.

Light-Tissue Interaction

Cells and biological tissue respond to light at a wide range of wavelengths from ultraviolet to the near- infrared. Selecting the correct wavelength ensures the light will penetrate through skin, fat and muscle to reach the target cells to be treated. Biological tissue eitherreflects, absorbs, or transmits light. The primary chromophores in tissue that are relevant for laser therapy applications are hemoglobin, oxyhemoglobin, water, and melanin. The following chart shows the absorption coefficient for these various components as a function of wavelength.

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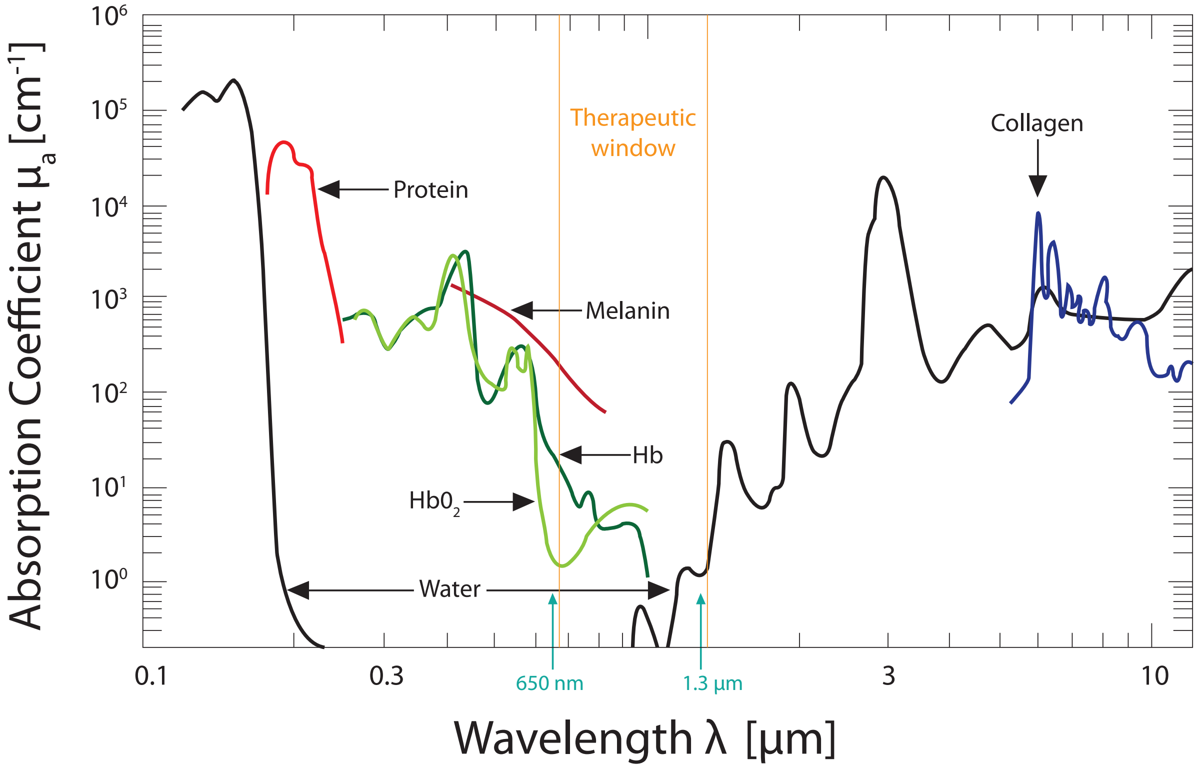

Figure 1. Optical absorption spectra of various tissue components in the ultraviolet to infrared frequency range. From The Warren Research Group at Duke University

This graph shows that the ideal window for the delivery of light into tissue ranges from around 650 nm to 1.1 microns. As the melanin content increases, the window is narrowed to about 860 nm to 1.1 microns. Melanin is a critical component when determining how to treat specific tissue. To minimize absorption by melanin in darker skin and/or hair, longer wavelengths are required. Many studies fail to point this out when addressing depth of penetration. As can be seen from the values on the chart above, it is a critical component to absorption. Water is another component which is often misunderstood. The above chart is plotted on a logarithmic scale. This format allows the presentation of data that varies by many orders of magnitude on the same graph. Water absorption is not a substantial concern until above 1 micron. For example, the absorption coefficient of water at 970 nm is 0.001 and the absorption coefficient of melanin is greater than 10 which is orders of magnitude greater. Below is a spectrum for water absorption from the UV (ultraviolet) to the IR (infrared). Also illustrated is a section of the spectrum magnified to show a slight variance of absorption in this optical window. You can see that there are some peaks: however the values are minimal in the overall picture.

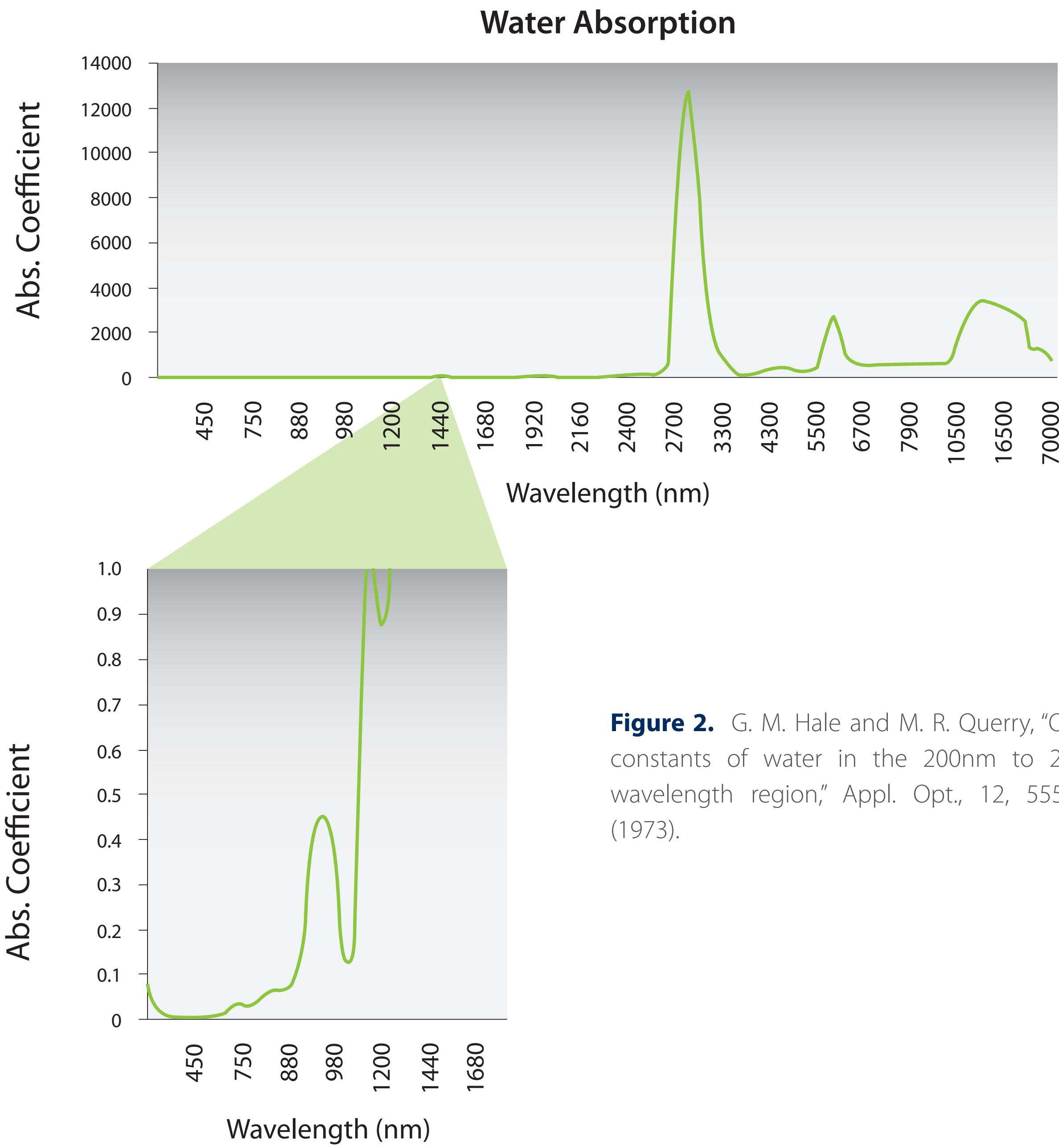

Figure 2. G. M. Hale and M. R. Querry, "Optical constants of water in the 200nm to 200µm wavelength region," Appl. Opt., 12, 555--563, (1973).

The following figure, reproduced from a published study, demonstrates the transmission of light through adipose breast tissue. This clearly shows the optimal region in the spectrum for transmission is from around 740 nm to 1.1 microns. It also shows that absorption in this region is fairly flat. The import component missing from this study is melanin.

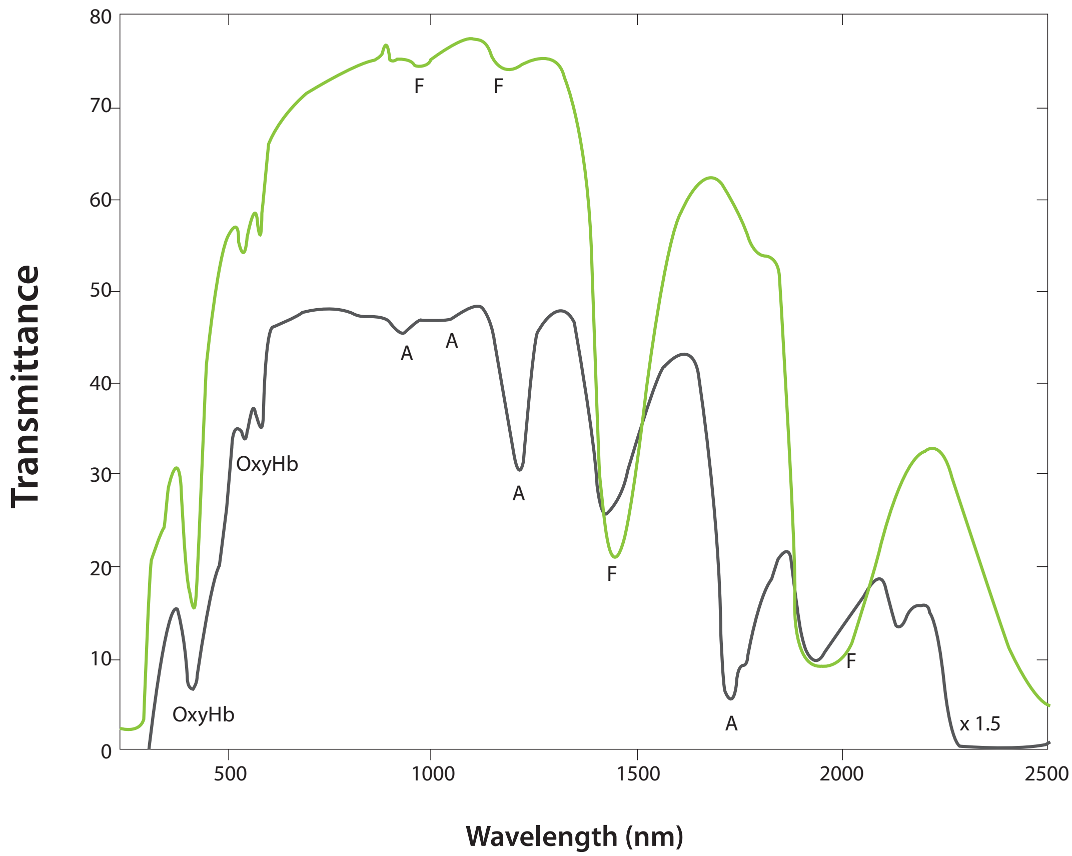

Figure 3. Optical Transmittance through 3 mm of adipose breast biopsy and 500 microns of fibroglandular breast biopsy (----). The absorption peaks marked F and A are due to fibroglandular and adipose tissue respectively. The absorption resonances marked 'OxyHb' are hemoglobin resonances in the tissue. Frontiers in Bioscience 3, a1-10, January 1, 1998 by Fay A. Marks General Electric Corporate Research and Development.

This point is also illustrated in the figure 4 which shows the absorption spectrum of liver tissue. As expected, this spectrum correlates well with the breast tissue spectra. Studying liver tissue is a great example of light absorption in water and hemoglobin. However, the lack of melanin in the tissue makes it very different than treating through skin and hair. When treating patients with higher melanin concentration in their skin and/or hair, the penetration of shorter wavelengths is reduced significantly. Hair removal lasers, for example, are designed to target melanin utilizing the principle of selective photothermolysis, the preferential heating of the hair follicle with light. The higher relative absorption by the melanin kills the follicle, while not being absorbed to any great degree in the skin. The most popular wavelengths for this application are 755 and 810 nm, since the melanin absorption is high, and hemoglobin absorption is low.

Target cells of interest for laser therapy have such a generous absorption curve (UV through to IR), that choice of wavelength is as much determined by what the light is not absorbed in water, melanin, hemoglobin etc.

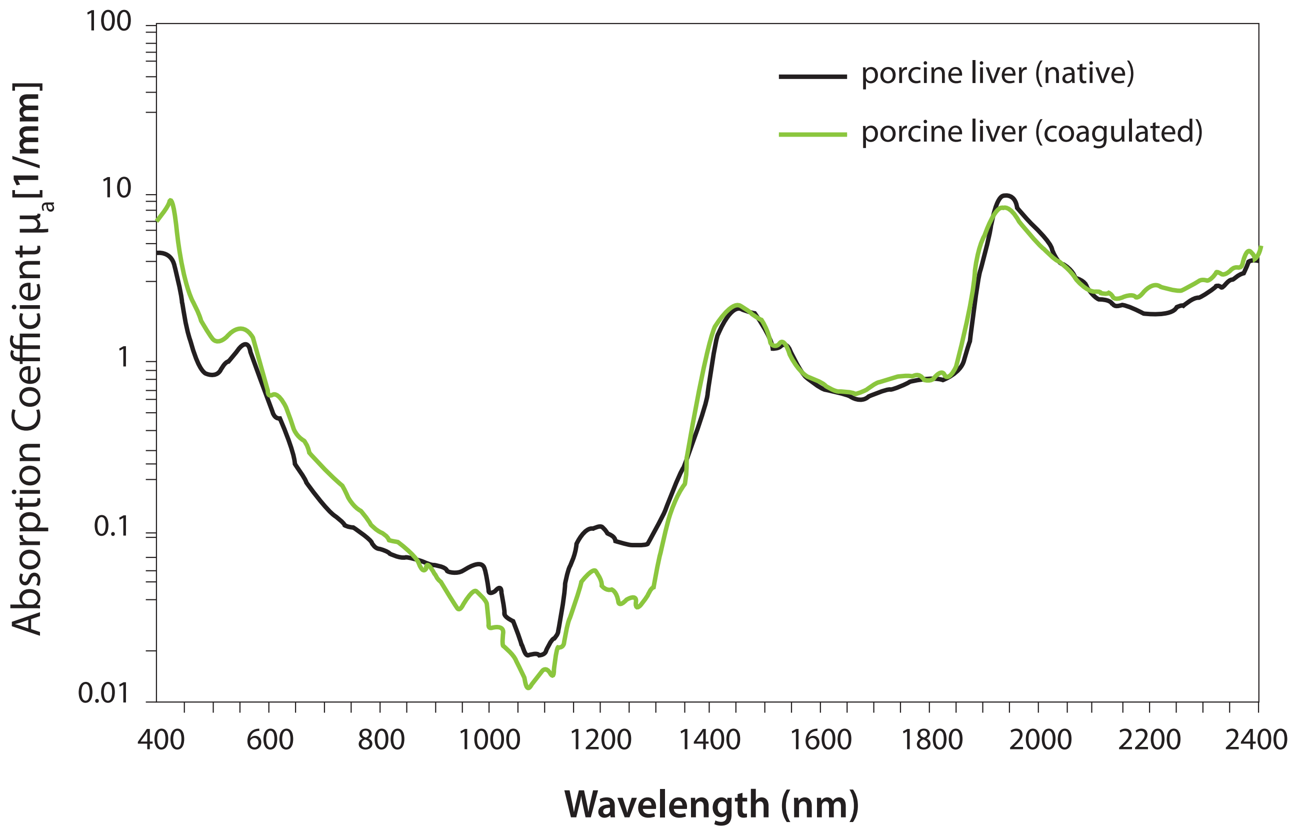

Figure 4. Joerg-P. Ritz, et al, Lasers in Surgery and Medicine 29:205±212 (2001)

In order to deliver a therapeutic dosage to deep tissue it is very important to choose the correct wavelength and use the correct amount of light. The text book definition of 'depth of penetration' is the depth at which the initial intensity of light drops to 1/e or ~37%. It does not consider the actual measurable amount of light. By this definition the wavelength is the only important factor.

When determining practical dosages in a clinical setting, it is critical to consider wavelength as well as the initial intensity of light. Assume the depth of penetration of 800 nm light into muscle tissue is 5 mm. If we start with 100 mW of power we would get 37 mW at 5 mm. Now raise the initial power to 10 W, we will get 3.7 W at a depth at 5 mm. The more power delivered to the surface of the tissue, the larger the dosage that will be delivered to deeper tissue.

Protocols – Where do they come from?

As described above, depth of a therapeutic dosage is dependent on the wavelength and the amount of light delivered to the skin surface. The goal of a therapy protocol is to optimize dosage at the cellular level. An example of proper protocol development is demonstrated by a recent series of laboratory studies on nerve repair.

The initial study was performed in vivo on rat dorsal root ganglion nerves. These nerve cells were split into 2 groups; one group was placed into a glucose medium, the other served as the control and put in a standard medium. The glucose group experienced severe impairment in axonal sprouting, while the control group remained unchanged. The impaired cells were then exposed to various wavelengths and dosages of laser light. The optimum axonal sprouting, which was 90% of the control, occurred when using a 980 nm laser with a dosage of 100 mJ/cm^2. Reference Juanita Anders ASLMS

The next step is to determine the correct dosage to deliver on the surface in order to achieve this dosage at the impaired nerve. In this next study, white New Zealand rabbits were used to determine how to get a dosage to the peroneal nerve. Small electro-optic detectors were introduced into the tissue and placed directly over the peroneal nerve. Since both hemoglobin and oxyhemoglobin have different absorption, the rabbits were anesthetized during these experiments, rather than euthanized. It was found that only 2.45% of the initial dosage (applied to the surface), penetrates to the peroneal nerve. This is only a depth of ~ 2.5 cm of tissue. Working backwards from the data gleaned in the Petri dish study, i.e. a dosage of 100 mJ/cm^2at the nerve for optimal repair, it was calculated that the dose at the skin surface needed to be 4 J/cm^2.

This dosage was then applied in a clinical study utilizing New Zealand rabbits. In this study, the peroneal nerve was transected and then immediately repaired surgically. The peroneal nerve is critical for the toe spread reflex, so each rabbit was video-taped in order to precisely measure the amount of toe spread. This was then compared to the unimpaired leg. Laser therapy, plus standard of care, was administered to half of the rabbits each day, for 8 days. The control group was treated with standard of care, plus a sham laser treatment for the same period of time. As early as six weeks, the laser-treated group showed a statistically significant amount of functional recovery indicating nerve repair when compared to the control. The laser group showed 90% repair after just 9 weeks post-transection.

This study is one example of how dosages and protocols are determined for specific laser treatments. In many cases, specific cells or tissues are tested in vivo, in order to determine a range of optimal parameters. Depth of penetration studies have been done in cadavers and in anesthetized animals. There have been many studies done on how light penetrates tissues. All of these parameters have been studied for years for medical laser applications including cosmetic / aesthetic procedures, laser surgery, as well as diagnostic applications.

Applying Protocol Development to the Patient

When performing laser therapy it is critical to choose the correct dosage and wavelength, but additionally the size of the area to be treated must be considered. This is because it is the dosage in J/cm^2 multiplied by the treatment area in cm^2 that determines the total energy required for a particular treatment protocol. Using the 4 J/cm^2 dosage example from above and applying this to a 500 cm^2 treatment area, 2000 Joules of energy would be required for an effective treatment to be administered. The output power of the laser will have a dramatic impact on the time required to deliver the energy. 1 watt is equal to 1 J/sec and therefore the following treatment times would result at different laser power output levels:

Output Power	Dosage	Size of Treatment Area	Treatment Time
5mW	4J/cm^2	300 cm^2	66 hours 40 minutes
100mW	4J/cm^2	300 cm^2	3 hours 20 minutes
250mW	4J/cm^2	300 cm^2	1 hours 20 minutes
500mW	4J/cm^2	300 cm^2	40 minutes
5W	4J/cm^2	300 cm^2	4 minutes
10W	4J/cm^2	300 cm^2	2 minutes
15W	4J/cm^2	300 cm^2	1 minute 20 seconds

This chart shows that treatment times are dramatically decreased as power is increased. Treatment at the higher power levels has been demonstrated to be both safe and efficacious in numerous studies and in clinical practice.

The Role of Wavelength

The wavelength will be determined by the types of conditions you wish to treat. Superficial treatments such as wounds can be treated with shorter wavelengths in the red region of the spectrum. If deeper conditions are going to be treated, a longer wavelength in the range of 800 nm to 1 micron will be optimal. When treating darker skinned, or hirsute patients, the longer wavelengths will have optimal penetration. The dosage will be determined by the condition, the color of the patient's skin and hair, and the depth, and type, of tissue to be treated.

Conclusion

The understanding of the fundamentals of laser therapy; the clinical research and science, as well as the commercial product technology have advanced significantly over the last 30 years. The medical industry is just now beginning to use and experience the benefits of these research, scientific, and technology advances.

Applying the principles of sound scientific and clinical research with broader awareness and education of the healthcare community will lead to an increasing application of laser therapy technology and successful outcomes for healthcare practitioners and their patients. In turn, our society will benefit through the increased contributions of patients who have been more quickly rehabilitated and restored to their normal productive capacity, while reducing the costs associated with extended disability and treatment times.