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Tissue Welding Using (800±10nm) Diode and (1064nm) Nd: YAG Lasers

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Abstract: Background: Joining tissue is a growing problem in surgery with the advancement of the technology and more precise and difficult surgeries are done. Tissue welding using laser is a promising technique that might help in more advancement of the surgical practice. **Objectives:** To study the ability of laser in joining tissues and the optimum parameters for yielding good welding of tissues. **Methods:** An in-vitro study, done at the Institute of Laser, Baghdad University during the period from October 2008 to February 2009. Diode and Nd-YAG lasers were applied, using different sessions, on sheep small intestine with or without solder to obtain welding of a 2-mm length full thickness incision. Different powers and energies were used to get maximum effect. **Results:** Welding of sheep intestine had been achieved by Nd-YAG laser 1064 nm at 400 and 500 mJ and PRR 4Hz, using human albumin 20% as a solder. Welding failed using the diode laser 4W for 10 min with albumin and indocyanine green. **Conclusion:** Laser may be useful tool in certain condition for joining tissue and wound closure. This is important because in certain circumstances no other technique is feasible for wound closure.

Introduction

With advancing technology, surgery becomes more complicated and more advanced methods for joining tissues are needed, the staplers were introduced in the last century and represented a suitable method for effective tissue joining in special conditions especially intestinal anastomosis (1). The new modality of adjoining tissues by welding is involving holding tissue margins together with acceptable strength until healing take place using the thermal effect of the laser. The mechanism involving melting or denaturation of the protein component of the tissue which act as a "glue" that holds the edges of the wound together. Adding an external material usually albumin which act as a "solder" will increase the adhesive strength and decrease the thermal side effects of the laser (Talmor, et al., 2001)

In laser tissue welding techniques, laser energy is used to induce thermal changes in the molecular structure of the tissues being joined, hence allowing them to bond together. Laser tissue soldering, on the other hand, is a bonding technique in which a protein solder is applied to the tissue surfaces to be joined, and laser energy is used to bond the solder to the tissue surfaces. The addition of protein solders to augment tissue repair procedures significantly reduces the problems of low strength and thermal damage associated with laser tissue welding techniques (McNally, et al., 1999)

Most common and effective lasers used in tissue welding and soldering are those in the infrared region so as not much penetration is occurred during the welding procedure. The most common types used are the diode laser (810 nm), Nd:YAG (1064 nm), THC:YAG (2150 nm), KTP (532 nm), Ho:YAG (2100 nm), CO_2 (10600 nm) (Bleustein, et al., 2000).

Tissue welding may be performed without adding any material to the tissue. This means that the tissue protein itself will undergo denaturation and melting leading to welding effect. Adding a protein material (solder) to the tissue can improve the yielding results producing more powerful adhesion and less sideway tissue thermal damage. Serum human, bovine, porcine and canine albumin both fatty acid containing and fatty acid-free in different concentrations have been used as solders (Bleustein, et al., 2000).

Different techniques have been used; liquid, dried (with or without dye), single or two-layer film (white layer of bovine albumin and black layer of carbon black) (Lauto, et al., 1999).

To increase the absorption of the light chromophores are used, which are different types of dyes that can absorb the incident laser beam in certain wavelengths and hence transfer its energy to the tissue. These dyes includes the followings; indocyanine green, methylene blue, fluorescein isothiocyanate (Chuck, et al., 1989) and food colorings in different concentrations (Byrd, et al., 2003). The aim of this study was to measure the type and parameters of the laser beam which can induce tissue welding.

Materials and Methods

A fresh small intestine from a sheep 20 cm in length and 0.5 cm in diameter was taken. A freshly prepared indocyanine green dye 0.4 mg in 1 cc of buffered phosphate saline solution was used. The dye was mixed with human albumin 20% concentration to be used as a solder. A 2 mm length full thickness transverse incision was made on the sheep intestine.

Increasing power and longer duration of diode lasing sessions (CW, starting with 1 watt power for 2 minutes and ending with 4 watts for 10 minutes), were applied to the incision of the intestine to record the effect and this was regarded as control. These same sessions were repeated after adding the albumin and the dye mixture and observing the effect. Safety measures were respected during this procedure.

Then, Q-switched, pulsed, 1064 nm, Nd-YAG laser was used. The same settings of the sheep intestine was used, a small incision 2 mm full thickness was made in the intestine. Different PRRs and energies were used trying to obtain a plaque that bonds the edges of the incision. The laser handle was held 9 cm away from the intestine, at this distance an audible spark formed. Less and more distance produced no spark and no sound and gave no result. The laser handle was held vertical to the wound, this was considered as control.

The same procedure was repeated but after applying human albumin 20% to the incision with application of the Nd-YAG laser beam in the same setting as in the control sample. The result were recorded and compared in both samples.

Results

A diode laser (CW) was used with escalating power and prolongation of duration for welding the intestinal wound without adding any thing this was used as control, with all powers and durations used no effect happened.

After adding the albumin 20% and the dye and applying the laser beam in same powers and durations as in the control sample, no visible adhesion or adhesive plaque of the albumin had formed over the wound in all powers and durations used (Table 1 and Figure 1).

Table (1): Results of welding by diode laser (810 mm) with albumin 20% and indocyanine green 4mg/ml, and without adding any material (control).

Power (Watt)*	Power density watt /cm^2 SA= 0.5024 cm^2	Duration (minute)	Result
1	1.99	2	No effect
2	3.98	4	No effect
3	5.97	6	No effect
4	7.96	8	No effect
4	7.96	10	No effect

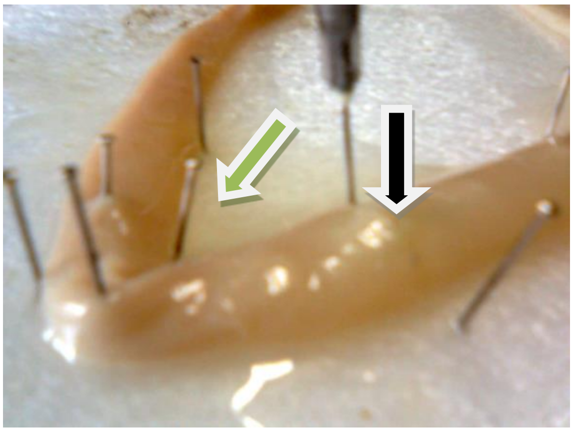

Fig. (1): Failure of welding by diode laser (black arrow) with leakage of water (green arrow) from the incision.

The power mentioned is the apparent power displayed by the machine used. The real (measured) power should multiplied by the factor 0.625 (this factor was obtained by measuring the maximum power output (it was 2.5 W) and dividing it by the power displayed on the screen of the machine. This factor is valid only during the time of the current study and should be re-measured whenever the machine is reused since it may change with time).

After many trials with different parameters, no welding effect could be obtained, but a perforation occurred with the high energy, i.e. at PRRs = 4 &5 Hz (successively), 500 mJ for 20 shots, this was considered as control, (Table 2).

Human albumin solution 20% were applied to the intestinal incision, and after many trials with the same previous settings, a plaque of albumin that glues the incision partially (superficially) was formed which could withhold water inside the intestine, (Figure 2).

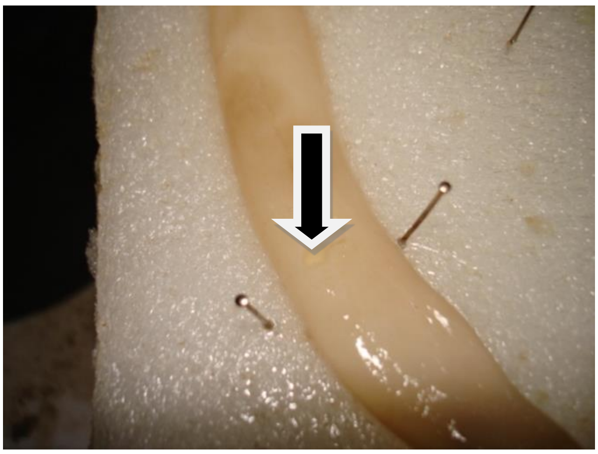

Fig. (2): Albumin plaque over incision (black arrow) of small intestine of sheep.

Many layers of the albumin were applied and after each layer, laser was applied to induce the soldering effect after application of three layers fairly good plaque was obtained that could glue the incision and withhold a column of water of about 5 cm height. This happened at PRRs = 4 Hz and 400, 500 mJ (successively) for 20 shots, (Table 3).

Table (2): Results of Q-switched Nd:YAG applied to the sheep intestinal incision without adding any material, (control).

PRR (Hz)	Energy (mj)	Number of shots	Effect
1	100	1	No effect
1	100	5	No effect
1	100	10	No effect
1	100	20	No effect
2	200	5	No effect
2	500	5	No effect
3	300	5	No effect
3	400	5	No effect
4	300	5	No effect
4	500	5	No effect
4	400	10	No effect
4	500	10	No effect
4	500	20	Perforation
5	500	20	Perforation

Table (3): Results of Q-switched Nd:YAG applied to the sheep intestinal incision after application of human albumin 20%.

PRR (Hz)	Energy (mJ)	Number of shots	Effect
1	100	1	No effect
1	100	5	No effect
1	100	10	No effect
1	100	20	No effect
2	200	5	No effect
2	500	5	No effect
3	300	5	No effect
3	400	5	No effect
4	300	5	No effect
4	500	5	No effect
4	400	10	Plaque formation
4	500	10	Plaque formation
4	500	20	Perforation
5	500	20	Perforation

Discussion

The results of the diode laser may be explained by the low maximum power of the machine used which give (2.5 w) maximum power as measured by a power meter. (Ogan, et al., 2003) used a diode laser 810 nm pulsed of 20 W with 50% liquid albumin-indocyanine green to seal the collecting system of the kidney and achieve hemostasis in heminephrectomy of female pigs.

Another factor might be the concentration of the albumin used was fixed to 20% and increasing the concentration of the albumin needs special techniques which were not available. Also, the type of albumin is important, most of studies used powdered bovine serum albumin. The higher the albumin concentration, the better the bonding power the average tensile strength of laser soldered tissues increased as the protein solder concentration increased (Lauto. 1998). In many studies, the albumin concentration was between 40 -60% (Lauto, et al., 2004). Ware and Buckley (Ware and Buckley . 2003) found that, the optimum condition for obtaining good welding of porcine small intestinal submucosa was a solder composition of 45% bovine serum albumin, indocyanine green concentration of 0.5 mg/ml deionized H_2O, and a laser irradiance of 21 W/cm2 form 808 nm diode laser. Another study by McNally *et al* made on bovine aorta specimens showed that the best parameters were an irradiance of 6.4 W cm-2 from 808 diode laser CW using a solid protein solder composed of 60% bovine serum albumin and 0.25 mg/ml indocyanine green. Using this combination of laser and solder parameters, surface temperatures were observed to reach 855 ^{o}C with a maximum temperature difference through the 150 micrometer thick solder strips of about 15 ^{o}C.

Histological examination of the repairs formed using these parameters showed negligible evidence of collateral thermal damage to the underlying tissue. Scanning electron microscopy suggested albumin intertwining within the tissue collagen matrix and subsequent fusion with the collagen as the mechanism for laser tissue soldering (McNally, et al., 1999).

Nanotechnology has entered the field of tissue welding. Gold nano shells, as an exogenous absorber, suspended in albumin solder showed to allow the usage of light sources that are minimally absorbed by tissue components, thereby, minimizing damage to surrounding tissue and allowing welding of thicker tissues (Gobin, et al., 2005, and Huang, et al., 2013). The Nd-YAG laser, in the present study, was successful in forming a plaque over the incision of the intestine. The Nd-YAG laser was used by researchers to weld tissue, as the study performed in Japan to unite large intestine of rabbit (Kawahara, et al., 1996) and cutaneous wounds (Abergel, et al., 1986).

Still there was the problem of sufficient strength to withhold the wound strong enough until healing occurs. In the present study, the wound seal could withhold a pressure of 5 cm water column. This may be not strong enough, since the intestinal intraluminal pressure may range from 5 to 10 mm Hg (Leonard Johnson, 2014.). This weak seal may be related to low albumin concentration used in present study. A study done in the USA, found that the best results of tissue welding were obtained with concentration of albumin of 50%, when it was used with Nd-YAG laser beam (Massicotte, et al., 1998). Newer solders have been used which showed better tensile strength, these solders have been used with different types of lasers, examples of these substances are collagen-based scaffolds (Steinstraesser, et al., 2010), poly-caprolactone (PCL) scaffold (Pabittei, et al., 2012), and concentrated autologous plasma protein (Stewart, et al., 2001).

In conclusion, tissue welding by Nd:YAG laser is feasible but it needs higher concentration of human albumin. Also, more specialized accessories of the laser system are needed to focus the beam. Certainly, more experience is vital and continuing practice will improve the results.

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لِــحَــام الأنسجة باستخدام ليزر شبه الموصلات وليزر النيوديموم

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الخلاصة : **الخلفية** تعتبر عملية لحام الأنسجة في الجراحة الحديثة تحد كبير للجراحين، حيث أن التقنيات الحديثة في الجراحة الدقيقة والمنظارية تجعل من الضروري إيجاد بدائل للطرق التقليدية في ربط الأنسجة ببعضها باستخدام الخيوط الجراحية. ولعل استخدام الليزر يمثل إحدى هذه الحلول المتاحة. **الطرائق** أجريت هذه الدراسة في معهد الليزر للدراسات العليا في بغداد للفترة من تشرين أول 2008 – شباط 2009. وتم استخدام نوعين من الليزر هو شبه الموصل والنيوديميم لغرض تحقيق لحام لجرح مصطنع بطول 2 ملم في نموذج للمعي الدقيق للخروف. تم استخدام مادة الألبومين الإنساني مع أو بدون صبغة مشجعة للامتصاص هي "إندوسيانين الخضراء". وباستخدام طاقات مختلفة لليزر تم قراءة النتائج. **النتائج** لم يتم الحصول على خثرة لاصقة باستخدام الليزر شبه الموصل بعد إضافة الألبومين والصبغة. ولكن تم الحصول على هذه الخثرة لاحمة باستخدام ليزر النيوديميم وباستخدام الألبومين فقط، وبطاقة 400 -500 ملي جول وبتردد نبضي 4 هرتز. **الاستنتاجات** الليزر يمكن أن يكون أداة مفيدة للحام الأنسجة مع بعضها ويمكن أن يكون مستقبلا بديل مناسب لاستخدام الخيوط الجراحية في بعض الحالات الخاصة.