Assessment of the effectiveness of low-level laser therapy (LLLT) on the knee hydrarthrosis by optoelectronics methods

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Low-level laser therapy is widely used all over the world as a method for the treatment of various diseases. However, its use for therapeutic purposes is still a controversial subject due to the lack of consensus on the effectiveness of this method in some medical applications. In this paper we investigated if low-level laser therapy is effective in the treatment of knee hydrarthrosis. The optical and thermal properties of the affected and normal knee were determined by diffuse reflectance spectrometry and thermal infrared imaging before and after each laser irradiation session. The results demonstrated that low-level laser therapy induced in the affected knee an increase of diffuse reflectance with ΔR = 9.9094% and a decrease of average temperature with 1.92°C after three treatment sessions. After three days of treatment, the values of the optical and thermal parameters for affected knee were relatively close to those of normal knee. In conclusion, the effect of low-level laser therapy on the knee hydrarthrosis was demonstrated based on the variation of two measurable physical parameters. Low-level laser therapy has proven to be effective in treating the pathology addressed, requiring only three treatment sessions so that affected tissues to gain its normal physical properties.

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1. Introduction

Low-level laser therapy (LLLT) is a medical procedure that uses miliWatts-order laser radiation to stimulate a biological process. This therapeutic approach has been promoted in recent decades for its beneficial effects to relieve pain [1], accelerate healing processes [2-5], joints treatment [6], laseropuncture [7], etc. For both doctors and patients, the most spectacular results about using LLLT have been obtained for atonic lesions and various ulcers and in general, for trophic problems at patients with diabetus and arteriopathies [8, 9]. Nevertheless, the LLLT therapeutic use is still a controversial subject, because some studies report biologic beneficial effects and other researchers are more critic about proofs and quantifications regarding its efficacy in medical purposes [10,11]. The researches in this area continue in order to determine whether there is a demonstrable effect.

The aim of this study was to demonstrate the effect of LLLT on the knee hydrarthrosis. Knee hydrarthrosis means effusion in the joint, most of the time by inflammation of the synovial liquid and rarely with infectious causes or blood (when it is called haemarthrosis). Hydrarthrosis is usually accompanied by painful movements on flexion/extension of the knee and exacerbating pain on weight-bearing positions, such as walking or standing position or stairs climbing/walking down. To demonstrate the effect of LLLT on the knee hydrarthrosis healing, the changes in optical and thermal properties of the damaged tissue induced by laser irradiation were determined by diffuse reflectance spectrometry and thermal infrared imaging.

2. Materials and methods

2.1. Subjects

Nine subjects with age between 18-60 years old diagnosed with knee hydrarthrosis were recruited in this study. They were informed about all the details regarding the therapeutic and assessment methods and signed an informed consent for participating in this study, in respect with the ethical committee decision. The selection of the patients was based on a rigorous physical examination (local inflammation signs, instability signs, passive and active knee range of motion) and confirmed by knee X-ray and ultrasound methods. Exclusion criteria were uncontrolled or potentially cardiovascular decompensations.

2.2. Low-level laser therapy

A diode laser system (SCL-TR, INOE 2000, Bucharest, Romania) emitting continuous light with a wavelength of 635±10 nm and an output of 15 mW was used in this study. Laser irradiation was performed through the contact method on the injured area. The spot size on the tissue was 0.92 cm^2 with a power density of 16.31 W/cm^2 and the time exposure was set at 300 s. The subjects were irradiated daily for 3 consecutive days. The biological response at laser treatment was assessed by two non-invasive optoelectronic methods: diffuse reflectance spectrometry and thermal infrared imaging. We chose these methods because they provide us quantitative information about the optical and thermal properties of skin surface and their changes during LLLT.

2.3. Diffuse reflectance spectrometry

Diffuse reflectance spectroscopy is an optoelectronic technique that measures the characteristic reflectance spectrum produced as light passed through biological tissue. This technique is sensitive to both scattering and absorption properties of the tissue, over a wide range of wavelengths and, consequently, it can provide spectra that contains information about the optical properties and structure of the biological tissue being investigated. We used this technique to monitor changes in the optical properties of the knee hydrarthrosis area as response to LLLT therapy. Optical reflectance spectra in the wavelength range (500 - 1100) nm were obtained with AvaSpec optic fiber spectrometer (Avantes, The Netherlands, Europe). This fiber based spectrometer use a tungsten halogen lamp coupled to an optical fiber which deliver light to a probe type FCR-7IR200-2. Other six collection fibers carry reflected light back to a CCD-based spectrometer. The reflectance spectra corresponding to each subject with confirmed knee hydrarthrosis were recorded before and after each irradiation session during the whole period of LLLT treatment. The reflectance spectra of the healthy knee were registered as a control-group.

2.4. Thermal infrared imaging

Thermal infrared imaging is an optoelectronic technique usually used for the qualitative measurements of thermal emissions from bodies. It offers the possibilities to create a thermal map (IR image) of temperature distribution in a non-contact way. We used this technique for the measurement of temperature variation in the affected area with hydrarthrosis during LLLT. Thermal infrared imaging was performed using a ThermaCamB2 infrared camera (FLIR Systems, Sweden) which operates at a wavelength range from 7.5 to 13 μm. The temperature measurement range lies between -20°C and +100°C. Its accuracy is ±2% of the reading. Thermal sensitivity is 0.10°C at 30°C. All patients were investigated in a supine position under the same conditions. The infrared camera was positioned 50 cm in front of the knee, in all cases. Thermal imaging was performed before and immediately after each session of laser irradiation. IR image were analyzed using the Quick Report v1.0 software which allows measurements over a defined region of interest.

2.5. Statistical analysis

The data are presented as mean values ± standard deviations. The mean value and its standard deviation have been calculated using Origin 8 software (OriginLab Corporation, USA).

3. Results and discussions

3.1 Diffuse reflectance variation of knee affected by hydrarthrosis as an effect of LLLT therapy

Diffuse reflectance spectra of the knee affected by hydrarthrosis in comparison with normal knee are presented in Fig. 1.

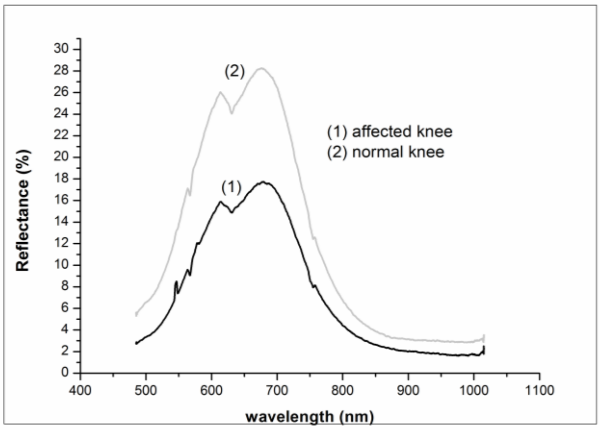


Fig. 1. Diffuse reflection spectra of knee affected by hydrarthrosis and healthy knee.

We can observe that both affected and healthy knee present two main reflection maxima located at different wavelengths and a reflection minimum is located at the λ_{min} = 631.02 nm (Table 1). The R_{max} and R_{min} values for healthy knee are about 1.6 times higher than those of affected knee.

Table 1. Reflection maxima and minimum for affected and healthy knee.

Peaks	Affected knee		Healthy knee	
	λ (nm)	R (%)	λ (nm)	R (%)
Maximum 1	613.59	15.8881	613.87	26.0512
Maximum 2	680.25	17.6924	692.97	27.3965
Minimum	631.02	14.8673	631.02	24.0507

As a result of exposure of the affected knee in the first session of LLLT using a laser that emits radiation with a wavelength of 635 nm (close to the wavelength corresponding to the reflectance minimum), diffuse reflectance of the knee decreases from R_i = 15.2611% at R_f = 12.4728% (λ = 635 nm) (Fig. 2a). During the next 24 hours, the knee reflectance increases to 14.3364%.

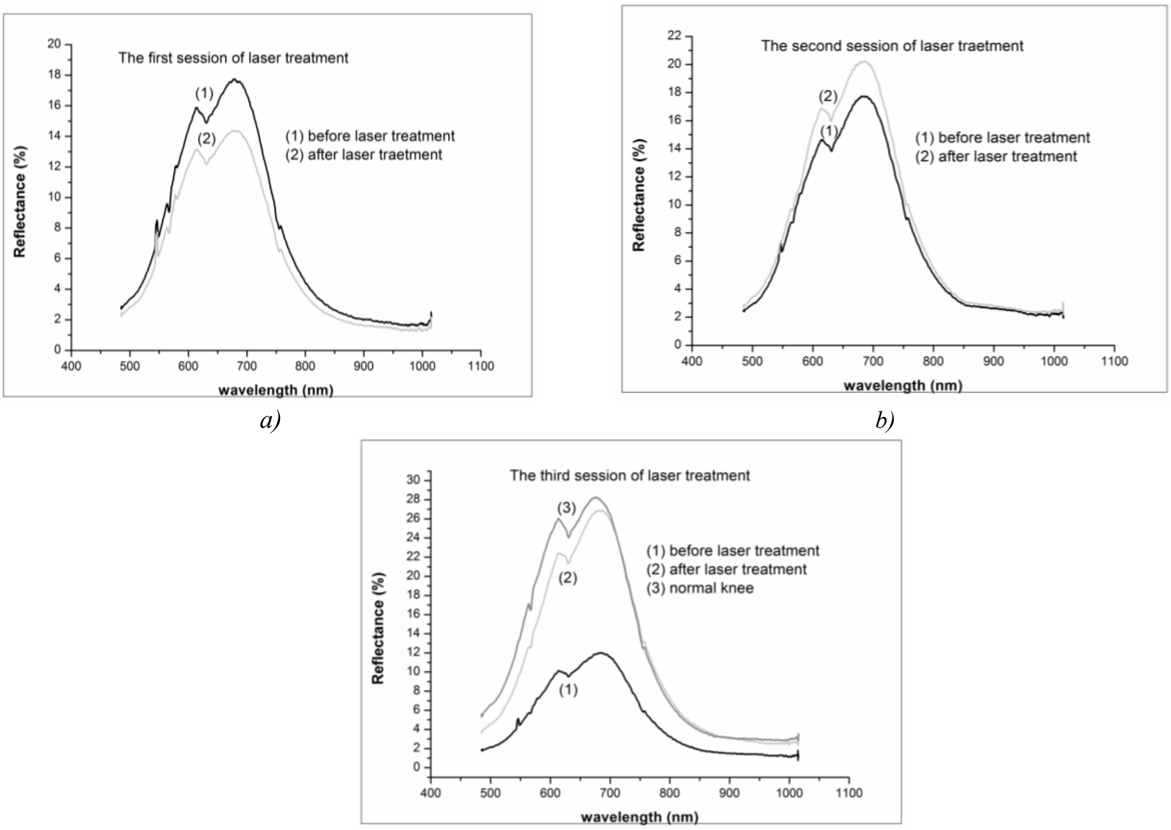


Fig. 2. Diffuse reflectance spectra of the knee affected by hydrarthrosis at different time moments during the LLLT sessions (patient 1); a) before and after the first LLLT session; b) before and after the second LLLT session; c) before and after the third LLLT session.

After the second LLLT session, a new increase in reflectance of affected knee with ΔR = 15.6791% (λ = 635 nm) was recorded (Fig. 2b). At 24h after the second LLLT session, the reflectance of knee reaches the value of 9.8490%. After the third session of LLLT, knee reflectance significantly increases reaching the value of 25.5283% (λ = 635 nm). This value is close to the normal values for healthy kneee (Fig. 2c).

Reflectance variation for knee affected with hydrarthrosis as a result of LLLT treatment for study group is presented in Table 2.

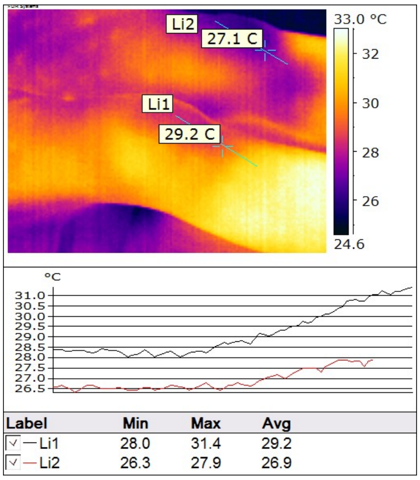
Table 2. Variation of reflectance for knee affected by hydrarthrosis as result of LLLT (λ = 635 nm)

Time moment	**R_{med} (%)**	
	Study group	**Control group**
Before the first laser irradiation session	15.6363±0.4213	
After the first laser irradiation session (first day)	12.9673±0.4419	
Before the second laser irradiation session	14.4403±0.5135	24.9731±0.4713
After the second laser irradiation session (second day)	16.5273±0.5124	
Before the third laser irradiation session	10.1400±0.4572	
After the third laser irradiation session (third day)	25.5457±0.5577	

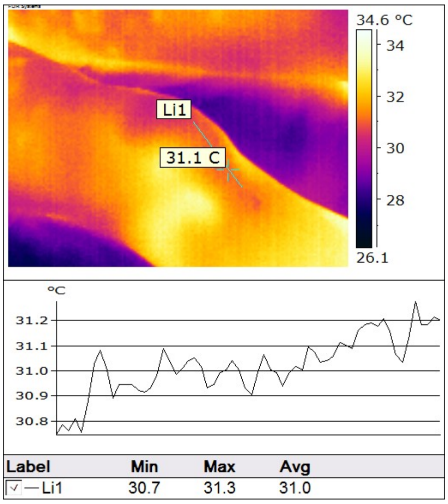
We can see that the diffuse reflectance of the affected knee decreases and increases during the entire treatment period. This time variation of diffuse reflectance is due to chemical and structural changes occurring at the cellular and tissular level as a result of laser irradiation, and biological response of the body in the interval between treatment sessions (24h). A significant result was obtained after three sessions of LLLT when diffuse reflectance values obtained for the study group were close to those of the control group and the clinical signs of hydrarthrosis were much diminished. Clinical exam performed one month after LLLT revealed no articular manifestation of hydrarthrosis type in the patients from study group. Therefore LLLT can be considered as an effective method for the treatment of the investigated pathology. These results also demonstrated that diffuse reflectance can be considered as an important quantitative parameter in monitoring LLLT.

3.2 Temperature variation for knee affected by hydrarthrosis as a result of LLLT treatment

Fig. 3 shows the thermal images acquired before and after the first session of LLLT. We can see that the affected knee before LLLT shows an average temperature value of 29.2°C (Li1 line). In contrast, the average temperature in a healthy knee in a symmetric location with the first line (line Li2) is 26.9°C (Fig. 3a).



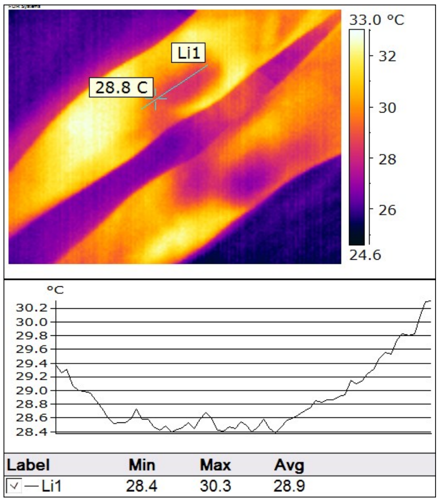
a)



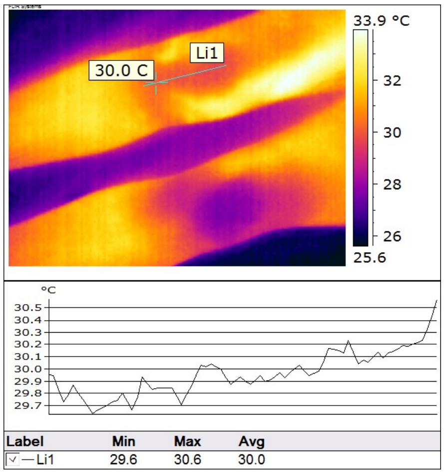
b)

Fig. 3. Thermal images of the knee with hydrarthrosis before and after the first LLLT (patient 1); a) before LLLT; b) after LLLT.

Temperature distribution on the investigated lines (Li1 and Li2) highlights the presence of a maximum temperature of 31.4°C in the affected knee indicating an inflammatory process in affected area. The maximum temperature value recorded for healthy knee was only 27.9°C. After the first session of LLLT, there is an increase in the average temperature in the affected area with ΔT_{avg} = 1.8°C (Fig. 3b). Within 24 hours after the first LLLT session, there was a decrease in the average temperature of the knee with ΔT_{avg} = 2.1°C. The second LLLT session determines a new local average temperature increase to 30.0°C (Fig. 4).



a)

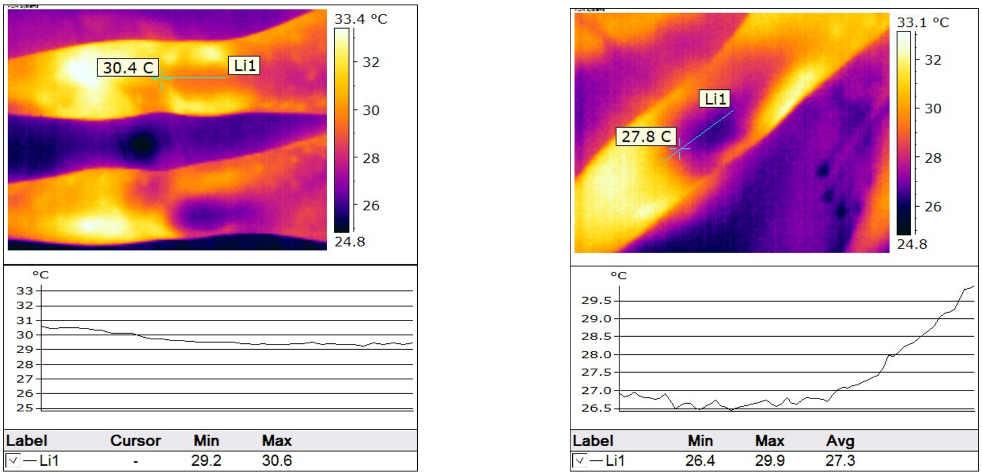


b)

Fig. 4. Thermal images of knee with hydrarthrosis before and after the second LLLT session (patient 1); a) before LLLT; b) after LLLT.

In the next 24 hours after the second laser treatment the average temperature of the affected area recorded also a small increase with only ΔT_{avg} = 0.6° C. At 24h after the third laser treatment, local average temperature drops to a value close to that of a healthy knee (T_{avg} = 27.3°C) (Fig. 5).

Similar changes in the average temperature of the affected knee where recorded for all patients (Table 2).



a) *b)*

Fig. 5. Thermal images of knee with hydrarthrosis before and 24 h after the third LLLT session (patient 1); a) before LLLT; b) 24h after LLLT.

Table 2. Changes in average temperature of the knee affected by hydrarthrosis as result of three LLLT sessions.

Time moment	**T_{avg} (°C)**	
	Study group	**Control group**
Before the first laser irradiation session	29.23±0.15	
After the first laser irradiation session (first day)	31.06±0.17	
Before the second laser irradiation session	28.94±0.21	26.93±0.13
After the second laser irradiation session (second day)	30.03±0.11	
Before the third laser irradiation session	30.66±0.19	
24 h post the third laser irradiation session (forth day)	27.31±0.11	

It should be noted that temperature of the affected knee increases after each LLLT session and decreases in the time interval between laser irradiation sessions and finally is approaching to the normal value of healthy tissue. A significant decrease in temperature was observed after 24 h post the third LLLT session (forth day). A month later, no *calor* sign has been observed at the clinical reexamination.

These results have revealed that one of the four signs of the inflammatory process described by Celsus [12] namely *calor* (temperature increase as a result of the blood vessels dilation from the affected area) disappeared after three LLLT sessions. The other signs of inflammation (*rubor, tumor* and *dolor*) were clinically assessed at the end of LLLT noticing their extinction. Be noticed that of these four signs, only one, namely *calor*, can be expressed quantitatively based on the local temperature values measured by thermal infrared imaging. Consequently, this non-invasive technique can be considered particularly useful in assessing the inflammatory process that accompanies hydrarthrosis.

4. Conclusions

In conclusion, these results demonstrate that LLLT can be considered as an effective method for the hydrarthrosis knee treatment. Diffuse reflectance and temperature of biological tissues (normal and pathological) can also be considered as two physical parameters particularly useful in objective assessment of the effect of LLLT on hydrarthrosis knee as well as other tissue pathologies.

Acknowledgments

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References

[1] R. T. Chow, M. I. Johnson, R. A. Lopes-Martins, J. M. Bjordal, Lancet **5**, 374 (2009).
[2] W. Posten, D. A. Wrone, J. S. Dover, K. A. Arndt, S. Silapunt, M. Alam, Dermatol Surg. **31**, 334 (2005).

[3] T. Mukesh, L. Dheeraj, Indian Journal of Physiotherapy and Occupational Therapy - An International Journal, **8**, 70 (2014).
[4] N. Herascu, B. Velciu, M. Calin, D. Savastru, C. Talianu, Photomed Laser Surg. **23**, 70 (2005).
[5] M.A. Calin, T. Coman, M.R. Calin, Romanian Reports in Physics, **62**, 617 (2010).
[6] H. Jang, H. Lee, Photomed Laser Surg. **30**, 405 (2012).
[7] G. D. Baxter, C. Bleakley, S. McDonough, J Acupunct Meridian Stud. **1**, 65 (2008).
[8] A. A. Yamany, H. M. Sayed, Journal of Advanced Research. **3**, 21 (2012).
[9] J. R. Basford, Lasers Surg Med. **9**, 1 (1989).
[10] J. R. Basford, Lasers Surg Med. **16**, 331 (1995).
[11] W. Yu, M. McGown, K. Ippolito, R. J. Lanzafame, Photochem. Photobiol. **66**, 866 (1997).
[12] M. Rocha e Silva, Agents Actions. **43**, 86 (1994).

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