Original Contribution

Journal of Cosmetic Dermatology, **11**, 201–206

Skin tightening induced by fractional CO_2 laser treatment: Quantified assessment of variations in mechanical properties of the skin

Michael Naouri, MD,[1,2,3,4,5] Michael Atlan, MD, Msc,[1,4,6] Elodie Perrodeau, MSc,[7] Gabriela Georgesco, MD,[2,3] Randa Khallouf, MD,[3,4] Ludovic Martin, MD, PhD,[8] & Laurent Machet, MD, PhD[1,2,3]

[1]*Université Francois Rabelais de Tours, France*
[2]*UMR INSERM U930, CNRS ERL 3106, France*
[3]*Dermatology Department, CHRU de Tours, France*
[4]*Multidisciplinary Laser and Scars Clinic, CHRU de Tours, France*
[5]*Laser Center of Nogent Sur Marne, France*
[6]*Plastic Surgery Unit, CHRU de Tours, France*
[7]*INSERM CIC 202, CHRU de Tours, France*
[8]*Dermatology Unit, Angers University Hospital, France*

Summary

Background Certain authors have reported the efficacy of fractional resurfacing laser treatment in patients with photodamaged skin resulting in skin tightening of treated area.
Objective To assess skin tightening after CO_2 fractional resurfacing laser treatment by measuring variations in mechanical properties in treated areas. Dermal elasticity was measured using suction applied with an *in vivo* skin elasticity meter (Cutometer®).
Methods A prospective observational study was undertaken from January 2007 to August 2009. Laser treatment was performed with the SmartXide Dot® (Deka®, Firenze, Italy) CO_2 fractional resurfacing device. Patients were offered quantified analysis using the Cutometer® before and after treatment.
Results Seventeen patients (61 areas treated) were included in the study. Median delay between before and after cutometric evaluations was 80 days. We found significant improvement in elastic (R2 +5.9%), viscoelastic (R8 −9.4%), fatigue (R3 and R9 −16.2% and −19.7%, respectively), and thickness (R0 −14.9%) parameters. These results are consistent with significant tightening and also elastic tissue improvement.
Conclusions It was possible to quantify skin tightening because of CO_2 fractional laser treatment using a noninvasive technique.

Keywords: fractional laser, CO_2 laser, aging, mechanical properties, elasticity

Requests for rejuvenation procedures have increased in recent years, and several non-surgical techniques have been developed using radiofrequency, ultrasound, and lasers to heat components of the dermis to achieve skin tightening.[1,2] A skin tightening effect was recently reported with ablative[3,4] and non-ablative fractional resurfacing lasers.[5–7] These lasers aim to create regularly spaced microscopic columns of thermal and/or ablative damage, leaving intervening areas of normal skin untouched, that allow rapid repair of laser-induced

Correspondence: Michael Naouri, MD, 4 Place du général Leclerc, 94130 Nogent sur Marne, France. E-mail: michaelnaouri@yahoo.fr

Accepted for publication April 1, 2012

injury. Although experienced by patients subjectively, the reality of the skin tightening effect is very difficult to objectify clinically or by analyzing photographs.[8] Histology studies may provide additional evidence but they are limited by their invasive nature and the fact that they provide morphological non-functional information. Biomechanical skin properties can be evaluated by a noninvasive bioengineering skin elasticity meter using a suction device that provides sensitive, objective, and reproducible measurements.[9]

The aim of the study presented here was to quantify the skin tightening effect of CO_2 fractional resurfacing laser using suction applied with an *in vivo* skin elasticity meter.

Materials and methods

Study design and patients

A prospective observational study was carried out from January 2007 to August 2009. All the patients referred to our multidisciplinary laser and scars clinic for CO_2 fractional resurfacing were offered dermal elasticity analysis before and after treatment to quantify its efficacy. The patients who met the inclusion criteria were those with medical or esthetic indications for facial CO_2 fractional resurfacing who wished for objective and quantifiable follow-up of their laser treatment. The exclusion criteria were pregnancy, treatment with isotretinoin discontinued for <1 year, medical history of abnormal scarring, skin diseases affecting skin elasticity (elastic tissue disease, scleroderma, etc.), and patients with suntanning, inflammatory, or infectious skin disease of the face.

Laser treatment

Laser treatment was performed with the SmartXide Dot® (Deka®, Firenze, Italy) CO_2 fractional resurfacing device using a fixed 120 μm microspot. This laser apparatus is approved in Europe for the treatment of patients (CE mark) and has been available since 2006. The parameters were chosen in accordance with the standard parameters recommended by the manufacturer (power 30 W, spacing 500 μm, pulse duration 1 ms, 1 pass per session).

A test session was performed at least 1 week before treatment with a square spot measuring 1×1 cm in front of the left ear. This test was designed to identify any potential abnormal responses and to familiarize the patient with the pain and consequences of the treatment. The pain was evaluated using a verbal scale from zero (no pain) to 10 (maximum pain). If patients said that they felt severe pain during the test session, regardless of the pain score, a topical anesthesia (Eutectic Mixture of Lidocaine and Prilocaine, Emla® cream) was applied every 10 min for 1 h before treatment. Antiviral prophylaxis (oral valacyclovir 1000 mg/day) was started 2 days before treatment for 7 days.

A single laser treatment session was performed for each patient. The areas treated were the cheeks, upper lip, chin and forehead. To ensure an overall effect, each area was completely covered and at least half of the face was treated.

Postoperative treatment consisted of the application of a healing cream (Cicabio®, Bioderma®, Lyon, France) repeated every 4 h until healing was achieved, and a liposomal sunscreen, index 50+ (Daylong Actinica®, Spirig®, Vandoeuvre-lès-Nancy, France) once a day in the morning for 1 month.

Assessment of efficacy

Two evaluations were performed: the first before laser treatment and the second after treatment, at final follow-up consultation. They included subjective assessment of efficacy by the patients themselves on a scale of 0–4 (0: ineffective, 1: mild, 2: moderate, 3: very effective 4: extremely effective) and by systematic cutometric measurement, assessment of pain on a scale of 0–10, and a detailed examination of any immediate side effects after treatment.

Skin elasticity was measured with an MPA 580 Cutometer® (Courage and Khazaka, Köln, Germany). This instrument is a noninvasive suction device that measures any vertical deformation of the skin surface. It is computer controlled and automatically makes the calculations and stores the results. Following application of a constant negative pressure (500 mbar), the skin is drawn up into a circular aperture (2 mm diameter) of the probe for a period of 2 s. The negative pressure is then stopped and the skin tends to return to its original shape. The degree of skin deformation is measured by an optical system that detects the reduction in light intensity of an infrared light beam. Three cycles interspaced by 2 s relaxation time were studied. The time-strain mode was chosen, allowing analysis of skin deformation as a function of time. The Cutometer® generates a graph depicting immediate deformation or skin extensibility (Ue), delayed distension (Uv), final deformation (Uf), immediate retraction (Ur), and final retraction (Ua) (Fig. 1).[9] The curve of the skin deformation values obtained was analyzed using the Cutometer® MPA 580 Software, and the R parameters were calculated automatically: R0 = Uf (skin distensibility), R1 = Uf-Ua,

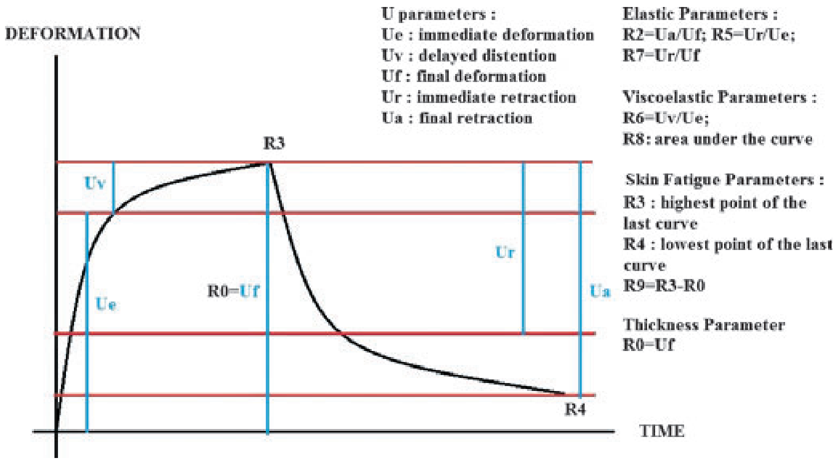

Figure 1 Skin extension when applying a constant force using the Cutometer®.

R2 = Ua/Uf (gross elasticity), R3 = the highest point of the last curve, R4 = the lowest point of the last curve R5 = Ur/Ue (net elasticity), R6 = Uv/Ue (viscoelastic ratio), R7 = Ur/Uf (biological elasticity), R8 = area under the curve (viscopart), R9 = R3−R0.

Skin elasticity is reflected by R2, R5, and R7, viscoelasticity by R6 and R8,[9] and R3, R4, and R9 represent skin fatigue.[10]

To avoid perturbation of elasticity indexes, assessment were realized in a conditioned room with constant temperature and humidity conditions and any cosmetic applications had to be stopped at least 1 week before measurements.

Statistical analysis

Statistical analysis was conducted by a statistician (EP) from the Center for Clinical Investigation of the University of Tours.

Analyses were undertaken on an intent-to-treat basis. Patient characteristics were reported with means and standard deviations or median and interquartile ranges for quantitative variables, and with size and frequency for qualitative variables. The variation in R parameters between the initial and the last available measurement was evaluated in a mixed model analysis with a random effect at patient level. A model with only fixed and random intercepts was used to evaluate the mean relative variation. Statistical analysis was performed with R 2.8.1.[11]

Ethics

This study followed the principles of the Declaration of Helsinki and was approved by the Ethics Committee of Angers University Hospital.

Results

Subjects

Seventeen consecutive patients were included in the study, providing follow-up of 61 areas (Table 1). Median (quartile) delay between preoperative and postoperative evaluation was 80 days (57;90). The indications were photoaging for 10 patients (59%) and atrophic scars associated with photoaging for the remaining seven patients. Phototype 2 was predominant (n = 10), and 9 (65%) of the patients smoked (Table 2). The median

Table 1 Number of measurements per area each time

Patients	17
Forehead	14
Cheek	32
Upper lip	7
Chin	8
Total areas treated	61

Table 2 Patient characteristics

Characteristics	
Age, mean (SD)	49 years (11)
Smoking, *n* (%)	11 (65)
Phototype, *n* (%)	
1	2 (12)
2	10 (59)
3	3 (17)
4	2 (12)
Indication, *n* (%)	
Scars	7 (41)
Photoaging	10 (59)

Table 3 Adverse effects and outcome

Event	
Pain score without contact anesthesia, med [Q1; Q3]	5.0 [4.5; 6.5]
Pain score with contact anesthesia, med [Q1; Q3]	3.5 [3.0; 5.5]
Duration of erythema (days), med [Q1; Q3]	5 [5; 7.5]
Duration of crusts (days), med [Q1; Q3]	5 [4; 5.5]
Edema, *n* (%)	4 (24)

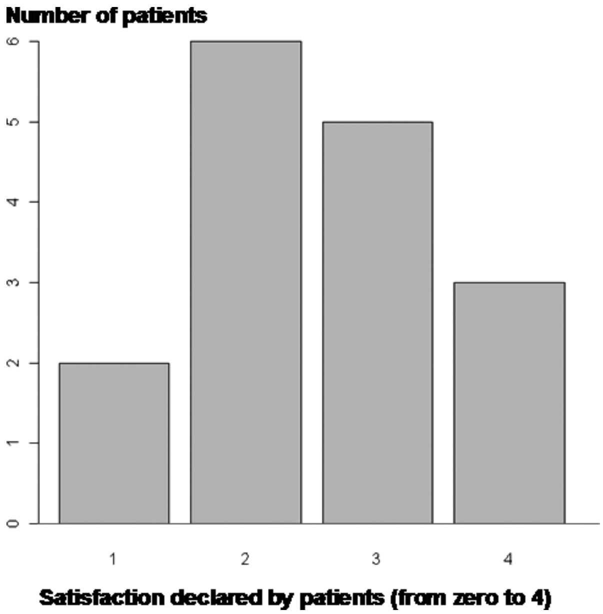

Figure 2 Patients' self-assessed satisfaction (n = 16, one data missing). Median satisfaction [Q1; Q3]: 2.5 [2; 3].

(quartiles) preoperative pain was evaluated at 3.5/10 (3; 5.5) with contact anesthesia and 5/10 (4.5; 6.5) without it. Median (quartiles) duration of intervention follow-up was 5 days (5; 7.5) for erythema and 5 days (4; 5.5) for crusting (Table 3). The median score for patient self-evaluations of was 2.5/14 (Fig. 2).

Changes in parameters of skin mechanical properties after treatment

There was a significant decrease ($P < 0.05$) in parameters R0, R3, R8, and R9, (average 14.9% [95%CI: −19.3; −10.6], 16.2% [95%CI: −20.1; −12.2], 9.4% [95%CI: −15.3; −3.6], and 19.7% [95%CI: −29.8; −9.6], respectively). However, there was a significant increase in parameter R2 ($P = 0.025$) (average 5.9% [95%CI: [0.8; 11.1]). Variations were not significant ($P > 0.05$) for parameters R1, R4, R5, R6, and R7 (Table 4).

Table 4 R Parameters of fixed effects

	Intercept	95%CI	*P*
R0	−14.9	[−19.3; −10.6]	<0.0001
R1	−17.6	[−38.8; 3.5]	0.100
R2	5.9	[0.8; 11.1]	0.025
R3	−16.2	[−20.1; −12.2]	<0.0001
R4	−15.4	[−32.2; 1.4]	0.072
R5	4.6	[−11.9; 21.1]	0.578
R6	−6.0	[−20.4; 8.33]	0.402
R7	3.5	[−8.2; 15.1]	0.554
R8	−9.4	[−15.3; −3.6]	0.002
R9	−19.7	[−29.8; −9.6]	0.0002

Discussion

Our study demonstrated real skin tightening assessed by objective modifications of the skin's mechanical properties, with significant improvements (varying from 5.9% to 19.7%) occurring after CO_2 fractional laser treatment. Moreover, this was in agreement with the moderate to significant (Figs 3 and 4) improvement declared by the patients.

Our study showed an increase in elastic (R2, R5, and R7) and a decrease in viscoelastic (R6 and R8) parameter values. Only one elastic (R2) and one viscoelastic (R8) parameter were significantly modified, but it is currently assumed that single parameters in each group correlate directly with each other.[9] The skin's elastic properties reflect its ability to return to its initial position after deformation, whereas the viscoelastic proprieties represent the persistence of a slight deformation after mechanical stress[9] and could represent a loss of skin firmness. The elastic capacity of the skin decreases during chronological and photoaging, whereas the viscoelastic component increases under the same conditions.[9,12] Our results are consistent with the fact that treatment with fractional CO_2 laser allows the treated skin to recover some of the biomechanical properties of younger skin. This increased elasticity of 5.9% after only one session of CO_2 fractional resurfacing represents a significant gain compared to the estimated loss of skin elasticity estimated at only 30% between the beginning of adulthood and the age of 80 years.[13] The significant decrease in skin fatigue (R3 and R9), that is, losing mechanical properties progressively between the first and last cycles,[10] is also consistent with improvement in the skin's mechanical properties after laser treatment. Moreover, skin fatigue is probably an important factor in the constitution of expression wrinkles.

Figure 3 Patient with acne scar and photoaging.

Figure 4 Same patient after laser treatment. Improvement of acne scars and skin tightening.

Unlike other R parameters, R0 is not a ratio but an absolute measurement that is inversely dependent on skin thickness.[9] The decrease in this parameter is consistent with the increases in dermal thickness we reported using high-resolution ultrasound imaging after fractional CO_2 laser treatment in a recent study.[14]

It has been postulated that the depth of ablation and zone of residual thermal damage determine the efficacy of CO_2 resurfacing, especially in its skin tightening effect.[3] Fractional resurfacing allows a greater depth of penetration of the laser beam. With similar parameters and similar microspot diameter, Hantash *et al.* showed almost 1000 μm depth of thermal damage,[15] whereas the depth of thermal damage reported was <500 μm with traditional CO_2 resurfacing.[3] As also shown in this study CO_2 fractional resurfacing therefore appears to be a well tolerated and effective method for the treatment of skin laxity. Nevertheless, it is currently assumed that beam power decreases progressively from surface to deepness, because of absorption by the tissue water. Therefore, we chose a 2 mm probe that explores mainly skin elasticity of epidermis and upper dermis in order to objective the effect of the CO_2 fractional laser where it was the more relevant.

The changes in the skin's mechanical properties observed are the result of the effects of the laser beam on the dermal fibroblasts and on components of the extracellular matrix. Heat denaturation of collagen generates a shrinkage phenomenon.[2,3] Tissue tension in human skin immediately increases because, although the fibers become shorter, the heat-stable cross-links between molecules are maintained, thus increasing the elastic properties of collagen polymers.[2] Histological studies evaluating a fractional 1540 nm Erbium Glass laser treatment in pig skin demonstrated that fractional thermal damage induced mature collagen synthesis, elastic fiber regeneration and fibroblast development only in the horizontal direction within 35–58 days of treatment, suggesting traction stress on the skin during the course of scar formation that could explain the improvements in elastic parameters and thickness.[7] Moreover, a recent study suggest that the maximum effect of CO_2 fractional laser ranged 3 months after treatment.[16] In this respect, median delay of 80 days between treatment and evaluation seems to be sufficient to demonstrate these modifications. Improvements in viscoelastic and fatigue parameters that are mainly related to the displacement of interstitial fluids were probably due to conformational changes in the collagen and extracellular matrix components that induced increased dermal hydration that cannot be evidenced with standard histology.

References

1 Dierickx CC. The role of deep heating for noninvasive skin rejuvenation. *Lasers Surg Med* 2006; **38**: 799–807.

2 Sadick N. Tissue tightening technologies: fact or fiction. *Aesthet Surg J* 2008; **28**: 180–8.

3 Rahman Z, MacFalls H, Jiang K *et al.* Fractional deep dermal ablation induces tissue tightening. *Lasers Surg Med* 2009; **41**: 78–86.

4 Ancona D, Katz BE. A prospective study of the improvement in periorbitalwrinkles and eyebrow elevation with a novel fractional CO_2 laser – the fractional eyelift. *J Drugs Dermatol* 2010; **9**: 16–21.

5 Sukal SA, Chapas AM, Bernstein LJ *et al.* Eyelid tightening and improved eyelid aperture through nonablative fractional resurfacing. *Dermatol Surg* 2008; **34**: 1454–8.

6 Dainichi T, Ueda S, Fumimori T *et al.* Skin tightening effect using fractional laser treatment II: a pilot animal study on skin remodeling. *Dermatol Surg* 2010; **36**: 71–5.

7 Dainichi T, Kawaguchi A, Ueda S *et al.* Skin tightening effect using fractional laser treatment: I. A randomized half-side pilot study on faces of patients with acne. *Dermatol Surg* 2010; **36**: 66–70.

8 Chan HH, Lam LK, Wong DS *et al.* Use of 1,320 nm Nd:YAG laser for wrinkle reduction and the treatment of atrophic acne scarring in Asians. *Lasers Surg Med* 2004; **34**: 98–103.

9 Dobrev H. Study of human skin mechanical properties by mean of Cutometer. *Folia Med (Plovdiv)* 2002; **44**: 1–5.

10 Dobrev H. Application of Cutometer area parameters for the study of human skin fatigue. *Skin Res Technol* 2005; **11**: 120–2.

11 R Development Core Team. *R: A Language and Environment for Statistical Computing*. Vienna, Austria: R Foundation for Statistical Computing, 2008.

12 Ryu HS, Joo YH, Kim SO *et al.* Influence of age and regional differences on skin elasticity as measured by the Cutometer. *Skin Res Technol* 2008; **14**: 354–8.

13 Lévêque JL. Mesures biomécaniques de la peau. Encycl Méd Chir (Editions Scientifiques et Médicales Elsevier SAS, Paris, tous droits réservés), Cosmétologie et Dermatologie esthétique, 50-140-G-10; 2001: 4p.

14 Naouri M, Atlan M, Perrodeau E *et al.* High resolution ultrasound imaging to demonstrate and predict efficacy of CO_2 fractional resurfacing laser treatment. *Dermatol Surg* 2011; **37**: 596–603.

15 Hantash BM, Bedi VP, Chan KF *et al.*. Ex vivo histological characterization of a novel ablative fractional resurfacing device. *Lasers Surg Med* 2007; **39**: 87–95.

16 Ortiz AE, Tremaine AM, Zachary CB. Long-term efficacy of a fractional resurfacing device. *Lasers Surg Med* 2010; **42**: 168–70.