Preliminary report on treatment of PFB with a long pulse Nd:YAG laser

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Introduction

Pseudofolliculitis barbae (PFB) is an inflammatory condition of the beard area, usually observed in men with thick, coarse hair. Typically the follicle is at an acute angle to the skin surface, and the sharpened end of the shaved shaft re-enters the skin at or next to the follicular opening. The subsequent formation of inflammatory papules and pustules results in patient discomfort, sometimes secondary infection, and even hypertrophic or keloidal scars (1-12). Growing a beard is usually curative. However, in the military a clean-shaven face is required; therefore, the condition is sometimes grounds for administrative separation. Since 1984, the US Navy has not allowed the wearing of beards, citing interference with the proper fitting of breathing apparatus and/or gear used against biochemical warfare agents.

PFB continues to be a significant problem in the military with tremendous cost to the U.S. government, both in direct treatment of the condition as well as indirectly in loss of man hours in personnel training, clinic visits, and ultimately, possible administrative separation. Anecdotal reports in the past century estimate the prevalence of PFB to be anywhere from 0.2% to 83% depending on locale. Reliable estimates of disease prevalence are lacking due to poor tracking of cases and loss to follow up. Because black men are predominantly affected, racial and unit cohesion among ranks can be jeopardized. Accounts in the literature support interracial friction and hostility at least partly attributable to PFB (1, 4).

By finding a cure for PFB, the benefit would be significant for all branches of the Armed Services and the U.S. Government. Affected, otherwise able, personnel would not be lost by attrition and could more readily perform prescribed duties. Disease-free members would be able to contribute readily to command missions that require form-fitting facial masks. Examples are Operation Desert Storm, where the threat of chemical warfare was a daily reality, or in the aviation or diving communities where oxygen masks or breathing apparatus are required.

The impact of PFB extends beyond the military environment. Existing remedies for controlling PFB include topical steroids, antibiotics, and /or exfoliating agents. While these agents play a sometimes-helpful role in the treatment and management of PFB, the positive effects are often short-lived. Physical modalities such as electrolysis have also been used in treatment, but this technique, in addition to being tedious, can cause pigmentation abnormalities, scarring, and/or residual keratin abscesses from fragmentary destruction of the hair follicle (2, 3, 5, 6, 8, 13). Previous investigators have used lasers in the treatment of PFB (6). Nanni et al (14) reported the use of a 755 nm laser, but noted that hair reduction was temporary. They also suggested that part of the decrease in papules and pustules might be due to a gentle exfoliative effect often observed after treatment. More recently, Battle et al (15) have reported the use of a novel long pulse 800 nm laser (20 –200 ms) in darker skin types (up to Type VI). They have reported safe and effective hair reduction by combining lower fluences with longer pulses.

Because longer wavelengths penetrate better and therefore intrinsically allow for greater epidermal sparing, we investigated the long pulse 1064nm Nd:YAG laser for the treatment ofPFB in patients with skin types IV, V and VI. The rational for this treatment was to eliminate the cause of the PFB by reducing the numbers of coarse hairs in the neck and chin areas.

Materials and Methods

We have enrolled 37 patients in this two-phase study. The number of patients that completed both phases of the study to date is 24, with the average follow up time after a single treatment of 3 months. Of the 24 patients completing the study, the following characteristics are noted.

a. Average age: 24
b. Skin type break down
   I. 20 type VI, (11 VIa and 9 VI b)
   II. 2 type V
   III. 2 type IV

It should be noted that skin typing is very imprecise (at least the standard system whereby tolerance for UVB light has been used to establish the type). For example, within the 20 "black" patients enrolled in this study, there were two subgroups, 1) those patients with very dark skin (consistent with patients of Western African descent) and 2) those black patients with "brown" skin, a skin hue akin to that seen in patients of Ethiopian descent. We have designated those patients as VIa, and the "darker" patients as VIb, respectively.

All of the patients showed some evidence of pseudofolliculitis barbae. Most patients showed only mild disease, but many of these patients were clipping their hair (to ~ 1/8 inch) rather than shaving to aid in the control of their condition.

The study was divided into two parts. In the initial phase of the study (**Phase I**), patients were tested for epidermal tolerance of the laser, as follows. An area of the patient's thigh was marked off with tattoos to demarcate a 6x6 cm area. This large square was subdivided into 4 smaller squares (3x3 cm each) and the areas were treated with the following fluences.

1. 50 J/cm^2
2. 80 J/cm^2
3. 100 J/cm^2
4. control (only cooling, not heating)

The pulse duration was held constant at 50 ms. The laser pulses were delivered with a scanner that generated pulses at 4 Hz. Each spot within the scan was 5 mm. The scan size varied from 10 x 10 mm to 25 x 25 mm and was operator controllable (generally the scan size was decreased for patients who found the treatment too uncomfortable). It follows that for darker patients and higher fluences, the scan size was decreased. Scans were laid down adjacent to each other with less than 10 % overlap between scans. There was no overlap between spots within the scan. The beam was fired through a cooled sapphire window approximately 3 cm in diameter. For each scan, the window was left in contact with the skin surface for 3-5 sec for the 50 and 80 J/cm^2 fluences, and for 5-10 seconds for the 100 J/cm^2 setting. The window was cooled by circulating water which continuously cooled the surrounding gold-plated copper fastener at ~5°C.

The treated areas were followed for three months and hair counts were performed by a blinded investigator. If no side effects were observed two weeks after treatment in **Phase I**, the patient subsequently began **Phase II.** In **Phase II**, a small (15 x 15 mm) area of the chin was treated with the highest fluence tolerated in **Phase I**. A site of the same size contiguous to the treatment site served as a control. In **Phase II**, the same scanner configuration was used as in **Phase I**. Patients were instructed not to shave for two weeks prior to treatment at the control and treatment sites (to allow for decreased inflammation at the sites). Then, they shaved on the morning of therapy, after which they resumed shaving and/or clipping (whatever their normal protocol was) beginning one week after **Phase II** treatment. The number of shaving bumps was counted 90 days after treatment both at the treatment and control sites.

Summary of Results

In **Phase I** the following tissue reaction and side effects were observed with all three skin types at various fluences.

For type IV patients, all fluences were well tolerated by the epidermis. There was no crusting or blistering. Also, the pain level during the scans was less than that experienced by patients from the other pigment groups. Larger scans were used in this patient group due to the high level of pain tolerance.

For skin types V and VIa, the results were as follows:

For the two type V patients (One Mexican American and one American Indian), all fluences were well tolerated. There was no crusting or blistering. Pain was overall less that than in Groups VIa and VIb. However, pain was sufficient in the 80 J/cm^2 and 100 J/cm^2 groups that the areas treated were subdivided into smaller scans; that is, rather than the 25 x 25 mm grid (the largest scan size), typically the 10 x 15 mm grid was used. In the VI a group, findings were similar to the group V patients.

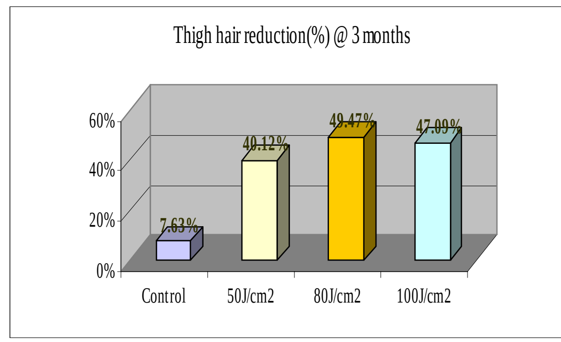
Skin type VIb:

For the type VIb patients, we found that the highest universally tolerated dose was 50 J/cm^2. Doses of 80 J/cm^2 usually resulted in peri-follicular crusts and some slight crusting and/or early hyperpigmentation coincident with the individual spots within the scan. After approximately 7 days, these small crusts had resolved, leaving either: a. areas of mild hypopigmentation around the follicle (~ 0.5 mm in diameter), or b. areas of mild hypopigmentation coincident with the 5 mm spots within the scan. Typically, these hypopigmented areas were slightly smaller than the diameter of the spot, and measured about 3 mm in diameter. These areas of crusts and eventual hypopigmentation were more apparent in the 100 J/cm^2 sites than the 80 J/cm^2 sites. By 30 days, these hypopigmented areas had begun to re-pigment without change in texture of the skin (scarring).

The one exception to the above outcome was a **VI b** patient in which EMLA was used. This was a very dark patient who was unable to tolerate treatment without anesthesia (even after decreasing the scan size). The patient returned one week later and we attempted treatment again. Up to this time, we had precooled the skin as noted above (3-5 sec for the 50 and 80 J/cm^2 doses, and 5-10 seconds for the 100 J/cm^2 doses. These pre-cooling times were adopted since they were the cooling periods necessary for pain control. In this patient, the EMLA worked so well that we only pre-cooled for about 1-2 seconds. Upon his return 2 days later, the thigh showed blisters at the 80 and 100 J/cm^2 sites coincident with the 5-mm spots within the scan. Within 2 more days, these had turned into crusts which healed with hypopigmentation and very mild central (~ 1 mm) loss of epidermal skin markings and induration (consistent with mild scarring).

Hair counts for Phase I:

In Phase I of the study, all patients were treated once. The following chart represents the results of the hair counts. Note that at higher fluences



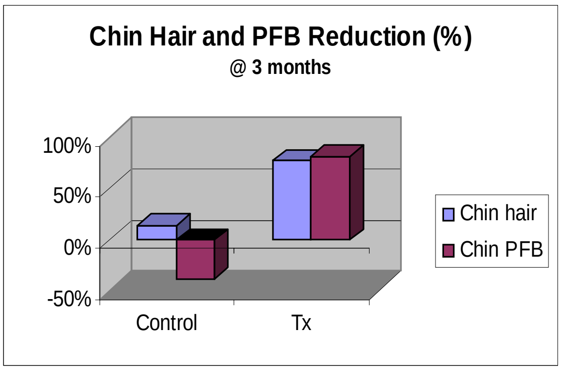
(80 and 100 J/cm^2), the 3-months results showed greater clearance than at the lower fluence of 50 J/cm^2.

In **Phase II** of the study, the highest tolerated fluence from **Phase I** was considered as the absolute maximum fluence to be used on the face. Typically, the fluence was reduced by 10—20% from this maximum, as the fluence choice was also based on skin type, density of hair, and the thickness of the individual hairs as well as the pain threshold of individual patients. Generally, fluences between 50J/cm^2 and 80J/cm^2 were applied. However, there were two patients with skin Type IV that were treated with 100J/cm^2.

All patients were observed for side effects on day 2 after the treatment. Eight out of twenty four patients exhibited mild perifollicular erythema and crusting. In seven patients all side effects were resolved by day 7 following the treatment. One patient had a prolonged crusting that turned into hyperpigmentation, which resolved by day 60 following the treatment. This patient was skin Type V and was treated at 80J/cm^2.

Hair and PFB counts for Phase II:

All patients in Phase II were treated once in the small test area, and the sites were observed for 3 months following treatment. The mean bump count was significantly reduced in the treatment sites ($p<0.05$ as determined by a two tailed paired test) after 3 months. The following chart shows the results:



Note that although the chin hair counts in the control site decreased slightly over the three-month period, the number of shaving bumps increased dramatically by 40%.

Biopsies:
Biopsies were performed in six patients, five from the thigh and one from the face. The biopsies from the thigh were performed 2 days after treatment, and were performed at 50, 80, and 100 J/cm^2. The biopsies from the thigh showed severe thermal damage to the hair bulb with peripheral destruction of the follicle (see Figures 1, 2 and 3.). The one facial biopsy showed complete follicular destruction down to the base of the follicle in the fat. These changes were more noticeable at higher fluences. In all cases epidermal preservation was observed.

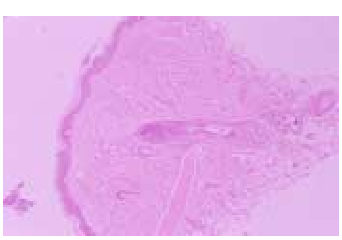


Fig. 1 Thigh hair treated at 100 J/cm2 and 50 msec
Low Magnification

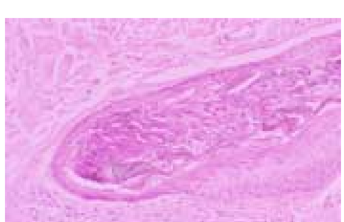


Fig. 2
Thigh hair treated at 100 J/cm2 and 50 msec
High Magnification

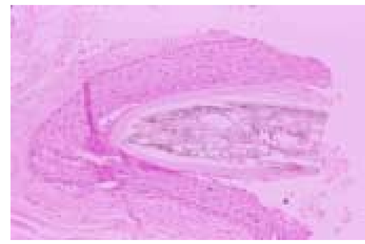


Fig. 3 Facial hair treated at 50 J/cm2 and 50 msec
Low Magnification

Discussion

The data show that safe hair reduction is possible in the darkest patients with a long pulsed Nd:YAG laser coupled with a contact-cooling window. More importantly, the elimination and/or miniaturization of hair shafts was positively correlated with a decrease in the number of inflamed papules characteristic of PFB. The data suggest, not unexpectedly, that the hair shaft itself is the principal contributor to inflammation and pustulation in patients with PFB.

Most importantly, we were able to exploit the differences in melanin concentration between the hair bulb and epidermis in patients with type V and VI skin. Previous investigators have shown that the absorption coefficient for 800 nm light for black hair is about 75 cm^{-1}(Source: Deiter Manstein, M.D., Wellman Laboratories of Photomedicine, Boston, MA, personal communication). Using data from Jacques et al (16-18), one can estimate the absorption coefficient for black hair for 1064 nm to be ~ 27 cm^{-1}. Likewise, the epidermal μ_a for a very dark epidermis has been estimated at 18 cm^{-1}. Thus, for black thick hair and brown skin (typical patient with PFB), there is a window, or ratio, ofμ_a's that should allow for sufficient hair heating without epidermal damage, particularly if epidermal cooling is applied.

The ratio of melanin absorption for 800 nm and 1064 nm is about 3:1. One might argue, then, that simply by reducing the incident fluence for 800 nm or other even shorter wavelengths, the same hair reduction could be achieved in darker skin without epidermal damage. In other words, why introduce more photons into the skin at a longer wavelength when they will be absorbed less by the hair follicle. The reason is scattering, which is less for the longer wavelengths, so that there is greater penetration into the dermis. This enhanced penetration was shown nicely by Zhong-Quan and Fairchild (19), who showed that in black skin, the penetration of 1064 nm light was 3x higher than of 700 nm light at 3.3 mm depth in the dermis (typical depth of a hair bulb). It follows that, if one plots the ratio of T_E to T_B (temperature of the epidermis to the temperature of the hair bulb) as a function of wavelength, one observes that the ratio of dermal to epidermal temperature (and subsequent thermal damage) increases with increasing wavelength (20).

Questions remain regarding this strategy for treating PFB. One issue is the permanence of thehair loss. Extended observations have shown that for the great majority of patients following a single treatment, thigh hair counts returned to normal by 180 days post-treatment, regardless of dose. This was most noticeable in patients with thinner hair. In the few patients with thicker thigh hair, there was longer-lived hair loss. We have noted on the face, in longer term follow up (> 3 months), that some hairs have regrown in the test areas. However, these hairs are thinner than pre-treatment and do not appear to be associated with PFB. It remains to be seen whether this miniaturization of the hair will persist with longer intervals post treatment (i.e. 6-12 months). If the hair diameters do return to their pre-treatment size, one scenario for treatment might include maintenance laser irradiation every 3-4 months.

Pic. 1a Patient with severe PFB before the treatment

Pic. 1b 12 weeks following one treatment

Treatments were well tolerated by most patients. However, full neck treatments, performed routinely now that the formal study is completed, have required EMLA (Astra Pharmaceuticals, Wayne, PA) or another anesthetic topical preparation for patient comfort. The pain experience on the thigh was clearly dose dependent, with greater pain at the 80 and 100J/cm^2 doses. Pain was reduced by slightly longer applications of the cooling window. It should be noted that because the window is larger than the scan size, the laser cooling configuration provided pre, parallel and post treatment cooling. The pain with the procedure is presumably associated with 1) heating of the hairs, as we noted patients wincing when particularly thick hairs were irradiated, 2) heating of the epidermis, 3) heating of tissue water, as the absorption coefficient for water is large enough that some discomfort is observed even where there are no hairs (i.e. even in white patients with thin brown hairs), and 4) heating of blood vessels. However, unless one encounters a larger vessel in the treatment field, we have not observed focal increases in pain as a blood vessel entered the treatment field. Most likely this is because the blood vessel diameter is too small at these modest fluences to result in significant vessel temperature elevation. The mild pain experienced by the type IV patients suggests that: 1. the amount of epidermal melanin; and 2. the size of the hair shafts, limited the degree of heating in these patients. The type VIb patient with blistering was instructive in that it affirmed the role of pre-cooling in contact cooling applications. This experience also suggests that pain and epidermal injury might be related, particularly as this patient was probably the darkest patient in the study and also was the one with the greatest pain (without EMLA), even though his hair density, color, and thickness were not grossly different from the other type VIb patients.

The mechanisms for hair follicle injury with 1064 nm light are most likely similar to other wavelengths for millisecond time domains. Based on histology, the hair bulb appears to be the most severely damaged focal structure. This finding is not unexpected, as this zone contains the greatest concentration of melanin in the body. Interestingly, where we observed vessels near the bulb, they appeared undamaged on routine H and E stains. However, Adrian et al (21) recently reported that Factor VIII stains showed evidence of peribulbar vascular injury after both 800 and 1064 nm irradiation, suggesting that vascular injury might

Pic. 2a Patient with severe PFB before the treatment

Pic. 2b 12 weeks following one treatment

at least be a contributing factor in subsequent follicular injury. As PFB is a major problem for the military and civilian sectors alike, long pulse 1064 nm laser treatment represents a significant breakthrough in the treatment of this disease. The wavelength, cooling type, and pulse duration all contribute to the safety and efficacy of this device for thick black hairs in deeply pigmented skin.

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