Prospective, Comparative Evaluation of Three Laser Systems Used Individually and in Combination for Axillary Hair Removal

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BACKGROUND. Using the concept of selective photothermolysis, a variety of laser systems have been developed to remove unwanted hair.

OBJECTIVE. To evaluate the relative efficacy, tolerability, and subject satisfaction of three different laser systems used individually and in rotation for axillary hair removal.

METHODS. Twenty female patients (17 with dark-colored hair, 3 with red or light-colored hair) with Fitzpatrick phototype II skin received three treatments performed at 6- to 8-week intervals. Each axilla was divided in half to yield four distinct areas that were treated by the following lasers: (1) three sessions with a long-pulse 755 nm alexandrite laser, (2) three sessions with a long-pulse 810 nm diode laser, (3) three sessions with a long-pulse 1,064 nm neodymium:yttrium-aluminum-garnet (Nd:YAG) laser, and (4) rotational treatment consisting of a single session by each of the three laser systems. Percent hair reduction and acute and long-term side effects were evaluated after treatment. Subjects completed questionnaires assessing tolerability and satisfaction.

RESULTS. All subjects tolerated the treatments well, with only local, transient side effects seen. At the 3-month follow-up, the greatest average hair reduction was comparably similarly seen after the alexandrite laser at 59.3 ± 9.7% and the 810 nm diode laser at 58.7 ± 7.7%. The Nd:YAG laser and rotational regimens were less efficacious, with 31.9 ± 11.1% and 39.8 ± 10.1% hair reduction, respectively. Subjects with red or light-colored hair experienced 5 to 15% reduced efficacy with any laser system used. Subjects found the alexandrite and diode lasers to be equally tolerable, with only slight discomfort, and the Nd:YAG laser to be the least comfortable of the three systems. Overall, subject satisfaction of each treated site, in decreasing order, was (1) the 810 nm diode laser, (2) the alexandrite laser, (3) rotational therapy, and (4) the Nd:YAG laser.

CONCLUSION. At the 3-month follow-up, the long-pulse alexandrite and 810 nm diode lasers demonstrated no statistically significant differences in efficacy, comparable efficacy and tolerability, and highest subject satisfaction. Rotational therapy with the three laser systems is not as effective as treatment with the alexandrite laser or diode laser alone but is statistically more effective than use of the long-pulse Nd:YAG system alone. Individuals with red or light-colored hair and Fitzpatrick phototype II skin have decreased efficacy of laser treatment than those with dark-colored hair and the same phototype.

JAGGI RAO, MD, AND MITCHEL P. GOLDMAN, MD, HAVE INDICATED NO SIGNIFICANT INTEREST WITH COMMERCIAL SUPPORTERS.

LASER HAIR removal is a relatively well-tolerated, effective modality to achieve permanent reduction of unwanted body hair. Using the concept of selective photothermolysis, a variety of laser hair removal systems are currently available. This study addresses the practical interest of comparing the efficacy, tolerability, and satisfaction of three popular lasers of different wavelengths for axillary hair removal. Furthermore, the utility of combining these lasers in a novel, rotational regimen is examined.

Materials and Methods

Patients

Twenty healthy adult women with Fitzpatrick skin type II were selected for the study. Of these, 17 subjects had dark brown axillary hair and 3 subjects had red or light-colored hair in their axillae. None had a history of axillary laser hair removal. Three treatment sessions were performed at 6- to 8-week intervals on each subject using four different treatment regimens. No topical or local anesthesia was required or administered with any laser treatment.

Laser Systems

The LightSheer XC long-pulse diode laser (Lumenis Ltd., Yokneam, Israel) system uses a semiconductor diode at a

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wavelength of 810 nm with a variable pulse duration of 5 to 400 milliseconds, adjustable fluences of 10 to 100 J/cm², and a square spot size of 12 × 12 mm. For this study, the pulse duration and fluence were kept constant at 30 milliseconds and 25 J/cm², respectively. The epidermis was cooled before, during, and after laser irradiation by placing a sapphire window-based dynamic 5°C cooling system (ChillTip) onto the skin surface.

The Apogee 6200 long-pulse alexandrite laser (Cynosure, Inc., Chelmsford, MA, USA) system uses a beryllium alluminate crystal to achieve a wavelength of 755 nm with a variable pulse duration of 5 to 40 milliseconds, a maximum fluence of 50 J/cm², and round spot sizes of 10 to 15 mm in diamater. For this study, the pulse duration, fluence, and spot sizes were kept constant at 10 milliseconds, 18 J/cm², and 12.5 mm, respectively. Epidermal cooling was achieved by 5°C continuous cold air blown on the treatment surface before, during, and after laser irradiation by the SmartCool cooling system (Cynosure, Inc.).

The Smartepil II long-pulse Nd:YAG laser (Cynosure, Inc.) system has an output wavelength of 1,064 nm through a neodymium:yttrium-aluminum-garnet (Nd:YAG) source. The system has a variable pulse duration of up to 100 milliseconds, adjustable fluences ranging from 16 to 200 J/cm², and several spot sizes ranging from 2.5 to 10 mm. For this study, the parameters were kept constant at a 10-millisecond pulse duration, a fluence of 75 J/cm², and a 7 mm spot size. As with the Cynosure Apogee laser, this system uses dynamic air cooling delivered by the SmartCool skin cooling system.

Treatment Protocol

After careful selection, each subject signed an informed consent form. Subjects were instructed to shave their axillae the day prior to each laser treatment. Each subject's axilla was divided in half to yield four distinct treatment areas: the (1) right upper axilla, (2) right lower axilla, (3) left upper axilla, and (4) left lower axilla. This is depicted in Figure 1. Prior to the first laser hair removal treatment session, a 1 × 1 cm square-shaped magnifying lens was placed well within the confines of each treatment area, and hair counts were accurately performed on each of the four 1 cm² axillary regions.

Each treatment area was then assigned the following treatment regimen:

1. Right upper axilla: long-pulse alexandrite laser for each of the three treatment sessions
2. Right lower axilla: long-pulse Nd:YAG laser for each of the three treatment sessions
3. Left upper axilla: long-pulse 810 nm diode laser for each of the three treatment sessions
4. Left lower axilla: long-pulse alexandrite laser for the first treatment session, long-pulse 810 nm diode laser for the second treatment session, and long-pulse Nd:YAG laser for the third and final treatment session

A board-certified dermatologist performed all laser treatments. Immediately after each laser treatment, subjects were evaluated for immediate side effects (such as burned hair, erythema, edema, and pain) and were asked to keep a log of the duration of these events.

At 3 months after the third and final treatment session, all subjects were seen for repeat hair counts using the same methodology as described above (Figure 2). Subjects were also evaluated for long-term complications and completed questionnaires assessing laser tolerability and satisfaction of hair reduction in each treatment area. All data were analyzed.

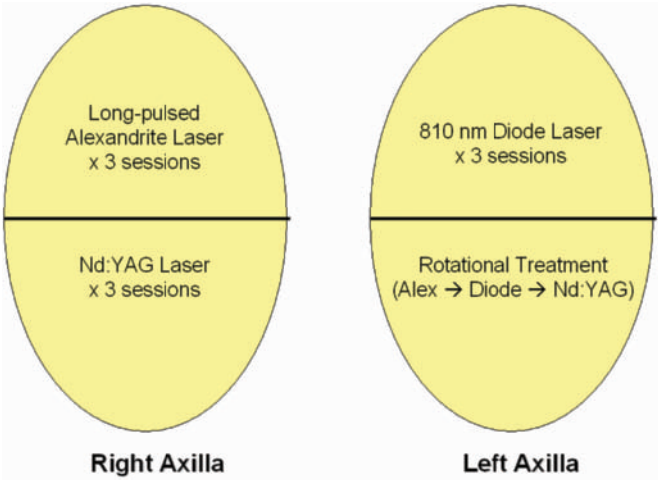

Figure 1. Axillary map illustrating treatment regimens for the four distinct treatment regions created by dividing each axilla in half.

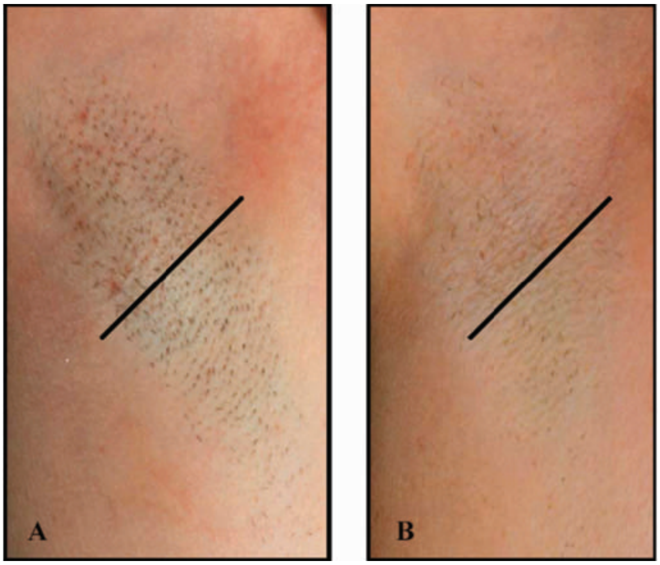

Figure 2. Left axilla. (A) Before treatment and (B) 3 months after laser hair removal sessions with the 810 nm diode laser for the upper area and a rotational regimen for the lower area.

Results

Hair Reduction

The clinical responses for all 20 subjects are listed in Table 1. The average hair reductions were 58.7 ± 7.7 (mean percentage reduction ± standard deviation), 59.3 ± 9.7, 31.9 ± 11.1, and 39.8 ± 10.1 for the alexandrite, diode, Nd:YAG, and rotational regimens, respectively. There was no statistically significant difference in hair removal between the alexandrite and the 810 nm diode laser systems. The rotational regimen was statistically more effective than Nd:YAG treatments alone but considerably less effective than alexandrite and 810 nm diode laser treatments alone.

Subjects with red or light-colored hair experienced a statistical decrease in effectiveness of 5 to 15%, depending on the laser regimen used.

Table 1. Percentage of Hair Reduction after Three Laser Hair Removal Sessions*

Patient	*Apogee*	*Nd:YAG*	*LightSheer*	*Rotational*
1	65	42	68	52
2	62	36	60	49
3	74	48	74	53
4	**50**	**21**	**44**	**23**
5	60	36	52	45
6	52	12	60	20
7	52	23	57	38
8	66	48	70	48
9	56	36	62	47
10	60	34	57	45
11	56	22	53	33
12	70	40	76	48
13	67	34	67	45
14	67	42	70	50
15	56	44	53	38
16	**50**	**38**	**48**	**36**
17	60	16	65	23
18	**46**	**20**	**42**	**29**
19	54	27	57	36
20	50	18	50	38
Average	58.7	31.9	59.3	39.8
SD	7.7	11.1	9.7	10.1
Average	60.4	32.8	61.8	41.6
SD	6.9	11.2	8.0	9.6
Average	**48.7**	**26.3**	**44.7**	**29.3**
SD	**2.3**	**10.1**	**3.1**	**6.5**

*Data are derived from hair counts made prior to the study and at 3 months' follow-up.

Regular print **indicates dark/black hair;** ***bold print*** **indicates red/light hair.**

Side Effects

No scarring, pigmentary change, or any other chronic sequelae of the skin were observed or reported at any time during the study. Acute side effects included the presence of burned hairs, perifollicular erythema, edema, and pain in nearly all treatment areas immediately after each laser session. These side effects were transient, reported to last a maximum of 3 days after their onset.

Subject Tolerability and Satisfaction

Based on subject questionnaires, the long-pulse alexandrite laser and long-pulse 810 nm diode laser were equally tolerable, with average pain scores of 2.2 and 2.1 of 4, respectively. This translates to only slight discomfort during laser irradiation (Table 2). Conversely, the Nd:YAG laser was found to be less tolerable, with an average pain score of 3.5 of 4.

As a measure of satisfaction at 3 months following the last laser treatment session, subjects were asked to rank the degree of hair reduction in each of the four treatment areas of their own axillae. The average ranking correlated to the following hair removal regimens, listed from most improvement to least improvement: (1) the 810 nm diode laser, (2) the long-pulse alexandrite laser, (3) rotational therapy, and (4) the 1,064 nm Nd:YAG laser (Table 3).

Discussion

Selective Photothermolysis and Laser Hair Removal

The various laser systems available today for hair removal are based on the concept of selective photothermolysis.[1]

Table 2. Tolerability of Laser Hair Removal Systems Based on Subject Questionnaires

Laser System	*Average Pain Score**
Long-pulse 755 nm alexandrite laser	2.2
Long-pulse 810 nm diode laser	2.1
Long-pulse 1,064 nm Nd:YAG laser	3.6

*1 = no discomfort during irradiation; 2 = slight discomfort; 3 = moderate discomfort; 4 = severe discomfort.

Table 3. Subject Ranking of Hair Reduction after Three Laser Hair Removal Sessions*

Ranking (Most to Least Improvement)	*Laser Hair Removal Regimen*
1	Long-pulse 810 nm diode laser
2	Long-pulse 755 nm alexandrite laser
3	Rotational therapy
4	Long-pulse 1,064 nm Nd:YAG laser

*Based on average subject evaluation at 3 months following the last laser treatment.

Specifically, laser light of a precise wavelength is selectively absorbed by a target chromophore, namely melanin in the case of laser hair removal. Once absorbed, the light energy is transduced into intense heat, which, if sufficient, may result in damage or destruction (photothermolysis) of both the target chromophore and the tissue it occupies. For laser hair removal, the key to permanent epilation is to impair the development of cells within the "bulb" (base of the hair follicle) and, more importantly, the "bulge" (portion of the isthmus that produces follicular stem cells) of the hair follicle.[2] As the bulb of the hair follicle contains melanin, the goal of direct photothermolysis is possible. It is unclear whether the hair follicle bulge is completely devoid of pigment, and successful photoepilation may involve heat transfer to this site from surrounding pigmented structures, causing indirect thermal injury of follicular stem cells.

To achieve effective photothermolysis of hair follicles with minimal surrounding damage, a laser system must possess the following:

1. Appropriate wavelength to accomplish selective photothermolysis of the follicle
2. Spot sizes that sufficiently maximize laser energy to the depth of the follicle
3. Pulse durations that approximate but do not exceed the thermal relaxation time of the hair follicle (approximately 7–40 milliseconds)
4. Adequate energy (fluence) to modify or destroy the follicle
5. Sufficient surface cooling to protect the epidermis from thermal injury

Wavelength

The amount of light that is selectively absorbed by a target is reliant on the absorption spectrum unique to its constituent chromophore. Figure 3 illustrates absorption spectra for the three major skin chromophores: melanin, oxyhemoglobin, and water.[3] When the three spectra are superimposed, it is evident that there are relatively preferential wavelengths for melanin absorption. At three of these specific wavelengths, 755 nm, 810 nm, and 1,064 nm, absorption by melanin is greater than competitive absorption by oxyhemoglobin and water. These wavelengths correspond to three popular hair removal lasers: the alexandrite, 810 nm diode, and 1,064 nm Nd:YAG lasers, respectively.

Longer wavelengths of light have greater skin penetration, which allows for more effective heating of deeper structures. The bases of hair shafts are typically found at depths of 2 to 6 mm beneath the skin surface. To reach these depths, the ideal wavelength of light is between 750 and 1,100 nm.[4] As such, the 694 nm ruby laser, which has a wavelength well absorbed by melanin, may not have the penetration capacity to reach deeper follicles.[5] It is also a fact that longer wavelengths of light possess less energy, and long wavelength lasers require greater energy to achieve the same clinical effect. For example, the 1,064 nm Nd:YAG laser requires three to four times the fluence of the 810 nm diode laser to achieve similar results.[6]

Spot Size

The spot size must be large enough to maximize laser energy to the depth of the hair follicle to achieve successful photoepilation. Optical transmittance across the skin surface increases with increased spot size, doubling from 5 mm to 12 mm.[7] Spot sizes less than 7 mm have been shown to deliver minimal energy deep into the follicle and are therefore rarely successful.[7] Spot sizes that are large require that the laser device produce higher amounts of energy to achieve comparable fluences, which is technically more difficult and expensive to achieve.[8] As such, most hair removal lasers are limited to spot sizes under 2 cm in diameter.

Pulse Duration

To minimize thermal damage, laser pulse duration must be less than the thermal relaxation time of the target so that heating is confined mostly to the target itself. This duration is directly proportional to the size, shape, and volume of the target. For hair follicles, research has shown that

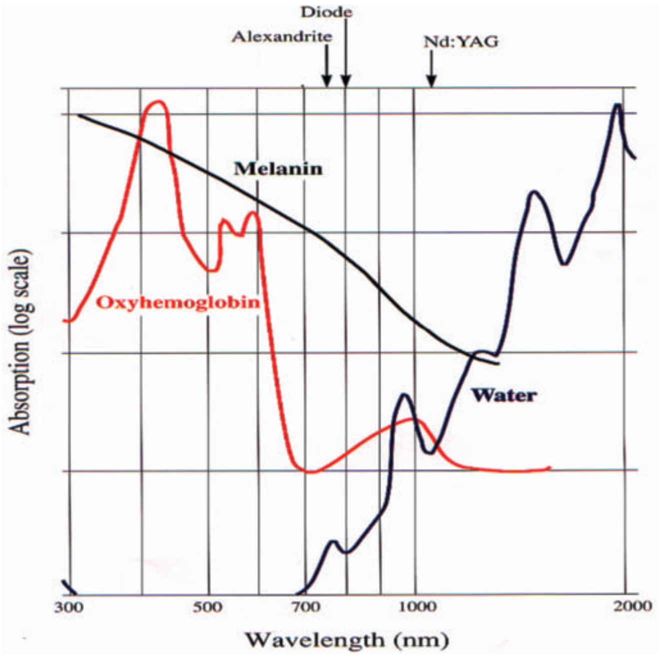

Figure 3. Absorption spectra of the three most common skin chromophores: melanin, oxyhemoglobin, and water. The three most popular lasers used for laser hair removal are indicated with their respective operating wavelengths.

ideal pulse widths vary from 10 to 100 milliseconds, depending on anatomic location, the diameter and length of hair follicles, and background skin color.[9]

The latter factor is very important. From the principle of selective photothermolysis, it is logical that the ideal laser hair removal patient is one with fair skin but dark-colored hair follicles. When the patient has dark hair and dark-colored skin, there is competitive absorption of laser light by epidermal melanin, which reduces the efficacy of hair removal and increases the likelihood of thermal injury to the skin surface. With these patients, it has been shown that by combining the actions of (1) increasing the pulse duration and (2) increasing surface cooling, the epidermis can be stabilized and protected while effective hair removal is achieved.[10] Although hair removal is not as efficient in this patient population, with the improvement of long-pulse lasers and refinement of chilling systems, laser technology will become a more practical solution for unwanted hair in this group.

Fluence

To achieve effective laser hair removal, maximal fluence must be delivered to hair follicles without causing collateral injury and subsequent cosmetic complications. In general, higher fluences translate to greater efficacy. Perifollicular erythema and edema without collateral blistering or purpura are a good immediate clinical response that demonstrates safe, effective heating of the hair follicle (Figure 4). This clinical sign often foreshadows effective photoepilation and is a good treatment end point. Light-colored skin types will generally be able to tolerate higher fluences because there is less competitive absorption by epidermal melanin. As such, patients with tanned skin should delay treatment until their tan fades.

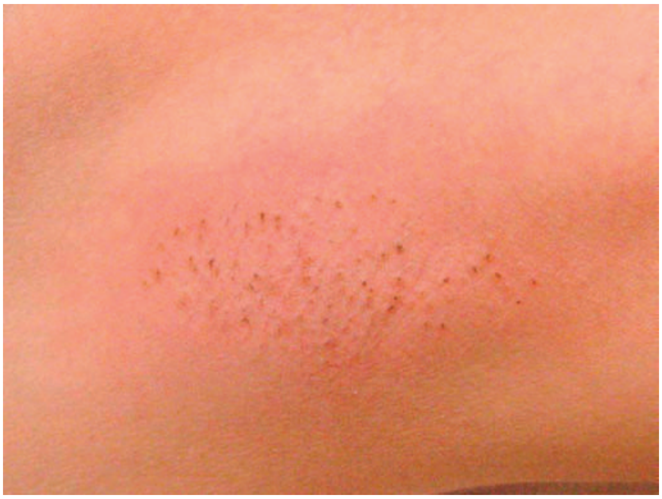

Figure 4. Perifollicular erythema and edema. The ideal clinical end point for a laser hair removal treatment session.

Current Study

Multiple lasers and noncoherent light sources are currently available for hair removal, and several studies document their safety and efficacy.[11–20] However, most of these studies have used variable subject skin types, anatomic sites of study, laser parameters, treatment regimens (number of treatments and treatment intervals), investigators, and hair counting techniques. This study differs in that it was conceived to compare various laser systems using a combination of subject, investigator, laser parameter, and diagnostic controls.

Subjects were selected to be of the same skin phototype, so differences in efficacy could be attributed to laser variables and not the subject. The majority of subjects (17 of 20) were selected on the basis of their dark-colored hair to create a cohort that was ideal for the principles of laser hair removal. Three of 20 subjects had red or light-colored hair and were purposely selected to illustrate any difference in efficacy that this variable would create, given that all else was kept constant. Indeed, this was the case because these subjects experienced a 5 to 15% decreased efficacy compared with the “ideal” cohort.

The axillae were chosen as the constant anatomic site of study because this is a popular area for subjects to desire hair removal and is cosmetically concealed in the event of adverse effects. To study the three most popular laser wavelengths used for hair removal, a split axillae study was designed to yield four distinct treat areas, three for each laser and a remaining fourth area. In lieu of keeping this fourth treatment area as a control, it was decided to use baseline hair counts for comparison and apply a novel, rotational regimen to this fourth area.

The rationale for rotating treatment between the various laser systems was the hypothesis that a variety of pigment-absorbing wavelengths would be more effective than either one alone. This study demonstrates that this hypothesis is not correct because greater efficacy was achieved by two of three systems (the long-pulse alexandrite and the 810 nm diode lasers).

The long-pulse alexandrite and 810 nm diode lasers were found to have almost equal efficacy and tolerability. Their wavelength proximity and relative noncompetitive absorption for melanin (see Figure 3) may be the reasons for these comparable results. Although the 694 nm ruby laser is more specific for melanin, with less competitive absorption than either the alexandrite or 810 nm diode laser, the depth of penetration of the lower wavelength is not sufficient to achieve photoepilation. For now, it seems that 755 nm and 810 nm are the ideal wavelengths for this indication for phototype II skin. These findings correlate with past reports.[6,17,18,20]

The 1,064 nm Nd:YAG system was shown to be effective for laser hair removal but not nearly to the degree of the long-pulse alexandrite or the 810 nm diode laser. In addition, subjects found this system to be less tolerable during treatment. With greater depth of penetration, it is possible that energy from the Nd:YAG laser may be affecting more cutaneous nerves than the other two lasers. Figure 3 demonstrates that the difference in absorption curves of hemoglobin, water, and melanin is less at 1,064 nm than at 755 to 810 nm. As such, there is greater absorptive competition at the 1,064 nm wavelength, which may be a factor in the relatively reduced efficacy of the Nd:YAG laser for hair removal. Perhaps with more fluence and greater surface cooling, the efficacy of the Nd:YAG may be increased. Studies have shown that post-treatment pigmentary alterations were less common with the Nd:YAG laser. This suggests that the Nd:YAG may find a niche in treating individuals of darker skin types. Of interest, after splitting the axillae into halves, the Nd:YAG laser was arbitrarily chosen to be used for both lower axilla, instead of being randomized to any axillary half. One could argue that this may have introduced study bias or the less likely possibility that the inferior axilla does not yield results as successful as those of the superior portion. Although this has neither been described in the literature nor observed by the authors, in retrospect, treatment randomization would have eliminated any possible doubt.

Conclusion

At the 3-month follow-up, the 755 nm long-pulse alexandrite and the 810 nm diode lasers have shown almost equal efficacy, tolerability, and satisfaction. The Nd:YAG laser demonstrated less tolerability and satisfaction and was least efficacious. Rotational treatment with all three laser systems offers no greater advantage than the alexandrite or 810 nm diode laser alone. This study was preliminary. Future studies will include larger sample sizes and representative subjects with various skin phototypes and hair colors and include internal controls.

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Commentary

Rao and Goldman's study very nicely compares the three most popular wavelengths used in laser hair removal and shows that each effectively reduces hair counts 3 months following three treatments. In their study, the 755 nm alexandrite and 810 nm diode lasers were shown to be more effective than the 1,064 nm Nd:YAG laser or a novel rotational treatment using all three lasers.

It is always very difficult to compare multiple laser systems and then ascribe the differences found solely to the wavelengths being used. Usually, there are several other factors that may account for the differences. In this study, it is possible that the smaller spot sized used in the treatments with the Nd:YAG laser and the Nd:YAG third of the rotational treatment may have accounted for the lower efficacy of the treatment and not the wavelength used. It is also very difficult to exactly match effective fluences between various systems. In addition, the two groups that had the best results were in the superior aspect of the axilla and the two with lower clearance were in the inferior axilla.

What this study does show, however, is that at these settings on the systems used, the alexandrite and diode lasers were found to be more effective than the Nd:YAG laser. Other studies have also found no statistical difference in hair removal between alexandrite and diode lasers,[1–3] and one study suggested that both the alexandrite and the diode lasers were slightly more effective than the Nd:YAG laser.[4] In addition, Rao and Goldman found the Nd:YAG laser to be more painful than the other systems. This is seen in clinical practice and may be due to the greater depth of penetration, as the authors suggest, and the greater absorption of Nd:YAG by water. As seen in other studies and in clinical practice, patients with red or light-colored hair in this study did not respond as well to the treatment.

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