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Comparative efficacy and safety of single-pulse mode vs. six-pulse mode 1,064 nm Q-switched neodymium-doped yttrium aluminum garnet laser for treating facial pigmentary disorders in Republic of Korea: retrospective clinical study

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Background: Facial pigmentary disorders, including melasma, post-inflammatory hyperpigmentation, and solar lentigines, present significant therapeutic challenges in dermatology. The 1,064 nm Q-switched neodymium-doped yttrium aluminum garnet (Nd:YAG) laser has been established as an effective treatment modality for these conditions. This study aimed to compare the clinical efficacy and safety profile of single-pulse mode vs. six-pulse mode 1,064 nm Q-switched Nd:YAG laser treatment for facial pigmentary disorders.

Methods: The retrospective analysis included 40 patients with facial pigmentary disorders, who were divided equally into two groups: one treated with the single-pulse mode (n = 20) and the other with the six-pulse mode (n = 20). Outcomes were evaluated using medical records and pre- and post-treatment photographs.

Results: The six-pulse mode group demonstrated significantly superior improvement in pigmentation compared to the single-pulse mode group (mean score, 4.05 vs. 3.3; $p < 0.05$). The Mann–Whitney U test yielded a U statistic of 92.5 with statistical significance ($p < 0.05$). Both treatment modalities exhibited comparable safety profiles, with only mild, transient erythema and edema that resolved within 24-48 hours. No significant adverse effects were observed in either group.

Conclusion: The six-pulse mode 1,064 nm Q-switched Nd:YAG laser demonstrated superior therapeutic efficacy compared to the single-pulse mode for treating facial pigmentary disorders while maintaining an equivalent safety profile. These findings support the clinical application of multi-pulse technology, particularly for patients with refractory pigmentary conditions.

Key words: 1,064 nm Q-switched Nd:YAG laser; Facial pigmentary disorders; Single pulse mode; Six-pulse mode

INTRODUCTION

Facial pigmentary disorders, including melasma, post-inflammatory hyperpigmentation (PIH), and lentigines, are prevalent dermatological conditions that cause cosmetic and psychological distress, particularly affecting individuals with darker skin types [1]. Melasma presents as symmetrical brown or gray patches on the cheeks, forehead, and chin; PIH results from post-inflammatory melanin deposition; and lentigines are characterized as

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acquired epidermal aging processes [2]. These conditions are especially common in Asian and darker-skinned populations, contributing to social stigma and reduced quality of life [3].

Treatment options range from topical agents (e.g., hydroquinone, tretinoin) to chemical peels and laser therapies [4]. Topical treatments often yield inconsistent results and may cause side effects like skin irritation or pigmentary changes with prolonged use [5]. Chemical peels are effective for superficial lesions but less so for deeper pigmentation [6]. Laser therapies, particularly the 1,064 nm Q-switched neodymium-doped yttrium aluminum garnet (Nd:YAG) laser, offer precision by means of selective photothermolysis, selectively targeting melanin while minimizing damage to surrounding tissues [7]. This laser's near-infrared wavelength penetrates deeply, making it well-suited for addressing both epidermal and dermal pigmentary issues [8].

The Q-switched Nd:YAG laser delivers nanosecond pulses, disrupting melanosomes within melanocytes and melanophages through subcellular selective photothermolysis [9]. While single-pulse mode has been the traditional approach, recent advancements suggest multiple-pulse modes, such as dual-pulse or multi-pulse modes, may enhance efficacy by optimizing energy distribution [10]. The delivery of multiple pulses in rapid succession is hypothesized to improve melanin fragmentation while reducing thermal damage [11]. Studies on dual-pulse modes report comparable or superior outcomes with fewer side effects compared to single-pulse mode [12].

Although the six-pulse mode, a recent advancement in laser technology, has become available for treatment, data specifically on six-pulse mode are limited, necessitating further clinical investigation. This study aims to compare the efficacy and safety of single-pulse versus six-pulse mode 1,064 nm Q-switched Nd:YAG laser in treating facial pigmentary disorders. By analyzing retrospective data from 40 patients, we seek to provide evidence to guide clinical practice and optimize treatment protocols for these challenging conditions.

METHODS

Ethics statement: This retrospective study was approved by the Institutional Review Board (IRB) of Kangbuk Samsung Hospital (IRB approval number: KBSMC 2023-10-003-006). Informed consent was obtained from the participants for the study and publication of the study.

Data from 40 patients diagnosed with facial pigmentary disorders (melasma, PIH, lentigines) treated from January 2023 to December 2024 were included. Patients were divided equally into two groups: Group A (n = 20; single-pulse mode) and Group B (n = 20; six-pulse mode) (Table 1).

The single-pulse mode group (n = 20) had a mean age

Table 1. Demographic and clinical characteristics of patients in single-pulse mode and six-pulse mode groups

Patient ID	Age (yr)	Sex	Condition	Patient ID	Age (yr)	Sex	Condition
1	38	M	Melasma	21	40	M	Melasma
2	45	F	PIH	22	42	F	PIH
3	42	M	Melasma	23	41	M	Melasma
4	39	F	PIH	24	38	F	PIH
5	47	F	Melasma	25	46	F	Melasma
6	40	M	PIH	26	39	M	PIH
7	43	F	Melasma	27	44	F	Melasma
8	41	M	PIH	28	40	M	PIH
9	44	F	Melasma	29	43	F	Melasma
10	46	M	PIH	30	45	M	PIH
11	37	F	Melasma	31	38	F	Melasma
12	39	M	PIH	32	40	M	PIH
13	48	F	Melasma	33	47	F	Melasma
14	42	M	PIH	34	41	M	PIH
15	40	F	Lentigines	35	39	F	Lentigines
16	45	M	PIH	36	44	M	PIH
17	41	F	Melasma	37	42	F	Melasma
18	38	M	PIH	38	37	M	PIH
19	43	F	Melasma	39	45	F	Melasma
20	40	M	Lentigines	40	41	M	Lentigines

M, male; F, female; PIH, post-inflammatory hyperpigmentation.

of 42.1 years (standard deviation [SD] = 3.2), with 9 males and 11 females. The six-pulse mode group (n = 20) had a mean age of 41.8 years (SD = 3.1), with 10 males and 10 females. A two-sample t-test showed no significant difference in age between groups (t = 0.31; p = 0.76). A chi-square test confirmed no significant difference in sex distribution (χ^2 = 0.10; p = 0.75). Regarding pigmentation conditions, the single-pulse mode group consisted of 9 melasma, 9 PIH, and 2 lentigines cases; the six-pulse mode group included 8 melasma, 10 PIH, and 2 lentigines cases. A chi-square test showed no significant difference in condition distribution (χ^2 = 0.22; p = 0.90).

The device used in this study was the Brighton (Miin) (LTRA Global). The treatment parameters were as follows: Group A (single-pulse mode): 2.5-3.0 J/cm^2, 8 mm spot size, 10 Hz; Group B (six-pulse mode): 4.5-5.5 J/cm^2 delivered as six pulses, 8 mm spot size, 10 Hz. Treatments were administered every 4 weeks for 3 sessions.

Outcomes were measured by pigmentation improvement, assessed via pre- and post-treatment photographs (1 month after final treatment) using a 1-5 scale (1, aggravated; 2, no improvement; 3, 25%-50% improvement; 4, over 50% improvement; 5, over 75% improvement). During the treatments, side effects such as erythema, edema, crusting, and pigmentary changes were documented. The Mann–Whitney U test, a non-parametric test suitable for ordinal data, was used to compare treatment scores between groups. Mean scores and variances were calculated for descriptive purposes. A two-sample t-test was also performed for reference, assuming approximate normality for large samples. Statistical significance was set at $p < 0.05$.

RESULTS

The single-pulse mode group had a mean score of 3.3 (variance = 0.853), with 4 scores of 2, 8 of 3, 6 of 4, and 2 of 5. The six-pulse mode group had a mean score of 4.05 (variance = 0.787), with 1 score of 2, 4 of 3, 8 of 4, and 7 of 5 (Tables 2, 3). The Mann–Whitney U test yielded a U statistic of 92.5, with a p-value < 0.05, indicating a statistically significant difference in treatment efficacy that favored the six-pulse mode (Table 3). For reference, a two-sample t-test (assuming unequal variances) gave a t-statistic of approximately –3.27 (df 37.8; p = 0.002), supporting the same conclusion.

The six-pulse mode group demonstrated significantly greater improvement in pigmentation ($p < 0.05$). Both groups experienced mild, transient erythema and edema,

Table 3. Summary of treatment scores by group

Score	Single-pulse mode (n = 20)	Six-pulse mode (n = 20)
2	4	1
3	8	4
4	6	8
5	2	7
Mean	3.3	4.05
Variance	0.853	0.787

Table 2. Raw data of treatment scores for single-pulse mode and six-pulse mode groups

Patient ID	Treatment	Score	Patient ID	Treatment	Score
1	Single-pulse	2	21	Six-pulse	2
2	Single-pulse	2	22	Six-pulse	3
3	Single-pulse	2	23	Six-pulse	3
4	Single-pulse	3	24	Six-pulse	4
5	Single-pulse	3	25	Six-pulse	4
6	Single-pulse	3	26	Six-pulse	4
7	Single-pulse	3	27	Six-pulse	4
8	Single-pulse	3	28	Six-pulse	4
9	Single-pulse	3	29	Six-pulse	5
10	Single-pulse	4	30	Six-pulse	5
11	Single-pulse	4	31	Six-pulse	5
12	Single-pulse	4	32	Six-pulse	5
13	Single-pulse	4	33	Six-pulse	5
14	Single-pulse	4	34	Six-pulse	5
15	Single-pulse	4	35	Six-pulse	4
16	Single-pulse	5	36	Six-pulse	4
17	Single-pulse	5	37	Six-pulse	3
18	Single-pulse	3	38	Six-pulse	3
19	Single-pulse	2	39	Six-pulse	5
20	Single-pulse	3	40	Six-pulse	4

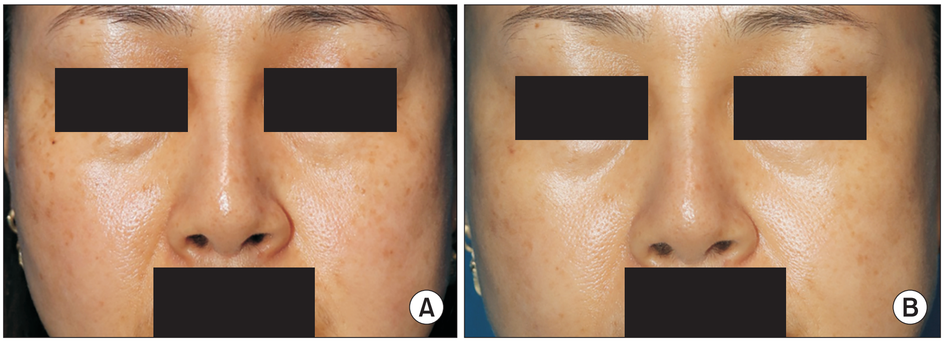

Fig. 1. No. 29 patient treated by six-pulse mode. (A) Before treatment. (B) After treatment.

resolving within 24-48 hours. No meaningful side effects were observed during treatment in both groups (Fig. 1).

DISCUSSION

This study indicates that the six-pulse mode of the 1,064 nm Q-switched Nd:YAG laser demonstrates superior efficacy compared to single-pulse mode for treating facial pigmentary disorders, leading to statistically significant improvements in pigmentation ($p < 0.05$). Both modes demonstrated comparable safety profiles, with only mild, transient side effects observed, which aligns with the laser's established safety profile in Fitzpatrick skin types III-V [13].

The superior efficacy of six-pulse mode may stem from its ability to deliver multiple pulses in rapid succession, thereby enhancing melanosome fragmentation while distributing thermal energy more evenly, thus reducing collateral damage [14]. This is supported by studies on dual-pulse modes, which report improved outcomes and reduced side effects compared to single-pulse mode [15]. The six-pulse mode likely extends these benefits by further optimizing energy delivery.

The clinical superiority of multi-pulse modes represents a novel treatment mechanism rather than simple pulse division. The multi-pulse technology demonstrates several critical advantages that establish it as a paradigm shift in laser therapy for pigmentary disorders. The cumulative heating effect of consecutive sub-pulses induces progressive dermal heating (thermal stacking), elevating dermal temperature to enhance targeting of primary chromophores including melanin and vascular structures while promoting papillary dermis remodeling. This dual mechanism enables simultaneous implementation of "laser toning" effects and "laser genesis" effects, providing a differentiated therapeutic paradigm with added clinical value beyond conventional single-pulse treatments. This dual-effect mechanism potentially explains the enhanced clinical outcomes observed in our six-pulse group, as patients may benefit from both pigment reduction and subtle skin quality improvement.

The ideal multi-pulse system should encompass: (1) clinically effective sub-pulse energy and duration; (2) uniform intervals with high output and stability; (3) sufficient cumulative energy for multifaceted therapeutic outcomes; and (4) customizable pulse configurations. The Brighton (Miin) laser system used in the study demonstrates several clinically significant advantages, primarily through its innovative multi-pulse technology. Each sub-pulse delivers clinically effective energy (≥450 mJ) with an optimal pulse duration (≤20 ns), ensuring therapeutic efficacy comparable or superior to conventional single-pulse toning. This is achieved while maintaining a stable and uniform sub-pulse waveform, delivering a total energy of 3,000 mJ with 500 mJ per sub-pulse. Such specifications address the limitations of traditional devices, which often suffer from irregular energy output and suboptimal sub-pulse energy, leading to reduced efficacy and increased adverse effects. Furthermore, the system's flexibility in adjusting pulse counts (4-8 pulses) based on patient-specific factors, including skin type, lesion characteristics, and sensitivity, facilitates personalized treatment optimization, transcending mere energy output improvements.

Facial pigmentary disorders are notoriously difficult to treat due to their complex etiology, involving genetic, hormonal, and environmental factors [16]. Recent research has elucidated the multifactorial pathophysiology of melasma, which involves hyperfunctional melanocytes, structural alterations in the epidermis and basement membrane, and various dermal changes including vascular abnormalities, mast cell activation, and senescent fibroblast involvement [17]. Our findings suggest that multi-pulse mode (six-pulse) further enhances the capability to address these complex pathophysiological mechanisms, potentially offering a more effective option for patients with refractory pigmentation.

Safety is a critical consideration, particularly in darker skin types prone to PIH or hypopigmentation [18]. Both treatment groups in this study exhibited only mild, transient side effects, consistent with prior research on low-fluence Q-switched Nd:YAG lasers [19]. The six-pulse mode's ability to deliver energy in smaller increments may contribute to its favorable safety profile while maintaining therapeutic efficacy. Comparisons with other studies reveal mixed findings. A study comparing dual-pulsed and single-pulsed modes found reduced side effects with dual-pulsed mode [11]. This aligns with our results, though the superior performance of six-pulse mode in our study may be attributed to the optimized energy delivery system and advanced pulse control technology.

The limitations of this study include: (1) its retrospective design, which may introduce selection bias; (2) a relatively small sample size (n = 40), which limits generalizability; (3) the lack of a control group or comparison with other modalities; (4) the absence of long-term follow-up to assess recurrence rates; and (5) potential variability in six-pulse mode parameters across different devices, affecting reproducibility. Prospective, randomized controlled trials with larger cohorts are needed to validate these findings.

In conclusion, the six-pulse mode of the 1,064 nm Q-switched Nd:YAG laser demonstrates superior efficacy compared to single-pulse mode for treating facial pigmentary disorders, while maintaining a comparable safety profile. These findings support its clinical application, particularly for patients with darker skin types, and underscore the need for further research to optimize laser parameters and treatment regimens.

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AUTHOR CONTRIBUTIONS

Conceptualization: GL. Data curation: GL. Formal analysis: JBL. Investigation: WSK. Methodology: WSK. Project administration: WSK. Software: GL. Validation: GL. Visualization: JBL. Writing–original draft: JBL. Writing–review & editing: all authors.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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DATA AVAILABILITY

Contact the corresponding author for data availability.

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SUPPLEMENTARY MATERIALS

None.

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