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Efgartigimod for induction and maintenance therapy in muscle-specific kinase myasthenia gravis

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Abstract

Background: The efficacy of efgartigimod in treating myasthenia gravis (MG) patients with muscle-specific kinase (MuSK) antibodies has not been demonstrated in the clinical trial, existing case reports, or observational studies.

Objectives: To evaluate the efficacy and safety of efgartigimod combined with immunotherapies such as tacrolimus or B-cell depleting agents, as maintenance treatment for MuSK-MG patients.

Design: This retrospective study included 14 MuSK-MG patients treated with efgartigimod at three tertiary hospitals from 2023 to 2024.

Methods: Data on the activities of daily living (ADL) scores, Quantitative Myasthenia Gravis scores, and the time reaching minimal symptom expression (MSE) were collected. The combined use of steroids, immunosuppressants, and rescue therapies, as well as the adverse event incidence, were also recorded.

Results: The mean age at first efgartigimod treatment was 55 ± 18 years old with a median follow-up time of 28 weeks. From baseline to week 4, MG-ADL scores decreased significantly from 10.1 ± 4.0 to 2.2 ± 3.1 ($n = 14$, $p = 0.001$). The majority of patients (92.9%) maintains a reduction of at least 2 points for more than 8 weeks. The median time to achieve MSE was 4 weeks, with 71.4% (10/14) of patients reaching MSE by week 12. In patients receiving CD20 B cell depleting therapy or tacrolimus as maintenance, the time-weighted average dosage of prednisone was 16 mg while that in those with prednisone alone was 37 mg. Of all the 14 patients, one developed an upper respiratory tract infection 4 weeks after rituximab (RTX), and one was infected with herpes zoster virus 13 weeks after RTX.

Conclusion: A single-cycle efgartigimod as an induction therapy, combined with immunotherapies such as tacrolimus or B cell depleting agents, as maintenance treatment, could benefit MuSK-MG patients.

Keywords: efgartigimod, muscle-specific kinase, myasthenia gravis, rituximab, tacrolimus

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Introduction

Myasthenia gravis (MG) is an autoimmune disorder characterized by autoantibodies targeting the components of the postsynaptic membrane at the neuromuscular junction. MG patients with muscle-specific kinase (MuSK) antibodies are often classified as refractory MG due to their failure to respond to conventional immunosuppressants (IS) such as azathioprine (AZA), tacrolimus, or mycophenolate mofetil, which are frequently combined with corticosteroid. Some patients require frequent rescue therapies, such as

intravenous immunoglobulin (IVIg) or plasma exchange (PE).[1–3] Early treatment with biological agents like rituximab (RTX), a B-cell-directed biologic, along with rescue therapies such as PE, has significantly improved prognosis. Consequently, the treatment goal for MuSK-MG has shifted from reducing mortality to achieving rapid improvement and sustained disease remission while minimizing adverse events (AEs).

MuSK antibodies, predominantly of the IgG4 subtype, exert their pathogenic effects primarily by blocking the interaction between MuSK and low-density lipoprotein receptor-associated protein 4 (LRP4), thereby preventing MuSK activation.[4] Unlike acetylcholine receptor (AChR) antibodies, MuSK antibody titers generally correlate with disease severity.[5,6] In patients treated with RTX, sustained clinical improvement has been associated with a reduction in MuSK titers.[7] The neonatal Fc receptor (FcRn) is widely expressed on the surface of immune cells and plays a role by binding to the Fc segment of the antibody. It functions as a protector of total IgG from lysosomal degradation by recycling and transcytosis of IgG. Efgartigimod is an FcRn antagonist that competitively inhibits the binding of IgG to FcRn, thereby selectively promoting the increased catabolism of all IgG subtypes, including IgG4. This finding suggests that MuSK-MG patients may theoretically benefit from IgG clearance.

Therapy with another FcRn antagonist, rozanolixizumab, demonstrated statistically significant and clinically meaningful improvements in adults with MuSK-MG ($n=21$),[8] and rozanolixizumab has been approved in the United States for the treatment of both generalized AChR-MG and MuSK-MG.[9] However, the application of efgartigimod in MuSK-MG did not yield positive results in the ADAPT trial, likely due to the small sample size ($n=6$).[10] Existing case reports and observational studies have also yielded inconsistent conclusions.[11–14] Therefore, we aim to evaluate the efficacy of efgartigimod in treating MuSK-MG in a larger population.

In this study, we reported our experience with 14 MuSK-MG patients who were treated with efgartigimod and described the outcomes of the patients with combined or subsequent immunotherapy profiles.

Methods

Study population

In this observational retrospective study, MuSK-MG patients who received efgartigimod from three tertiary referral centers from September 2023 to October 2024 were included. The participating centers included Huashan Hospital, Fudan University, Qilu Hospital (including Jinan and Qingdao Campus), Shandong University, and Xiangya Hospital, Central South University. The inclusion criteria were (1) age ⩾16 years old; (2) anti-MuSK antibody positive; (3) a Quantitative Myasthenia Gravis (QMG) score of ⩾6 points at baseline. Patients without MG-related activities of daily living (MG-ADL) scores at baseline were excluded. Patients who had less than 24 weeks' follow-up were also excluded. The reporting of this study conforms to STROBE guidelines (Supplemental Material).[15] Written informed consent was granted by each patient, and the study was approved by the ethics committees and institutional review boards of each participating hospital.

Given that efgartigimod is an off-label use for the treatment of MuSK-MG leading to higher cost, the specific number of infusions per cycle was determined based on the improvement of symptoms and the discussions with the patients. The use of subsequent cycles was also based on symptom worsening and the discussion with the patients. Maintenance immunotherapy with ofatumumab or RTX was initiated 2–3 weeks after the final efgartigimod infusion. The regimen of tacrolimus was 1 or 0.5 mg per dose, administered twice daily. The dosage of corticosteroids was adjusted according to clinical status during the subsequent treatment period.

Evaluation and collection

Demographic and clinical variables were collected before the first efgartigimod treatment. Demographic variables include gender, age at onset, and age at first efgartigimod infusion. Clinical features include disease duration from onset to the first efgartigimod infusion, comorbidities, Myasthenia Gravis Foundation of America (MGFA) classification, thymoma concurrence, previously used immunotherapies, MG-ADL score, and QMG score.

The following parameters were evaluated after efgartigimod administration: combined or sequential treatment, daily dosage of prednisone during 24 weeks, MG-ADL score (assessed weekly from baseline to the last visit), and QMG score (measured before the first RTX/ofatumumab treatment and at the last visit).

Efficacy assessments. The primary outcome of this study was the change in MG-ADL scores from baseline to week 24. The MG-ADL response was defined as a persistent improvement of at least 2 points sustained for ⩾4 weeks in the first treatment cycle. Minimal symptom expression (MSE) was defined as a total MG-ADL score of 0 or 1. Secondary outcomes included the need for rescue therapies or subsequent efgartigimod cycles.

Safety assessments. Safety evaluation included monitoring the incidence of AEs and serious AEs (SAEs).

Statistical analysis

Continuous variables that follow a normal distribution are reported as mean ± standard deviation, while nonnormally distributed data are presented as median (interquartile range, IQR). Categorical variables are expressed as frequencies (percentages). Wilcoxon tests were performed to compare ADL scores and QMG scores before and after the treatment. Time-weighted average prednisone dose was calculated by computing the area under the curve using the trapezoidal rule divided by the number of days from efgartigimod to week 12. Data analysis was conducted using IBM SPSS version 25.0 (SPSS Inc., Chicago, IL, USA) for statistical analysis and R version 4.2.2 (R Foundation for Statistical Computing, Vienna, Austria) for generating diagrams. Statistical significance was defined as a two-tailed p-value <0.05.

Results

Demographic and clinical characteristics

Demographic and clinical characteristics of the 14 MuSK-MG patients included in the study are summarized in Table 1. All patients are Chinese Han population. Among them, 10 patients (71.4%) were female. The mean (SD) age at first efgartigimod treatment was 55(18) years. The median (IQR) disease duration was 10 (4, 60) months, and the follow-up time was 28(24, 31) weeks. More than half (8/14, 57.1%) of the patients were classified as MGFA class IV when starting efgartigimod infusion. The majority of the patients (92.9%) showed involvement of bulbar muscles.

Prior to efgartigimod initiation, five patients (Patients 1, 4, 5, 6, 10) had not been treated with immunotherapy, five (Patients 2, 3, 9, 11, 12) with only steroid, one (Patient 7) with steroid and AZA, two (Patients 8, 14) with steroid and tacrolimus, and one (Patient 13) with tacrolimus and ofatumumab (see Table 1). Among nine patients who had previously received immunotherapy, four patients (Patients 2, 7, 13, and 14) had previously discontinued steroids or oral IS. Patients 2 and 14 discontinued steroids due to sustained symptom improvement, while Patients 7 and 13 discontinued AZA and tacrolimus, respectively, due to inadequate efficacy. All four patients experienced worsening dysphagia 2 years, 2 years, 3 months, and 3 weeks before efgartigimod initiation, respectively. The remaining five patients (Patients 3, 8, 9, 11, and 12) continued steroid therapy for durations ranging from 3 weeks to 11 months prior to efgartigimod initiation, yet all patients experienced poor response or even symptom exacerbation.

Efficacy of efgartigimod and maintenance immunotherapies. After the first efgartigimod treatment cycle, there was a rapid decrease in MG-ADL scores. From baseline to week 4, the mean ± SD MG-ADL scores decreased significantly from 10.1 ± 4.0 to 2.2 ± 3.1 ($n=14$, $p=0.001$; Figure 1(a)). At week 8, the mean ± SD MG-ADL scores were 2.2 ± 2.3, and at week 12 further decreased to 1.3 ± 1.5 ($n=14$, $p=0.002$). The majority of patients (92.9%) remained a reduction of at least 2 points for more than 8 weeks (Figure 1(b)). The proportions of MG-ADL responders at week 4, 8, and 12 were 78.6% (11/14), 92.9% (13/14), and 92.9% (13/14), respectively. The median time to reach MSE was 4 weeks (Figure 1(c)). The proportions of patients reaching MSE at week 4, 8, and 12 were 57.1% (8/14), 50% (7/14), and 71.4% (10/14), respectively. None of them required rescue therapies. Two patients underwent another cycle of efgartigimod: one at week 6 due to an

Table 1. The demographic and clinical characteristics of MuSK-MG patients treated with efgartigimod.

Patient	Age (years)	Sex	Age of onset (years)	Disease duration (months)	MGFA	Symptoms	Thymoma	Comorbidity	Previous/combined treatments
1	30s	F	30s	18	IIa	O, B, L	No	No	Ofa(2,3,4,10,14,18 w)
2	50s	F	30s	194	IIIb	*B*, N	No	Vitiligo, HTN	**S**(−192 m→−180 m,0→ persistent), RTX(4 w)
3	20s	F	20s	2	IVb	*B, R, N*	No	No	S(−3w→persistent), RTX(6 w)
4	30s	M	30s	10	IIIb	B, R	No	No	S(0→persistent), RTX(3 w)
5	80s	M	80s	1	IVb	O, B, N	No	Asthma, HTN	S(0→persistent), RTX(4 w)
6	80s	M	70s	60	IVb	O, *B*, N	No	No	S(0→persistent), RTX(6 w)
7	60s	M	40s	255	IVb	O, *B*, N	No	DM	S(−255 m→persistent), **AZA** (−126 m→−120 m), RTX(4 w)
8	40s	F	40s	10	IVb	O, *B*, L	No	No	S(−6 w→persistent), TAC(−6 w→6 w), Ofa(4,10,14 w)
9	70s	F	70s	8	IVb	O, *B, R, N*	No	No	S(−12 w→persistent)
10	70s	F	70s	4	IIIb	B	No	No	S(0→persistent)
11	40s	F	40s	4	IIIb	O, *L*, N	No	No	S(−16 w→persistent)
12	50s	F	50s	12	IIIa	*B, L*, N	No	HTN, DM	S(−11 m→persistent)
13	40s	F	40s	4	IVb	*B*	No	No	S(0→persistent), **TAC**(−12 w→−4 w,4 w→ persistent), **Ofa**(−4 w)
14	50s	F	50s	60	IVb	O, *B*	No	HTN, DM	**S**(−44 m→−32 m), TAC(−36 m→persistent)

Italicized text indicates worsening symptoms prior to efgartigimod therapy initiation. Bold formatting denotes treatment regimens discontinued before efgartigimod administration. Time intervals in parentheses are relative to the first efgartigimod infusion (designated as time 0). Negative values (e.g., −192 m) indicate time before efgartigimod initiation, while positive values (e.g., 6 w) indicate time after initiation. "Persistent" indicates treatments that were continued through efgartigimod initiation. Time units: "m" = months; "w" = weeks.
AZA, azathioprine; B, bulbar muscles; DM, diabetes mellitus; F, female; HTN, hypertension; L, limb muscles; M, male; MGFA, Myasthenia Gravis Foundation of America; MuSK, muscle-specific kinase; N, neck muscles; O, extraocular muscles; Ofa, ofatumumab; R, respiratory muscles; RTX, rituximab; S, steroid; TAC, tacrolimus.

ADL score of 8, and the other at week 16 with an ADL score of 7.

To estimate the optimal maintenance treatment, we analyzed the clinical response to combined immunotherapies with three major regimens (Figure 2(a)–(c)): Regimen (a) involved patients treated with CD20 B cells depleting therapy, with or without prednisone. Regimen (b) included patients treated with prednisone alone. Regimen (c) consisted of patients receiving tacrolimus, with or without prednisone. In patients receiving CD20 B cell depleting therapy or tacrolimus, the median maximum daily prednisone dose was 20 mg (range: 0–40 mg), with a time-weighted average daily dosage of 16 mg over 12 weeks. In contrast, patients receiving prednisone alone had a median maximum daily dosage of 50 mg (range: 40–60 mg) and time-weighted average daily dosage of 37 mg during the same 12-week period. Among eight patients with CD20 B cells depleting therapy, three patients did not experience symptom fluctuations; four patients with fluctuating MG-ADL scores showed improvement without

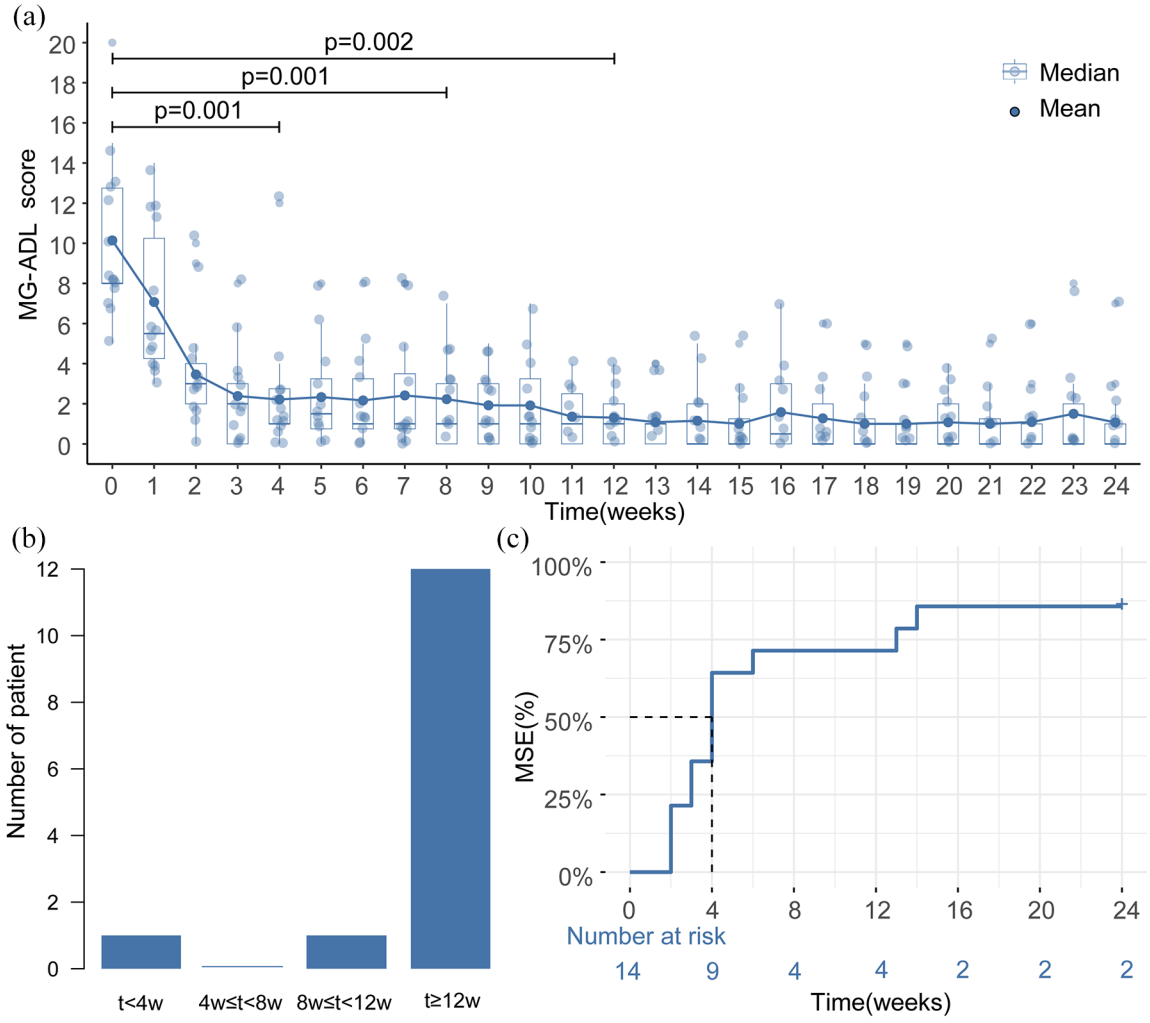

Figure 1. Changes in MG-ADL scores during the treatment and follow-up period. (a) MG-ADL score changes in MuSK-MG from baseline to week 24. (b) The duration of ⩾2-point reduction in MG-ADL score after efgartigimod treatment in MuSK-MG patients. (c) The time to reach MSE after efgartigimod combined with other immunotherapies in MuSK-MG.
MG-ADL, myasthenia gravis-related activities of daily living; MSE, minimal symptom expression; MuSK, muscle-specific kinase.

any additional immunotherapies. In Patient 8, the ADL score increased after 4 weeks but decreased again following the second cycle of two infusions. Among four patients who used prednisone alone, three patients showed long-lasting improvement, while one experienced relapse at week 12, and the symptoms improved following the second cycle of efgartigimod. Immunotherapies including prednisone, tacrolimus, and ofatumumab received within 12 weeks prior to efgartigimod are also illustrated in Figure 2.

Among them, eight patients were treated with sequential B cell depleting therapy, and four patients were treated with prednisone alone. To estimate the advantages of B cell depleting therapy, we compared the efficacy between two treatment regimens. The median follow-up time from the first efgartigimod infusion to the last visit was 28(24.5, 31) weeks in the anti-CD20 group and 30(28, 33.5) weeks in the prednisone group. QMG scores changed from 16.1 ± 3.8 to 4.0 ± 6.9 and ADL scores from 9.8 ± 3.4 to 1.5 ± 3.2 in the anti-CD20 group ($n = 8$). In the prednisone group, the QMG score changed from 21.0 ± 4.3 to 7.3 ± 5.9 and the ADL score from 12.3 ± 5.7 to 1.8 ± 1.5 ($n = 4$). There was no significant difference in the changes in ADL and QMG scores

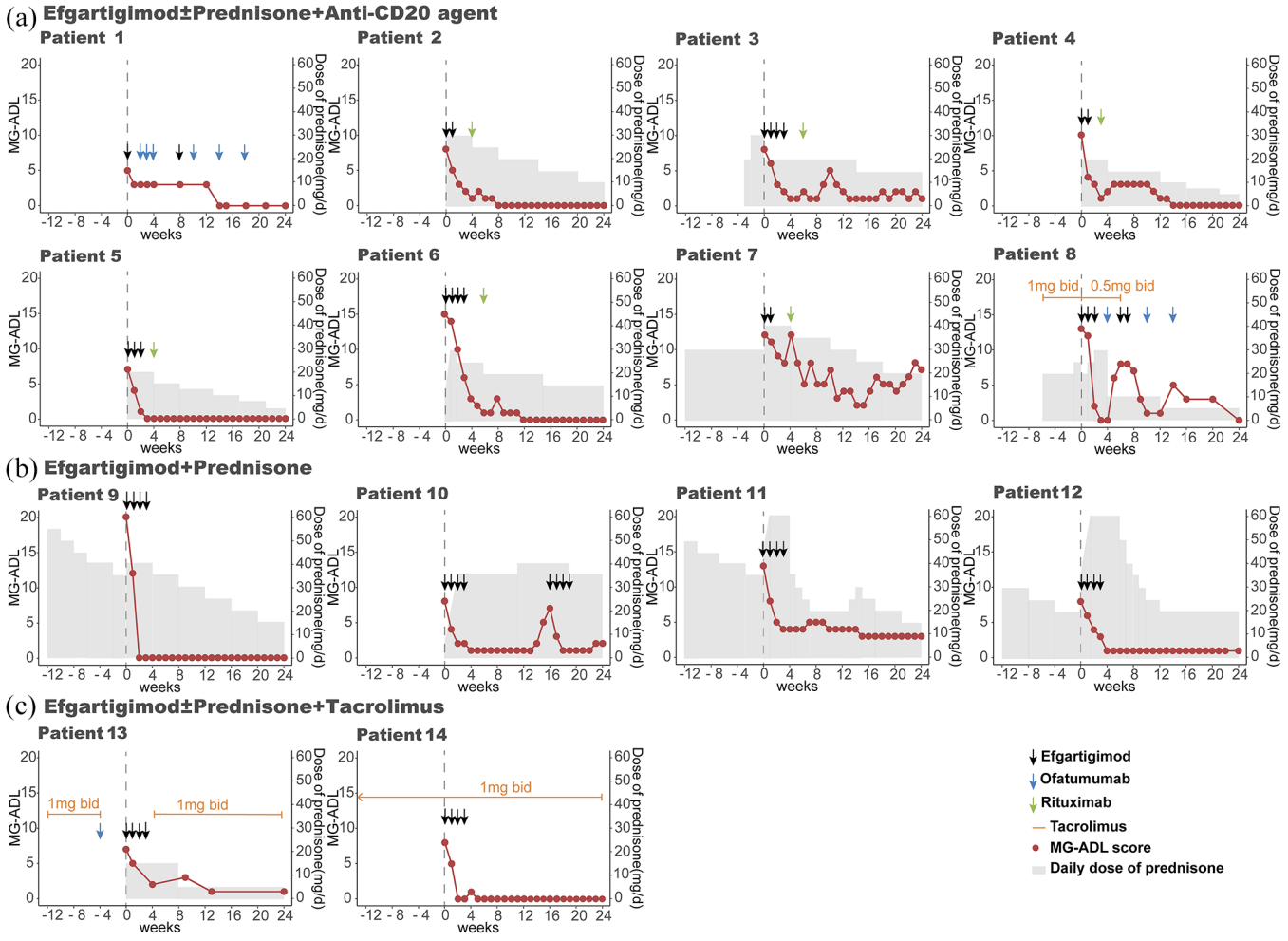

Figure 2. The effect of efgartigimod and subsequent maintenance treatment in MuSK-MG. The effect of efgartigimod combined with other immunotherapies on the MG-ADL score over time is shown for the patients ($n = 14$). The treatment administration dates of efgartigimod and anti-CD20 agents are marked with an arrow. The prednisone doses from baseline to week 24 are marked with gray blot. Orange lines represent the use of tacrolimus. (a) The patients were treated with depleting CD20 B cell therapy with or without the use of prednisone. (b) The patients were treated with prednisone alone. (c) The patients were treated with tacrolimus with or without the use of prednisone.
MG-ADL, myasthenia gravis-related activities of daily living; MSE, minimal symptom expression; MuSK, muscle-specific kinase.

between the two groups. At the last visit, the bulbar subdomain scores in QMG in the anti-CD20 group were 0, 0, 0, 0, 0, 0, 4, 1, while the scores in the prednisone group were 0, 1, 1, and 2, respectively. Regarding gross motor scores, the anti-CD20 group was 0, 0, 1, 1, 2, 2, 6, and 2, whereas the prednisone group had scores of 0, 1, 5, and 5, respectively. The proportions of patients reaching MSE for at least 4 weeks in the anti-CD20 group at week 8, 12, and 24 were 12.5% (1/8), 37.5% (3/8), and 62.5% (5/8), respectively, while in the prednisone group were 75% (3/4), 75% (3/4), and 50% (2/4), respectively. At week 24, 50% of patients in the anti-CD20 group achieved MSE with a daily dosage of no more than 5 mg of prednisone, compared to 0% in the prednisone-only group (4/8 vs 0/4).

Safety of efgartigimod and maintenance immunotherapies. One patient (Patient 7) developed an upper respiratory tract infection 4 weeks after RTX treatment and one patient (Patient 5) was infected with herpes zoster virus 13 weeks after RTX treatment. No SAE was reported throughout the study.

Discussion

Efgartigimod has demonstrated efficacy and safety as an add-on treatment for generalized MG.[10,16] However, in the clinical trial, the number of enrolled MuSK-MG patients was limited and all three patients in the efgartigimod group showed a response comparable to that in the placebo group.[10] In our study, MuSK-MG patients exhibited rapid improvement when treated with efgartigimod, with a reduction in MG-ADL scores. At week 4, the MG-ADL scores showed a mean reduction of 8 and a maximum decline of 20. Additionally, our study also revealed significant disease remission in our patients. The proportion of patients achieving MSE at week 4, 8, and 12 was 57.1% (8/14), 50% (7/14), and 71.4% (10/14), respectively. In comparison, our previous multicenter observation study indicated that the proportion of AChR-MG patients treated with efgartigimod reaching MSE at week 4, 8, and 12 was 44.6% (25/56), 32.1% (18/56), and 37.5% (21/56), respectively.[14] MuSK-MG patients treated with another FcRn receptor antagonist, rozanolixizumab, also demonstrated greater reductions in ADL scores (7.28 vs 3.03) and a higher rate of ADL-responders (5/5 vs 12/60) than AChR-MG patients.[17] Therefore, MuSK-MG patients may experience more rapid and significant improvement than AChR-MG patients following treatment with FcRn receptor antagonist.

The more rapid response observed in MuSK-MG may be attributed to the different mechanisms of action between the antibodies.[18] Anti-MuSK antibodies mask binding sites on MuSK that facilitate interactions with its binding proteins, including LRP4 and collagen Q (ColQ). This inactivating MuSK leads to a reduced postsynaptic density of AChRs.[4] The titers of MuSK antibodies were substantially associated with disease severity.[6,19] Therefore, the rapid reduction in MuSK autoantibodies following efgartigimod treatment results in quick clinical improvement. In contrast, AChR antibodies, in addition to interfering with ACh-AChR binding, can also mediate the destruction of AChRs and damage to the postsynaptic membrane through AChR internalization and complement activation.[20] These processes may be mitigated by efgartigimod infusion, but the structural repair may take longer than the adjustment of signal dysfunction following a decrease in antibody titers.

Considering the acting mechanisms, efgartigimod targets the pathogenic antibodies themselves rather than the upstream processes involved in antibody production, which limits its ability to provide durable improvement after just one infusion cycle. As a result, multiple cycles are often required, with the average interval between treatment cycles in the ADAPT+ trial being as short as 57 days,[21] and even shorter in real-world settings.[22] To address this limitation, alternative immunotherapies, which target the upstream mechanism of autoantibody production and offer a more sustained response, were added in our study.

We described three types of maintenance treatment regimens: steroids alone, steroid-sparing IS (such as tacrolimus) ± steroid, and B-cell-directed biologics (ofatumumab or RTX) ± steroid. Compared to other regimens, patients treated with prednisone alone required a higher maintenance dose, potentially increasing the risk of corticosteroid-related side effects.[23] It has also been shown that MuSK-MG patients receiving only steroids have a higher risk of relapse, with relapse rates of 56.4% in those without nonsteroid IS and 14.3% in those with such therapies.[24] In our study, three patients treated with tacrolimus exhibited different response patterns: Patient 13 and Patient 14 showed durable improvement with the combined treatment of tacrolimus (Patient 13 started tacrolimus after efgartigimod, while Patient 14 received tacrolimus both before and after efgartigimod). However, Patient 8 experienced symptomatic fluctuation after 4 weeks and discontinued tacrolimus at week 6, requiring a second cycle of two infusions.

In MuSK-MG, the pathogenicity of IgG4 does not involve antigen cross-linking, recruitment of immune cells via Fc receptors, or antigenic destruction through phagocytosis or antibody-dependent cellular cytotoxicity. Consequently, MuSK-MG patients derive limited benefit from IVIg and suboptimal responses to corticosteroids.[25,26] RTX has been demonstrated as an effective treatment for MuSK-MG in a multicenter blinded prospective review[27] and was recommended as an early therapeutic option in patients with MuSK-MG who have an unsatisfactory response to initial immunotherapy.[28] In our previous study, a single dose of 600 mg RTX provided sustained efficacy for at least 6 months.[29] This

may be attributed to the fact that MuSK-IgG4 antibodies are primarily produced by CD20-positive short-lived plasmablasts. Depletion of CD20-positive B cells results in a significant reduction in short-lived plasma cells and their precursors.[25,26] Due to the rapid progression of MuSK-MG, which often involves severe bulbar and respiratory dysfunctions, the delayed response of RTX—stemming from its action on upstream antibody-producing cells—may not meet the immediate therapeutic needs of these patients. In the ADAPT+ trial, the reduction in levels of various IgG subtypes (IgG1–4) over time was comparable.[21] In such cases, efgartigimod can serve as a fast-acting therapy, especially when PE is unavailable or contraindicated. Both RTX and ofatumumab, as IgG antibodies, can be affected by the competitive binding of efgartigimod to FcRn, potentially reducing their concentration. Therefore, in our study, maintenance immunotherapy with ofatumumab or RTX was initiated 2–3 weeks after the final efgartigimod infusion, allowing for five half-lives to elapse.[30]

In our study, we noted symptomatic fluctuations in five out of eight patients either before the administration of RTX or within 4 weeks after the infusion, with four of them showing improvement without the need for additional immunotherapies. Typically, RTX requires approximately 4 weeks to demonstrate its therapeutic efficacy in MG.[31] In the combined treatment regimen of efgartigimod and RTX, patients usually need to wait more than 6 weeks for the onset of RTX's efficacy after the last infusion of efgartigimod, as RTX is administered 2–3 weeks after the last infusion. During this period, symptomatic fluctuations may occur due to the diminishing effects of efgartigimod prior to the full onset of RTX's action.

Our study had several limitations: First, the small sample size and absence of a control group limited the generalizability of the findings, requiring larger studies to validate these findings; second, the number of infusions per cycle and the combination of different treatments with efgartigimod were determined based on symptom improvement and patient discussions, which may have introduced biases; third, the majority of the patient included in this study do not have a long disease duration (⩽2 years); finally, the follow-up period was relatively short, preventing the observation of disease relapse.

Conclusion

In conclusion, this study demonstrated that a single-cycle efgartigimod as induction therapy, combined with immunotherapies as maintenance treatments, could benefit MuSK-MG patients. These results contribute to the limited data on MuSK-MG, and we recommend future studies with larger sample sizes and extended follow-up periods for further validation.

Declarations

Ethics approval and consent to participate

We confirm that we have read and understood *Therapeutic Advances in Neurological Disorders*'s position on issues involved in ethical publication and affirm that this report is consistent with those guidelines. This study protocol was approved by the Ethics Board of Huashan Hospital, Fudan University (2023-1100). Written informed consent was granted by each patient.

Consent for publication

Informed consent for publication could not be obtained from the patients as the study was conducted retrospectively. All personal identifiers were removed to ensure anonymity and confidentiality, and the requirement for informed consent for publication was duly waived by the ethics committee.

Author contributions

Yufan Zhou: Data curation; Formal analysis; Investigation; Methodology; Writing – original draft.

Qian Zhou: Conceptualization; Investigation; Validation; Writing – review & editing.

Yaoxian Yue: Formal analysis; Investigation; Methodology; Writing – review & editing.

Sushan Luo: Data curation; Investigation; Methodology; Writing – review & editing.

Jie Song: Data curation; Investigation; Methodology; Writing – review & editing.

Chong Yan: Formal analysis; Funding acquisition; Writing – review & editing.

Dingxian He: Investigation; Writing – review & editing.

Jialong Zhang: Investigation; Writing – review & editing.

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Huan Yang: Conceptualization; Investigation; Writing – review & editing.

Qinzhou Wang: Conceptualization; Investigation; Methodology; Writing – review & editing.

Jianying Xi: Conceptualization; Formal analysis; Methodology; Supervision; Writing – review & editing.

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Competing interests

The authors declare that there is no conflict of interest.

Availability of data and materials

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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Supplemental material

Supplemental material for this article is available online.

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Appendix

Abbreviations

AChR	acetylcholine receptor
ADL	activities of daily living
AE	adverse event
AZA	azathioprine
ColQ	collagen Q
FcRn	The neonatal Fc receptor
IQR	interquartile range
IS	immunosuppressant
IVIg	intravenous immunoglobulin
LRP4	low-density lipoprotein receptor related protein 4
MG	myasthenia gravis
MGFA	Myasthenia Gravis Foundation of America
MSE	minimal symptom expression
MuSK	muscle-specific kinase
PE	plasma exchange
QMG	quantitative myasthenia gravis
RTX	rituximab
SAE	serious adverse event