**Table 3** Increased IFN-γ production induced by peptide analogues

| Replaced by | Relative IFN-γ response (BC20.7 / BC33.5 / BC42.1) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | P1 =86Y | P2 =87L | P3 =88I | P4 =89L | P5 =90S | P6 =91A | P7 =92R | P8 =93D | P9 =94V |
| K | */*/* | */*/* | */*/* | */*/* | */*/* | */*/* | 108/115/90 | */*/* | */*/* |
| E | */*/* | */*/* | */*/* | */*/* | */105/94 | */*/* | */*/* | */*/* | */*/* |
| Q | */*/* | 88/79/90 | */*/* | 92/79/81 | */*/* | */*/* | */*/* | */*/87 | */*/* |
| N | */*/* | 105/97/95 | */*/* | 88/92/97 | */*/* | */*/* | */*/* | */*/* | */*/* |
| T | */*/* | 177/210/86 | 110/92/81 | */*/* | 77/97/108 | */*/* | */*/* | */*/95 | 85/96/91 |
| S | */*/* | 155/187/90 | 95/95/99 | */*/* | 100/100/100 | 81/87/97 | */*/* | */*/* | 93/75/99 |
| G | */*/* | 110/98/79 | 90/100/92 | */*/* | */*/115 | 77/69/93 | */*/* | */*/* | 94/99/100 |
| A | 96/100/98 | 189/202/94 | 105/94/83 | 107/93/83 | 88/104/110 | 100/100/100 | */*/* | */*/* | 80/81/92 |
| V | 91/91/85 | 271/259/92 | 91/84/86 | 105/96/86 | 99/100/101 | 90/76/85 | */*/* | */*/* | 100/100/100 |
| L | 93/88/102 | 100/100/100 | 100/90/101 | 100/100/100 | */*/* | */*/* | */*/* | */*/* | */*/* |
| Y | 100/100/100 | */*/* | */*/* | */*/* | */*/* | */*/* | */*/* | */*/98 | */*/* |
| M | 89/93/91 | */*/* | 96/99/103 | 89/70/85 | */91/* | */*/* | */*/* | */*/* | */*/* |
| W | 90/103/109 | */*/* | */*/* | */*/* | */*/* | */*/* | */*/* | */*/* | */*/* |

Positions 1–9 (P1–P9) of BCGa p84-100 (EEYLILSARDVLAVVSK; with P1 underlined), was replaced by indicated amino acids. T cells were stimulated with peptide species at 16 μM. To obtain relative IFN-γ response values, plateau responses of IFN-γ (pg/ml) were first divided by plateau responses of proliferation (cpm). Then, the following calculation was performed; relative IFN-γ responses=100×[IFN-γ/proliferation to analogues]/[IFN-γ/proliferation to the wild-type BCGa p84-100]. The denominator was 0.0533. *Peptide that did not induce fully agonistic proliferation.

γ enhancement, whereas proliferation remained the same. Therefore, although not generalized, mutual replacement on G, A, V, L, S, or T at P2, tends to induce IFN-γ-specific enhancement. Such observations also have been reported in another study with different peptide species.[14] In this sense, analogue-induced clonal anergy is often observed, especially when residue replacement is made on P7 or P8.[11] Moreover, truncation of the C-terminal moiety of antigenic peptides, in general, exhibit TCR antagonism.[15] In other words, if a rule that applies to altered polyclonal novel responses induced by peptide analogues is established, it will lead us to novel therapeutic interventions using peptide analogues. Our observations on P2 replacement which is associated with increased IFN-γ production are imperative to furthering our understanding.

## ACKNOWLEDGEMENTS

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# Inhibition of CX3CL1 (Fractalkine) Improves Experimental Autoimmune Myositis in SJL/J Mice[1]

**Fumihito Suzuki,* Toshihiro Nanki,[2]* Toshio Imai,† Hirotoshi Kikuchi,‡ Shunsei Hirohata,‡ Hitoshi Kohsaka,* and Nobuyuki Miyasaka***

**Idiopathic inflammatory myopathy is a chronic inflammatory muscle disease characterized by mononuclear cell infiltration in the skeletal muscle. The infiltrated inflammatory cells express various cytokines and cytotoxic molecules. Chemokines are thought to contribute to the inflammatory cell migration into the muscle. We induced experimental autoimmune myositis (EAM) in SJL/J mice by immunization with rabbit myosin and CFA. In the affected muscles of EAM mice, CX3CL1 (fractalkine) was expressed on the infiltrated mononuclear cells and endothelial cells, and its corresponding receptor, CX3CR1, was expressed on the infiltrated CD4 and CD8 T cells and macrophages. Treatment of EAM mice with anti-CX3CL1 mAb significantly reduced the histopathological myositis score, the number of necrotic muscle fibers, and infiltration of CD4 and CD8 T cells and macrophages. Furthermore, treatment with anti-CX3CL1 mAb down-regulated the mRNA expression of TNF-$\alpha$, IFN-$\gamma$, and perforin in the muscles. Our results suggest that CX3CL1-CX3CR1 interaction plays an important role in inflammatory cell migration into the muscle tissue of EAM mice. The results also point to the potential therapeutic usefulness of CX3CL1 inhibition and/or blockade of CX3CL1-CX3CR1 interaction in idiopathic inflammatory myopathy.** ***The Journal of Immunology,*** **2005, 175: 6987–6996.**

Idiopathic inflammatory myopathy (IIM),[3] including polymyositis and dermatomyositis, is characterized by chronic inflammation of the voluntary muscles associated with infiltration of inflammatory cells, including CD4 and CD8 T cells and macrophages, in the skeletal muscle (1–3). Infiltrated CD4 and CD8 T cells express cytotoxic molecules, such as perforin and granzyme granules, and the T cells and macrophages express inflammatory cytokines, such as TNF-$\alpha$ and IFN-$\gamma$ (4–8). Therefore, the infiltrated inflammatory cells might play an important role in the pathogenesis of IIM. The inflammatory cell migration into the muscle is thought to involve the interaction of chemokines and chemokine receptors (9–14).

Chemokines are involved in leukocyte recruitment and activation at the site of inflammatory lesion (15). Approximately 50 chemokines have been identified to date, and they are classified into four subfamilies, C, CC, CXC, and CX3C chemokines, based on the conserved cystein motifs (16). Although the majority of chemokines are small secreted molecules, CX3CL1 (fractalkine) is expressed on the cell surface as a membrane-bound molecule (17, 18). The membrane-bound CX3CL1 is expressed on endothelial cells stimulated with TNF-$\alpha$, IL-1, and IFN-$\gamma$ (19–21), induces adhesion of the leukocytes, and supports leukocyte transmigration into tissue (22, 23). The soluble form of CX3CL1 is generated by proteolytic cleavage at a membrane-proximal region of the membrane-bound CX3CL1 by TNF-$\alpha$-converting enzyme (a disintegrin and metalloproteinase domain 17) and a disintegrin and metalloproteinase domain 10 (24, 25), and is known to induce leukocyte migration (23). In contrast, CX3CR1, a unique receptor for CX3CL1, is expressed on peripheral blood CD4 and CD8 T cells that express cytotoxic molecules and type 1 cytokines (26, 27). CX3CR1 is also expressed on monocytes/macrophages, NK cells, and dendritic cells (28, 29).

Based on the infiltration of CTLs and macrophages into the affected muscles in patients with IIM, we speculated that the CX3CL1-CX3CR1 interaction might contribute to the inflammatory cell migration. In the present study we induced experimental autoimmune myositis (EAM) in SJL/J mice and examined CX3CL1 and CX3CR1 expression in the affected muscle of EAM mice. Furthermore, we studied the effect of CX3CL1 inhibition on EAM mice.

## Materials and Methods

### *Induction of EAM*

Male 5-wk-old SJL/J mice were purchased from Charles River Japan. Purified myosin from rabbit skeletal muscle (6.6 mg/ml; Sigma-Aldrich) was emulsified with an equal amount of CFA (Difco Laboratories) with 3.3 mg/ml *Mycobacterium butyricum* (Difco Laboratories). Mice were immunized intracutaneously with 100 $\mu$l of emulsion into four locations (total, 400 $\mu$l) on the back on days 0, 7, and 14. On day 21, the mice were killed, and the quadriceps femoris muscles were harvested. The muscle tissues were frozen immediately in chilled isopentane precooled in liquid nitrogen, and then 6-$\mu$m-thick cryostat sections were prepared at intervals of 200 $\mu$m. The sections were stained with H&E or used for immunohistochemistry. The experimental protocol was approved by the institutional animal care and use committee of Tokyo Medical and Dental University.

### *Immunohistochemistry*

Immunohistological staining was performed as described previously (26, 30) with some modifications. Briefly, 6-$\mu$m-thick sections were air-dried and fixed in cold acetone at −20°C for 3 min. After air-drying at room

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[3] Abbreviations used in this paper: IIM, idiopathic inflammatory myopathy; EAM, experimental autoimmune myositis; PTX, pertussis toxin.



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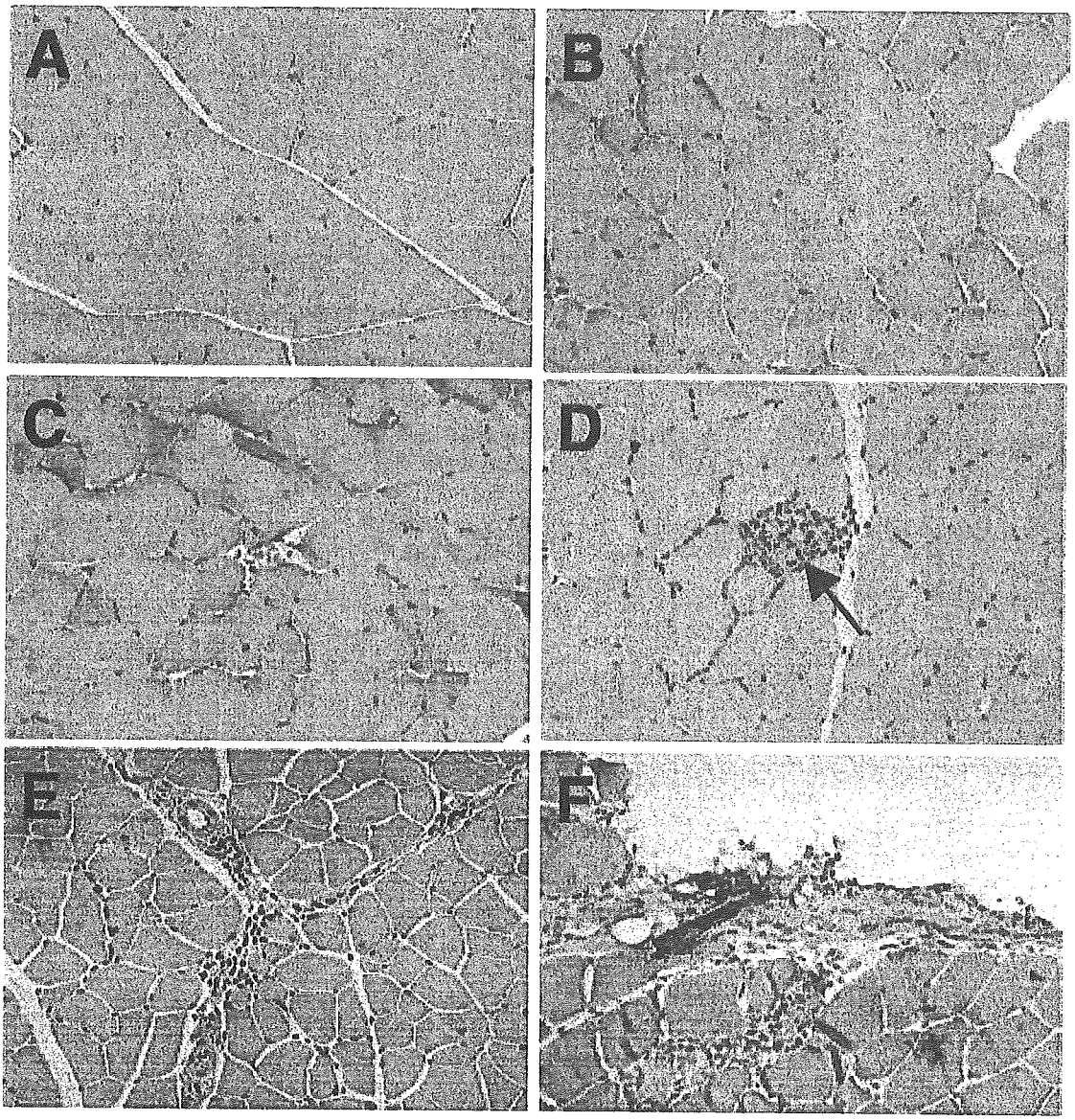


**FIGURE 1.** Histological changes found in the muscle of murine EAM. Quadriceps femoris muscle of normal mice and immunized mice on day 7 showed no inflammatory changes (*A* and *B*, respectively). On day 14, mild cellular infiltration in the muscle tissue was shown (*C*). Muscle tissues of EAM mice on day 21 showed cellular infiltration in the endomysium (*D*), perimysium (*E*), epimysium (*F*), and necrotic muscle fibers (arrow in *D*). H&E staining was used. Original magnification, ×200.

temperature, the slides were rehydrated in PBS for 2 min three times, and then the endogenous peroxidase activity was blocked by incubation in 1.0% $H_2O_2$ in PBS for 10 min, followed by rinsing for 2 min three times in PBS. Nonspecific binding was blocked with 10% normal rabbit serum in PBS for 30 min. For CD4, CD8, and F4/80 staining, the sections were incubated with 5 μg/ml rat anti-mouse CD4 mAb (GK1.5; Cymbus Biotechnology), 2 μg/ml rat anti-mouse CD8a mAb (53-6.7; BD Pharmingen), 5 μg/ml rat anti-mouse F4/80 mAb (C1:A3-1; Serotec), or normal rat IgG in Ab diluent (BD Pharmingen) overnight at 4°C. The samples were then washed three times in PBS for 5 min each time and incubated with biotin-conjugated rabbit anti-rat IgG (DakoCytomation) for 30 min at room temperature with 5% normal mouse serum. To analyze a time course of cell infiltration, numbers of $CD4^+$, $CD8^+$, and $F4/80^+$ cells in six randomly selected fields at ×200 were counted from three EAM mice on days 0, 7, 14, and 21.

For mouse vascular endothelial cell staining, we used a tyramide signal amplification kit (NEL700A; PerkinElmer). After blocking with 10% normal rabbit serum, the sections were incubated with 5 μg/ml rat anti-mouse vascular endothelial cadherin Ab (11D4.1; BD Pharmingen) or normal rat IgG overnight at 4°C. The samples were then washed three times in PBS for 5 min each time and incubated with biotin-conjugated rabbit anti-rat IgG for 30 min at room temperature with 5% normal mouse serum. After washing three times in PBS for 5 min each time, the sections were incubated with streptavidin-HRP for 30 min at room temperature and washed in PBS three times for 5 min each time. The samples were incubated with biotinyl tyramide amplification reagent at room temperature for 5 min, then washed three times in PBS for 5 min each time, and incubated again with streptavidin-HRP for 30 min. After washing three times in PBS for 5 min each time, diaminobenzidine tablets (Sigma-Aldrich) were used for visualization. The sections were counterstained in hematoxylin for 30 s and washed in tap water for 5 min.

For mouse CX3CL1 staining, the endogenous peroxidase activity was blocked by incubation in 1.0% $H_2O_2$ in methanol, and then the sections were incubated overnight at 4°C with goat anti-mouse CX3CL1 Ab (sc-7227; Santa Cruz Biotechnology) or normal goat IgG in Ab diluent at 5 μg/ml. The samples were then washed three times in PBS for 5 min each time and incubated with biotin-conjugated rabbit anti-goat IgG (DakoCytomation) for 30 min at room temperature with 5% normal mouse serum. After washing three times in PBS for 5 min each time, the sections were incubated with peroxidase-conjugated streptavidin (DakoCytomation) for 30 min at room temperature and washed three times for 5 min each time. For enhancing the expression of CX3CL1 on endothelial cells, a tyramide signal amplification kit was

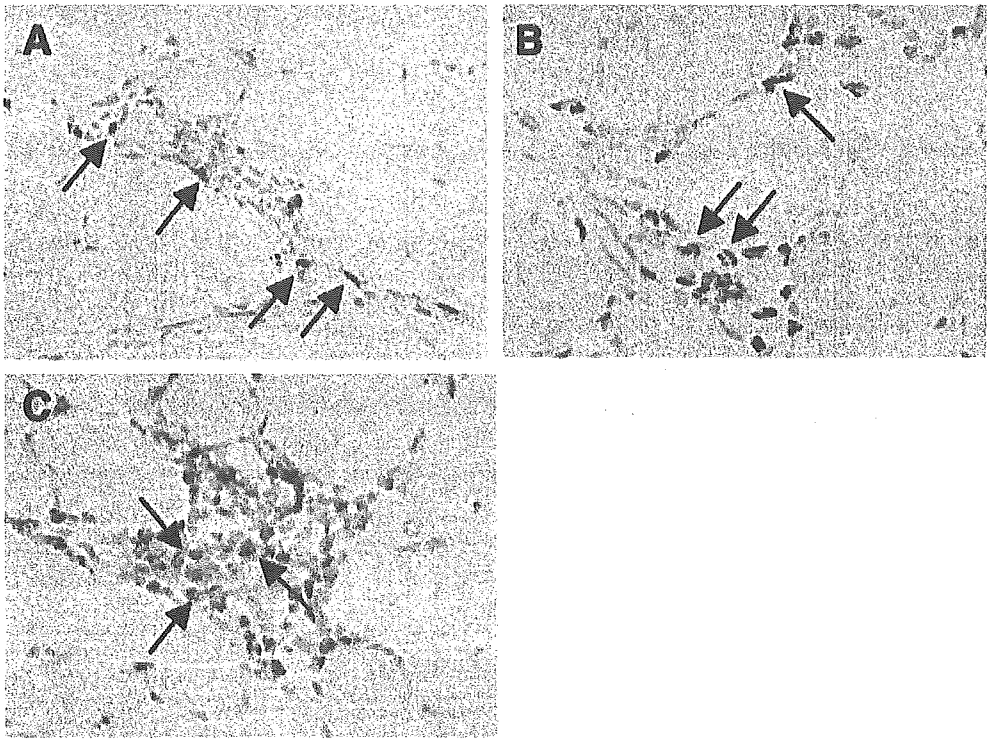


**FIGURE 2.** Infiltration of CD4 and CD8 T cells and macrophages in the muscles of EAM mice. Frozen sections of the quadriceps femoris muscle of EAM mice on day 21 were examined by immunohistochemistry using mAb against CD4 (*A*), CD8 (*B*), and F4/80 (*C*). The arrows indicate $CD4^+$, $CD8^-$, and $F4/80^+$ cells. Original magnification, ×200.

used as described above. Diaminobenzidine tablets were used for visualization. The sections were counterstained in hematoxylin for 30 s and washed in tap water for 5 min.

For CD4, CD8 or F4/80, and CX3CR1 double staining, the sections were incubated overnight at 4°C with 5 μg/ml rat anti-mouse CD4 mAb (GK1.5), 5 μg/ml rat anti-mouse CD8 mAb (53-6.7), 5 μg/ml rat anti-mouse F4/80 mAb (C1:A3-1), or normal rat IgG in Ab diluent. Subsequently, the samples were washed three times for 5 min each time in PBS and incubated with Alexa Fluor 488-conjugated goat anti-rat IgG (Molecular Probes) at 5 μg/ml for 1 h at room temperature. For CX3CR1 staining, the sections were washed three times in PBS for 5 min each time and then incubated with rabbit anti-mouse CX3CR1 Ab (30) or normal rabbit IgG at 5 μg/ml in Ab diluent for 2 h at room temperature. Next, the samples were washed three times for 5 min each time in PBS and incubated with Alexa Fluor 568-conjugated goat anti-rabbit IgG (Molecular Probes) at 5 μg/ml for 1 h at room temperature. The slides were examined using fluorescent microscopy (BZ-Analyzer; Keyence).

### *Treatment with anti-mouse CX3CL1 mAb*

A mAb against murine CX3CL1 was generated from Armenian hamsters immunized with recombinant murine CX3CL1 by a standard method. One mAb, 5H8-4, was selected for additional studies. The specificity was examined by ELISA using a panel of murine CXC (MIP-2, keratinocyte-derived chemokine, and CXCL9, 10, 12, and 13), CC (CCL1–7, 9–12, 17, 19–22, 25, 27, and 28), C (XCL1), and CX3C (CX3CL1) chemokines. The mAb reacted specifically with murine CX3CL1. Five hundred micrograms of hamster anti-mouse CX3CL1 mAb (5H8-4) or control Ab (hamster IgG; ICN Pharmaceuticals) was injected into the mouse peritoneal cavity three times per week from day 0 for 3 wk. The injection of anti-CX3CL1 mAb did not affect the number of PBMC (data not shown).

The severity of inflammatory changes was classified using five grades according to the classification of Kojima et al. (31) with some modification: score 0, no inflammation; score 1, mild endomysial inflammatory changes; score 2, severe endomysial inflammatory changes; score 3, perimysial inflammatory changes in addition to score 2; and score 4, diffuse extensive lesion. If multiple lesions were found in one muscle specimen, 0.5 point was added to the indicated score. To evaluate the severity of inflammation using a different aspect, we counted the number of necrotic muscle fibers, and $CD4^+$, $CD8^+$, and $F4/80^+$ cells in continuous three sections. Each section examined six random fields at ×400. The evaluation of histopathological inflammatory changes was performed in a blind fashion for the experimental group identity.

### *Real-time RT-PCR*

Total RNA was prepared from a 100 mg muscle block using RNA extraction solution, Isogen (Nippon Gene), and treated with DNase I (Invitrogen Life Technologies). The first-strand cDNA was synthesized using oligo$(dT)_{12-18}$ primers (Pharmacia Biotech) and SuperScript II reverse transcriptase (Invitrogen Life Technologies).

The relative quantitative real-time PCR was performed using SYBR Green I on ABI PRISM 7000 (Applied Biosystems) according to the instructions provided by the manufacturer. The cDNA was amplified with primers for TNF-α (5′, GTA CCT TGT CTA CTC CCA GGT TCT CT; 3′, GTG TGG GTG AGG AGC ACG TA), IFN-γ (5′, CCT GCG GCC TAG CTC TGA; 3′, CCA TGA GGA AGA GCT GCA AG), perforin (5′, CCA CGG CAG GGT GAA ATT C; 3′, GGC AGG TCC CTC CAG TGA), and GAPDH (5′, ATG CAT CCT GCA CCA CCA A; 3′, GTC ATG AGC CCT TCC ACA ATG). These primers were designed using the ABI Primer Express Software program (Applied Biosystems). The reaction buffer contained the following components: 25 μl of SYBR Green PCR Master Mix (Applied Biosystems), 300 nM forward and reverse primers, 50 ng cDNA template, and RNA-free distilled water up to 50 μl of total volume. The PCR was conducted using the following parameters: 50°C for 2 min, 95°C for 10 min, and 40 cycles of denaturation at 95°C for 15 s and annealing/extension at 60°C for 1 min. GAPDH mRNA was used as an internal control to standardize the amount of sample mRNA. A validation experiment demonstrated approximately equal efficiencies of the target and reference. Thus, the relative expression of real-time PCR products was determined using the ΔΔCt method that compares the mRNA expression levels of the target gene and the housekeeping gene (32, 33). One of the control samples was chosen as a calibrator sample.

### *Statistical analysis*

Differences in the score of tissue inflammation, number of necrotic muscle fibers, number of migrated cells, and relative expression levels of TNF-α, IFN-γ, and perforin between control Ab- and anti-mouse CX3CL1 mAb-treated EAM mice, and the relative expression levels of TNF-α, IFN-γ, and perforin between normal and EAM mice were examined for statistical significance using Mann-Whitney's *U* test. All data were expressed as the

mean ± SEM. The difference between two groups of mice was considered significant at $p < 0.05$.

## Results

### *Development of EAM*

SJL/J mice were immunized with purified rabbit myosin fraction and CFA on days 0, 7, and 14. On days 0, 7, 14, and 21, the quadriceps femoris muscles of these mice were histologically examined with H&E staining. All muscle specimens of normal SJL/J mice and immunized mice on day 7 showed normal appearance with no inflammatory changes (Fig. 1, *A* and *B*, respectively), whereas those of mice immunized with rabbit myosin fraction showed mild mononuclear cell infiltration at day 14 (Fig. 1*C*). On day 21, a significant number of mononuclear cells were infiltrated among the muscle fibers (endomysium; Fig. 1*D*), at perivascular areas (perimysium; Fig. 1*E*), and epimysium (Fig. 1*F*). Scattered lesions with aggregates of infiltrated mononuclear cells were formed, in which atrophic or necrotic muscle fibers were noted (arrow in Fig. 1*D*). Injection of PBS and CFA into SJL/J mice did not show infiltration of inflammatory cells in the quadriceps femoris muscles (data not shown).

To determine the subsets of infiltrating mononuclear cells in the quadriceps femoris muscles of EAM mice, we performed immunohistochemical analysis using mAbs against CD4, CD8, and F4/80. $CD4^+$ T cells were mainly located in the perimysium and some were found in the endomysium (Fig. 2*A*). $CD8^+$ T cells were predominantly detected in the endomysium and surrounded nonnecrotic muscle fibers (Fig. 2*B*). $F4/80^+$ macrophages were located in the endomysium as well and were especially present around the necrotic muscle fibers (Fig. 2*C*). Because these histological findings of inflammatory cell infiltration patterns resembled those of affected muscle lesions in IIM patients (34–36), we decided to use the EAM mice as an experimental model of IIM.

To evaluate a time course of cellular infiltration into the muscles, we counted the numbers of infiltrated $CD4^+$, $CD8^+$, and $F4/80^+$ cells on days 0, 7, 14, and 21 by immunohistochemical method. The majority of the infiltrating cells on day 14 were $F4/80^+$ macrophage (Fig. 3). In contrast, the number of $CD4^+$ and $CD8^+$ T cells was not increased until day 14, and they had significantly migrated into the muscles on day 21. These results were similar to previously reported data (37).

### *CX3CL1 and CX3CR1 expression in the muscle of EAM mice*

We examined the expression of CX3CL1 in the muscle of normal SJL/J mice and EAM mice by immunohistochemistry. In the quadriceps femoris muscles of normal mice, no CX3CL1 expression was detected (Fig. 4, *A* and *G*). In contrast, CX3CL1 was expressed on infiltrated mononuclear cells predominantly in the endomysium and vascular endothelial cells of EAM mice on day 14 (Fig. 4, *B* and *H*, respectively) and day 21 (Fig. 4, *C* and *I*, respectively).

We next examined the expression of CX3CR1 on the infiltrated mononuclear cells in the quadriceps femoris muscle of EAM mice by double immunohistochemical staining. Some $CD4^+$ T cells expressed CX3CR1 (Fig. 5, *A–C*). The majority of $CD8^+$ T cells and most of the $F4/80^+$ macrophages expressed CX3CR1 (Fig. 5, *D–F* and *G–I*, respectively).

### *Effect of anti-mouse CX3CL1 mAb on EAM mice*

To analyze the effect of anti-CX3CL1 mAb administration on EAM mice, we evaluated the histological changes in quadriceps femoris muscle using H&E staining. The incidence of inflammatory cell infiltration in control Ab-treated mice was 100% ($n = 10$). Treatment with anti-CX3CL1 mAb did not change the incidence of cellular infiltration (100%; $n = 10$). EAM mice treated with control Ab showed mononuclear cell infiltration with atrophy and necrosis of muscle fibers (Fig. 6*A*). In comparison, anti-CX3CL1 mAb-treated EAM mice showed milder histological changes (Fig. 6*B*). Analysis of histological scores of inflammatory changes in the quadriceps femoris muscles indicated that treatment with anti-CX3CL1 mAb significantly reduced inflammatory cell infiltration in the muscles of EAM mice compared with treatment with control Ab (Fig. 6*C*). Moreover, anti-CX3CL1 mAb treatment reduced the number of necrotic muscle fibers in muscles (Fig. 6*D*). A similar result was obtained in another independent set of experiments.

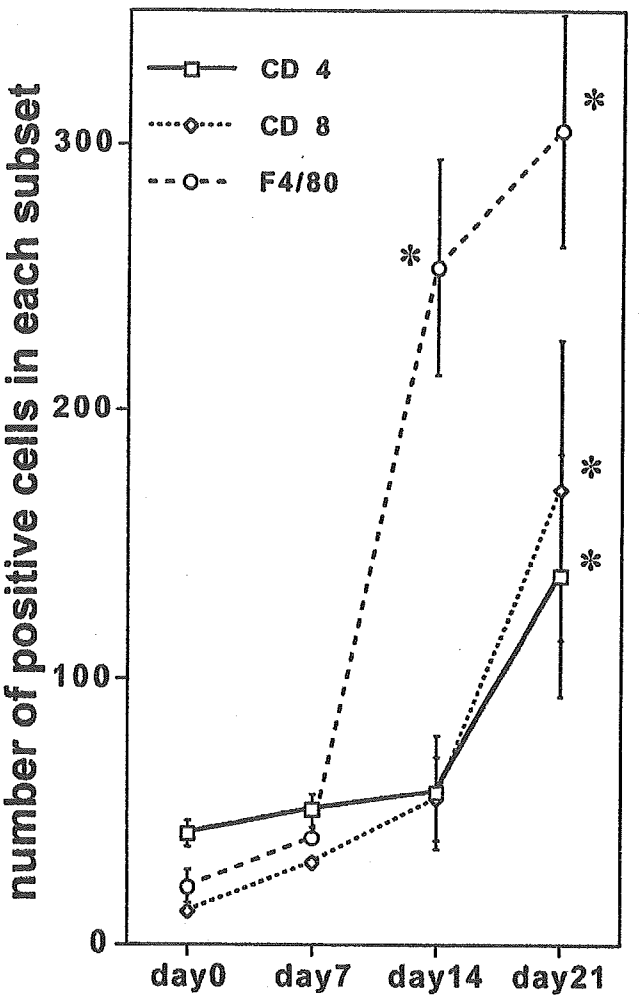


**FIGURE 3.** Time course of inflammatory cell infiltration into the muscle tissue of EAM mice. The numbers of infiltrating $CD4^+$, $CD8^+$, and $F4/80^-$ cells into the quadriceps femoris muscles were counted by immunohistochemistry. Data represent the mean ± SEM. *, $p < 0.05$.

We next examined the effect of anti-CX3CL1 mAb treatment on the numbers of each subset of infiltrating cells. The numbers of $CD4^+$, $CD8^+$, and $F4/80^+$ cells in quadriceps femoris muscles were counted and compared between mice treated with control Ab and those with anti-CX3CL1 mAb. Anti-CX3CL1 mAb treatment significantly reduced the number of infiltrated $CD4^+$ T cells by ~30% (Fig. 7*A*), $CD8^+$ T cells by ~50%, and $F4/80^+$ macrophages by up to 50% (Fig. 7, *B* and *C*).

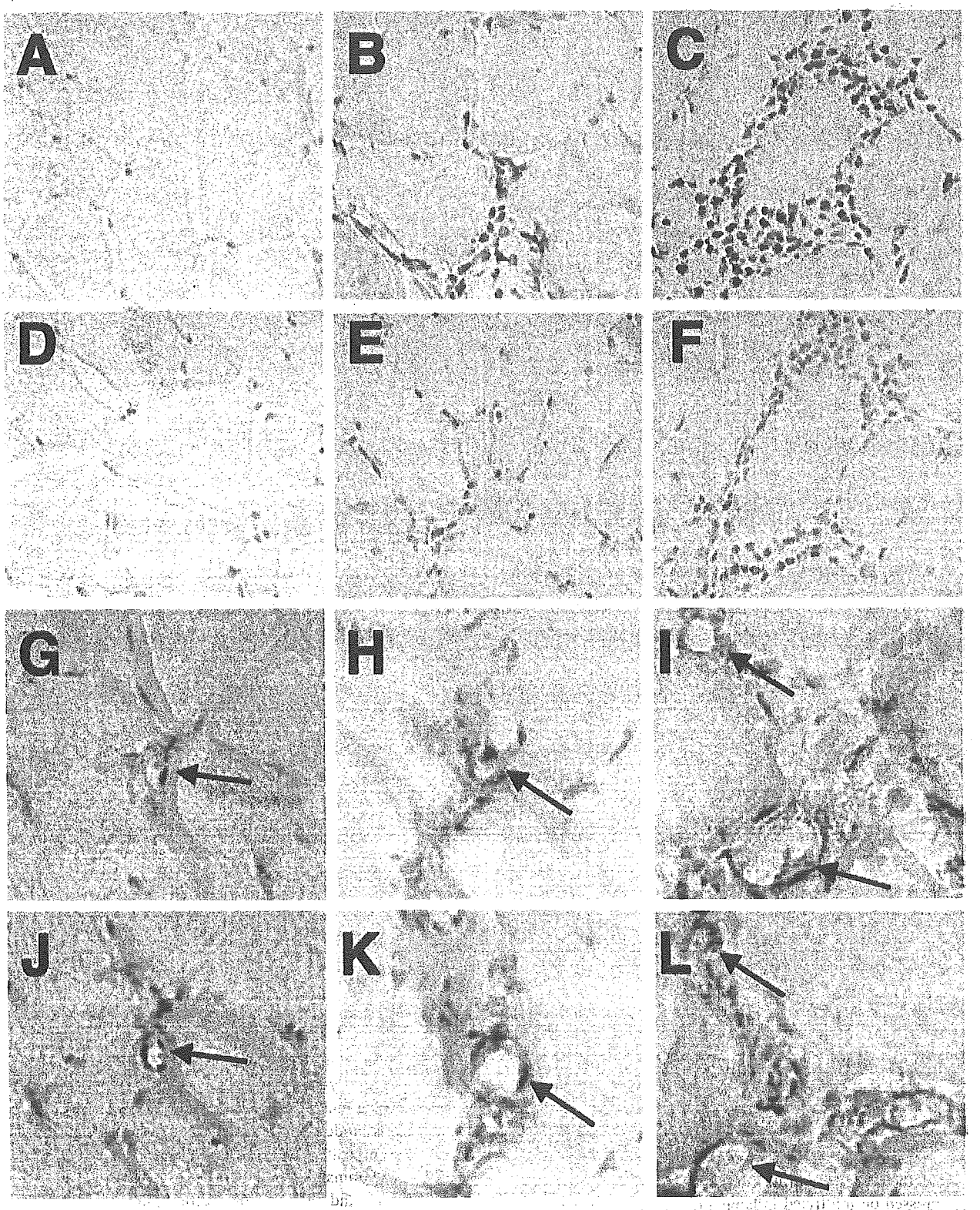


**FIGURE 4.** CX3CL1 expression in the muscles of EAM mice. Expression of CX3CL1 was examined by immunohistochemistry in normal mice (*A* and *G*) and EAM mice on day 14 (*B* and *H*) and day 21 (*C* and *I*). Vascular endothelial cadherin expression in the normal mice (*J*) and EAM mice on day 14 (*K*) and 21 (*L*) was also examined using serial sections with *G*, *H*, and *I*, respectively. Stainings with isotype control Ab for CX3CL1 are shown (*D*, normal mice; *E*, EAM on day 14; *F*, EAM on day 21). Arrows indicate vascular endothelial cadherin-positive endothelial cells (*J–L*), and corresponding endothelial cells (*G–I*). Original magnification, ×400.

We finally examined the effects of anti-CX3CL1 mAb treatment on the expression of cytokines and cytotoxic molecule in the quadriceps femoris muscle of EAM mice by quantitative RT-PCR. Although the relative quantities of TNF-$\alpha$, IFN-$\gamma$, and perforin mRNA were very low in normal SJL/J mice, they were significantly up-regulated in EAM mice that received control Ab treatment ($p < 0.05$). Furthermore, treatment with anti-CX3CL1 mAb strikingly reduced mRNA expression (Fig. 8).

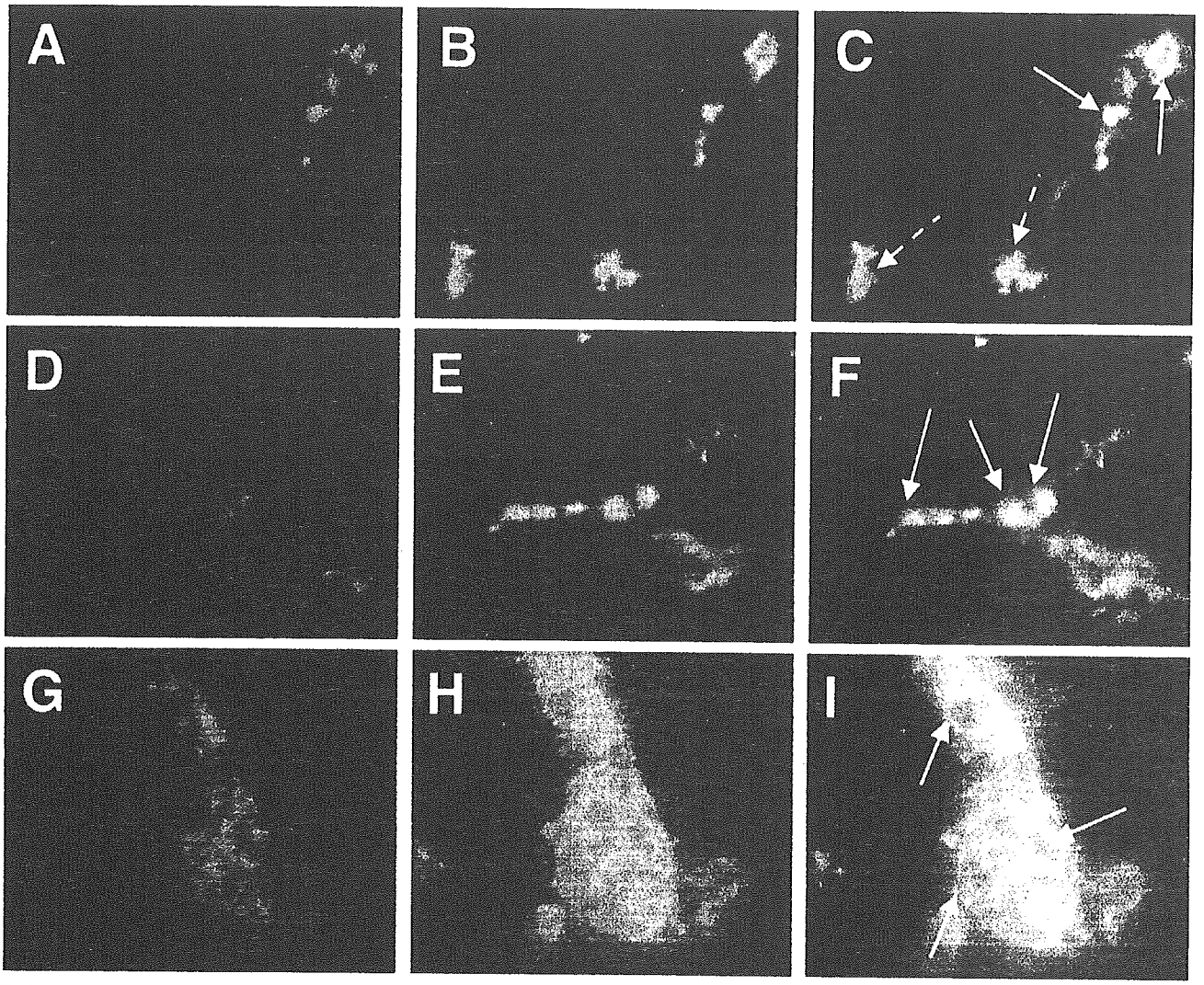


**FIGURE 5.** CX3CR1 expression on $CD4^+$, $CD8^+$, or $F4/80^+$ cells in the EAM muscle. Muscle tissues from EAM mice were double stained with CD4, CD8, or F4/80, and CX3CR1, and analyzed with fluorescent microscopy (*A*, CX3CR1; *B*, CD4; *C*, merged *A* and *B*; *D*, CX3CR1; *E*, CD8; *F*, merged *D* and *E*; *G*, CX3CR1; *H*, F4/80; *I*, merged *G* and *H*). Solid arrows indicate double-positive cells. Dotted arrows indicate CX3CR1-negative CD4 T cells. Original magnification, ×200.

Considered together, the above results indicate that treatment with anti-CX3CL1 mAb reduced infiltration of CD4 and CD8 T cells and macrophages and reduced the expression of various inflammatory cytokines and cytotoxic molecule in muscles.

## Discussion

The major findings of the present study were the following. 1) CX3CL1 was expressed on infiltrated mononuclear cells and vascular endothelial cells, and its corresponding receptor, CX3CR1, was expressed on infiltrated inflammatory cells in the muscles of EAM. 2) Treatment with anti-CX3CL1 mAb ameliorated histological inflammatory changes in EAM mice, reduced the numbers of infiltrated CD4 and CD8 T cells and macrophages, and reduced the expression of TNF-$\alpha$, IFN-$\gamma$, and perforin in the muscles. These results suggest that CX3CL1-CX3CR1 interaction seems to play an important role in inflammatory cell migration into the muscles of EAM mice.

Development of EAM in SJL/J mice by immunization with rabbit purified skeletal myosin fraction and CFA was previously reported (37–40). We modified the method by increasing the amount of immunized myosin and CFA and the addition of *Mycobacterium butyricum*. This modification shortened the period required for the development of myositis from 5 wk, which was thought to be appropriate for the induction (38), to 3 wk. Moreover, although pertussis toxin (PTX) injection into the peritoneal cavity increased the severity of inflammatory changes in the muscle (31), and thus, PTX was administered in the previous models (31, 36, 38), our modified method induces significant myositis without PTX injection. The EAM mice showed inflammatory cell infiltration in the endomysium, perimysium, and epimysium with muscle fiber necrosis. Immunohistochemical analysis showed that the invading cells surrounding nonnecrotic muscle fibers in the endomysium were mainly CD8 T cells, whereas macrophages were predominantly detected in necrotic fibers, and CD4 T cells were located in perimysium. Moreover, quantitative RT-PCR showed up-regulation of expression of TNF-$\alpha$, IFN-$\gamma$, and perforin mRNA in the muscle of EAM mice. These findings in EAM mice are similar to those reported in IIM patients (4–8, 34–36).

Inflammatory cell migration into the affected muscle of IIM is thought to involve chemokine-chemokine receptor interaction

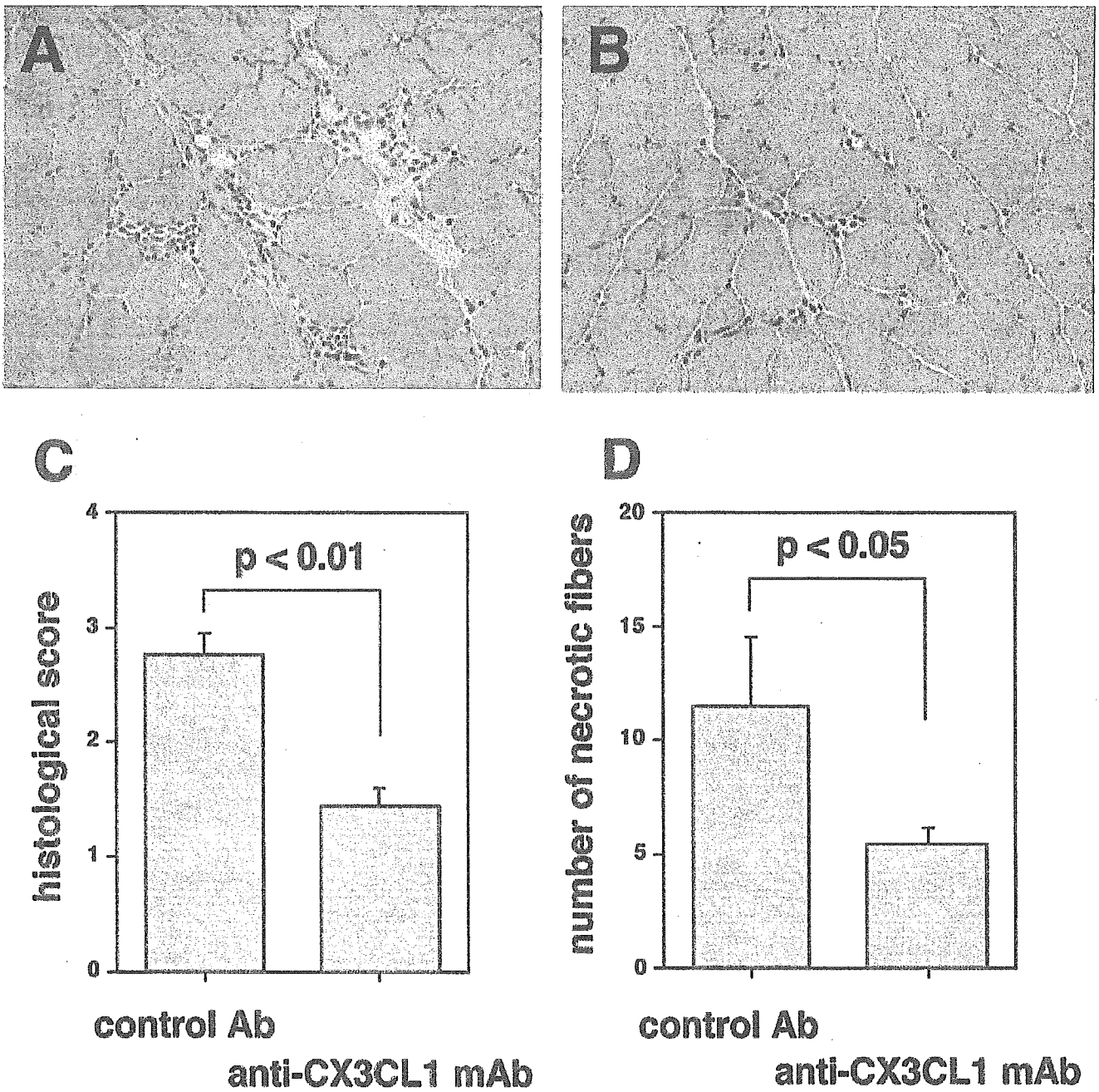


**FIGURE 6.** Inhibition of inflammatory changes in the muscle by treatment with anti-CX3CL1 mAb. Five hundred micrograms of hamster anti-mouse CX3CL1 mAb or control Ab was injected into the peritoneal cavity three times per week from day 0 for 3 wk. On day 21, the quadriceps femoris muscles of EAM mice were examined with H&E staining, histological scores were evaluated, and the numbers of necrotic fibers were counted. Mice treated with control Ab showed inflammatory cell accumulation (*A*). Mice treated with anti-CX3CL1 mAb showed milder inflammatory changes (*B*). Representative photomicrographs of histology from 10 animals in each group are shown. Histological scores of inflammatory changes in quadriceps femoris muscles were evaluated (*C*). The numbers of necrotic fibers were counted in the muscle tissues (*D*). Data represent the mean ± SEM.

(9–14). In the present study we focused on the role of CX3CL1-CX3CR1 interaction in the inflammatory cell migration. We showed the expression of CX3CR1 on some CD4 T cells and most CD8 T cells in EAM mice. It has been reported that CTLs including both $CD4^+$ and $CD8^+$ T cells invade the muscle fibers in IIM patients (3). These cells possess cytotoxic molecules, such as perforin and granzyme B, which are released into muscle cells (4, 5). Furthermore, type 1 cytokines, such as TNF-$\alpha$ and IFN-$\gamma$, were expressed in the inflammatory lesions of IIM patients (6–8). These findings suggest that the cytotoxic molecules and type 1 cytokines play important roles in the inflammatory lesions in IIM patients. In contrast, we reported previously that peripheral blood $CX3CR1^+$ T cells express cytotoxic molecules and type 1 cytokines (26, 27). Therefore, the interaction of CX3CL1 and CX3CR1 could induce the migration of T cells, which express cytotoxic molecules and type 1 cytokines, into the affected muscles.

The infiltrated macrophages into the affected muscle also express inflammatory cytokines (9, 41). They express TNF-$\alpha$ and IL-1$\beta$, which could stimulate T cells, macrophages, and

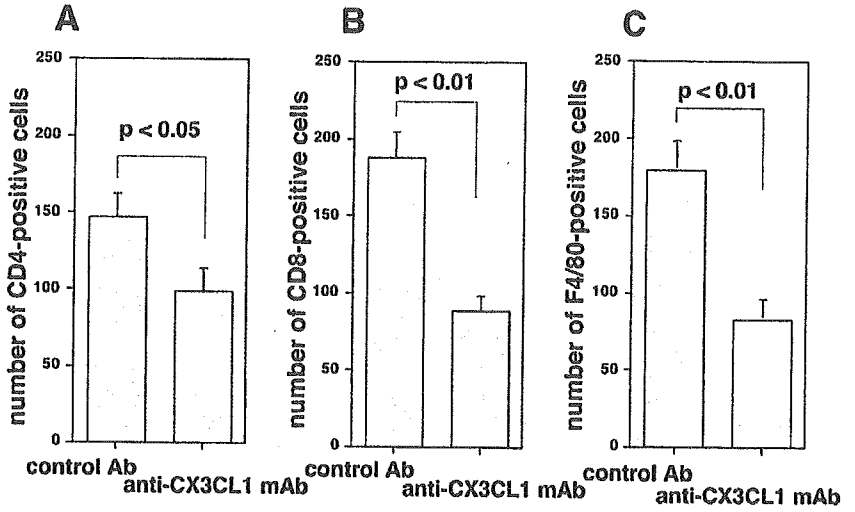


**FIGURE 7.** Decreased numbers of infiltrating cells of each subset by anti-CX3CL1 mAb treatment. Numbers of infiltrating $CD4^+$, $CD8^+$, and $F4/80^+$ cells were counted in the quadriceps femoris muscles from the experiment shown in Fig. 6. Data represent the mean ± SEM.

endothelial cells to produce various inflammatory cytokines, chemokines, and adhesion molecules. Moreover, these cytokines might have myocytotoxic effects (42–44). Our results showed that the majority of the $F4/80^+$ macrophages expressed CX3CR1 in the muscle of EAM mice. Thus, the CX3CL1-CX3CR1 interaction might also play an important role in macrophage migration into the affected muscle in addition to T cell migration.

CX3CL1 was expressed on infiltrated mononuclear cells in the affected muscles of EAM mice. Because CX3CL1 expression was located in the endomysium, infiltrated macrophages and/or CD8 T cells may express CX3CL1 in the muscles. Furthermore, we showed that CX3CL1 was also expressed on vascular endothelial cells in the EAM muscle tissue on days 14 and 21, but not in normal mice. It was reported that CX3CL1 was expressed on endothelial cells activated with TNF-α and IFN-γ in vitro (19–21). Expressed CX3CL1 on endothelial cells might recruit $CX3CR1^+$ cells, including macrophages and T cells, into muscle. These cells, in turn, express TNF-α and IFN-γ, which induce additional CX3CL1 expression on endothelial cells and also on recruited inflammatory cells. The enhanced expression of CX3CL1 may induce additional inflammatory cell migration. Consequently, these amplification cascades could contribute to the expansion of pathological changes in EAM mice. In fact, inhibition of CX3CL1 reduced the numbers of migrated CD4 and CD8 T cells and macrophages in the affected muscles of EAM mice and also reduced the expression of TNF-α, IFN-γ, and perforin. These results suggest that CX3CL1 blockade reduces the migration of inflammatory cells, which express cytotoxic molecules and cytokines, into the muscles. Thus, inhibition of CX3CL1-CX3CR1 interaction might be a potentially suitable therapeutic strategy for treatment of IIM.

Our data showed that mRNA expression of TNF-α, IFN-γ, and perforin was almost totally inhibited by anti-CX3CL1 mAb treatment, although the numbers of infiltrated monocytes were decreased by up to 50%. Recently it was reported that stimulation with CX3CL1 enhanced production of proinflammatory cytokines such as IFN-γ as well as the release of cytolytic granules by T cells (45). Thus, blockade of CX3CL1 might inhibit not only cellular migration, but also cytokine and cytotoxic molecule expression, by stimulation with CX3CL1 in the EAM muscle. Alternatively, because $CX3CR1^+$ T cells express type 1 cytokine and cytotoxic molecules (23, 26, 27), and $CX3CR1^{high}$ positive monocytes greatly produce inflammatory cytokines compared with $CX3CR1^{low}$ positive monocytes (46–48), treatment with anti-CX3CL1 mAb may selectively inhibit the migration of such specific T cells and macrophages. Therefore, anti-CX3CL1 mAb might be able to inhibit the expression of cytokine and cytotoxic molecules effectively in muscles, but additional study is required.

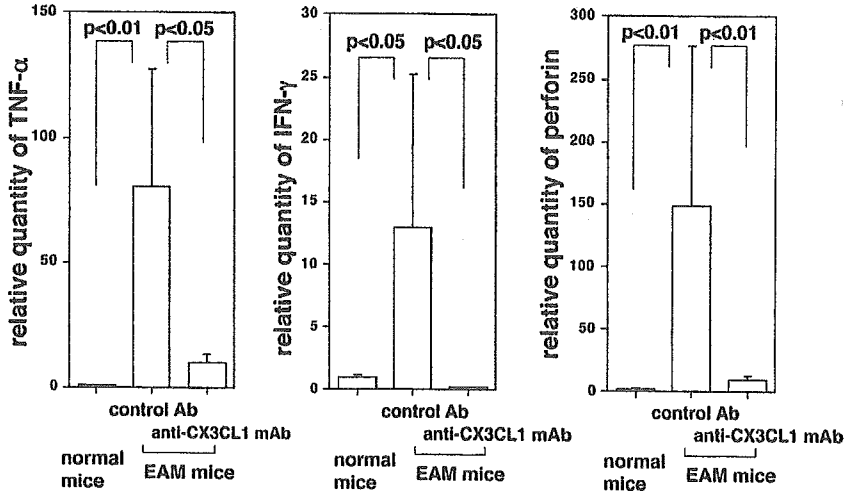


**FIGURE 8.** Reduction of TNF-α, IFN-γ, and perforin expression by anti-CX3CL1 mAb treatment. Expression of TNF-α, IFN-γ, and perforin mRNA in quadriceps femoris muscles from normal mice ($n$ = 10) and from the experiment shown in Fig. 6 were measured using real-time RT-PCR. Data represent the mean ± SEM.

We recently reported that inhibition of CX3CL1 ameliorated collagen-induced arthritis in mice, probably by suppression of inflammatory cell migration into the synovium (30). Others reported that anti-CX3CR1 Ab treatment blocked inflammatory cell infiltration in the glomeruli, prevented crescent formation, and improved renal function in the Wistar-Kyoto crescentic glomerulonephritis model (49). Furthermore, the gene deletion of CX3CR1 resulted in an ~50% decrease in the formation of atherosclerotic lesions and the number of infiltrated macrophages in the lesion in experimental atherosclerosis mice (50, 51). These results together with our findings suggest that blockade of CX3CL1-CX3CR1 interaction might be therapeutically useful for several diseases associated with inflammatory cell infiltration. In this study we propose that such treatment is also suitable for IIM. To our knowledge, this is the first report demonstrating that a chemokine inhibitor could reduce the severity of myositis.

In conclusion, we demonstrated in the present study that inhibition of CX3CL1 significantly improved histopathological changes in the muscles of EAM mice, suggesting that blockade of CX3CL1 might be therapeutically beneficial for IIM.

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## Disclosures

The authors have no financial conflict of interest.

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免疫学的検査/自己免疫関連検査

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# 抗Sm抗体

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## 異常値の出るメカニズムと臨床的意義

抗Sm抗体は全身性エリテマトーデス(SLE)患者の血清に見いだされて報告された自己抗体で，発見の由来となった患者名Smithの初めの2文字が冠されている．以前よく用いられた受身血球凝集(PHA)法による抗ENA抗体測定でRNase抵抗性抗体として検出される 抗核抗体(anti-nuclear antibody：ANA)の1つである．

この抗体は，細胞核内のRNA/リボ核蛋白複合体である核内低分子リボ核蛋白(small nuclear ribonucleoprotein：sn-RNP)分子のうちのU1，U2，U4/6，U5RNPと反応する．抗体結合蛋白はこれらの蛋白の共通構成成分であるB/B'，D1，D2，D3，E，F，Gなどの蛋白である．なかでもB/B'，D1，D3が認識されていることが多く，E，F，G蛋白はnativeな形でのみ認識される．

そもそもリボ 核蛋白は核内でRNAの成熟に関与する重要な蛋白である．しかし，この抗体をもつ患者の臨床症状がリボ核蛋白機能の障害に基づくわけではない．代わりに，この抗体はSLE診断の補助としての重要な臨床的意義をもつ．

この自己抗体が産生されるメカニズムは不明であるが，D蛋白とEpstein-Barr(EB)ウイルスのEBNA蛋白に分子上の相同性が認められるため，EBウイルス感染が契機であるとするものもいる．

## 臨床上の重要性と選択

●代表的なANAであり，原則として蛍光抗体法によるANA陽性例にのみ見いだされる．斑紋型(speckled pattern)に核が染色される例が多い．

● SLE患者に特異性が高く見いだされ，アメリカリウマチ学会によるSLEの分類基準にも組み入れられている．

● SLEの症状の中では腎症状，中枢神経症状の重症度との関連も報告されたが，これを否定する報告もあり，決定的なものはない．

●一方で，疾患活動性の高い症例で陽性になることが多く，そのために，疾患活動性が高いことにより，自己抗体が多クローン性に産生される状態で陽性になるという解釈がある．

## 正常と異常の判断

二重免疫拡散(DID)法では陰性．ELISA法では7.0 index未満(判定保留7.0～30.0 index)，陽性30.0 index以上．ELISA法にも種々の方法があり，一概にいえないものの，二重免疫拡散法より感度に勝るが，特異度に劣ると考えられている．

RNase抵抗性ENA抗体としては，PHA法で40倍以下である．

●生理的変動はない．

## 異常を示す疾患・病態

SLE患者の15～30%ほどに陽性とされる．陽性率には人種差が認められ，アフリカ系アメリカ人に多い．疾患特異性は極めて高く，他に陽性となるのはSLEの病態を包含する混合性結合織病やオーバーラップ症候群(10～20%程度)である．稀にSjögren症候群や強皮症などその他の膠原

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病や未分類膠原病でも陽性になることもある．

SLEでこの抗体が陽性の場合は，疾患活動性が高いことが多く，陰性となるまで月1度程度のフォローアップが望まれる．

## 関連検査

抗γ-グロブリン血症を持つ症例では，ELISA法で境界値ないし弱陽性を呈することがある．この際にはDID法で確認する必要がある．また，ほとんどの抗Sm抗体陽性血清は抗U1RNP抗体をもつ．初めにSm抗体が陽性になり，SLEの経過とともに抗U1RNP抗体が陽性となる例もあるものの，基本的に抗U1RNP抗体陰性例では抗Sm抗体陽性の判定に慎重であるべきである．

真の抗Sm抗体陽性例ではSLEを疑い，検査として抗DNA抗体，血清補体価，免疫複合体などの測定を行うべきである．

## 検査費用と保険請求

保険適用あり(保険点数は免疫拡散法，ELISA法ともに190点)．


文献

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免疫学的検査/自己免疫関連検査

# 抗Scl-70抗体

上阪　　等

medicina

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# 抗 Scl-70 抗体

上阪　等

## 異常値の出るメカニズムと臨床的意義

抗 Scl-70 抗体は強皮症(scleroderma)に特異的に出現するとして報告された自己抗体である．Scl は sclerodema の略で，70 は抗体の反応する抗原の分子量が 70 kDa であったことに由来する．同じ抗体は，Og 抗体など他の名称でも呼ばれた．その後，対応抗原が細胞核内に存在する DNA トポイソメラーゼⅠであることが明らかになり，さらに分子量も実際は 100 kDa で，当初報告された 70 kDa 蛋白はトポイソメラーゼⅠが部分分解されたものであったことがわかり，近年は抗トポイソメラーゼⅠ抗体と呼ばれることもある．

トポイソメラーゼⅠは二本鎖 DNA の超らせん構造を巻き戻す酵素の１つで，遺伝子発現や複製といった細胞の基本機能にかかわる酵素である．血清中に検出される本抗体が，細胞核内のかかる酵素を抑制して症状を起こす可能性はまず考えられない．この抗体も，他の自己抗体の多くと同様に，産生メカニズムは不明である．しかしながら，強皮症の診断や予後の推定に役立つ重要な自己抗体である．

## 臨床上の重要性と選択

● 代表的な抗核抗体(anti-nuclear　antibody：ANA)であり，蛍光抗体法による ANA 陽性例にのみ見いだされる．蛍光抗体法では，均質型(homogenous　pattern)に近い斑紋型(speckled pattern)を呈することが多い．

● 強皮症に特異性が極めて高く，他の膠原病や強皮症患者近親の健常者でも陽性になることはまずないと考えてよい．

● ことに皮膚硬化が肘を越えた近位部にも拡がるびまん性皮膚硬化型の強皮症に高頻度に認められ，進行性の肺線維症などの内臓病変を合併する頻度も高いとされる．

## 正常と異常の判断

二重免疫拡散(DID)法では陰性．ELISA 法では 16.0 index 未満(判定保留 16.0～24.0 index)，陽性，24.0 index 以上

ELISA 法は，従来，DID 法より感度に劣るとされてきたが，改良が進んでいる．ただし，ELISA 法の特異度は低いことが多く，方法によっては全身性エリテマトーデス(SLE)症例の 25%や C 型ウイルス肝炎患者で陽性だったとする報告もある．したがって，ELISA 法で低力価陽性の場合には解釈に注意を要する．

● 生理的変動についての報告はない．

## 異常を示す疾患・病態

強皮症患者全体の 20～40%程度に陽性であるが，びまん性皮膚硬化型に限れば 40～50%に達し，限局型では 10 %程度である．その反面，他の疾患ではほとんど陰性である．病初限局型の皮膚硬化を持つ症例でも，本抗体陽性者の場合には長期的には皮膚硬化範囲が拡大しやすい．

抗 Scl-70 抗体陽性の強皮症例では，肺線維症が重症化しやすいとされる．肺線維化を伴う症例の半分程度までが本抗体陽性ともいわれ，また本抗体陽性例は肺機能の長期予後が悪いという．た

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だし，最近のメタ解析では，本抗体と肺線維化の関連は従来ほど高くはないとの結果もある．

また，本抗体陽性例は陰性例に比べて死亡率が高く，おそらく肺疾患が原因となった心不全が多いことを反映していると考えられている．一方，腎クリーゼ発症や癌合併との関連を報告したものもあるが，これらを確認できた報告はない．

稀に，特発性間質性肺炎や逆流性食道炎とされている症例に，抗 Scl-70 抗体を認めることがある．これらの症例も経過を追うと皮膚硬化が現れることが多く，内臓病変の先行した強皮症ととらえられる．また，Raynaud 現象のみを症状とする患者も，本抗体陽性例では将来的に強皮症を発症する危険性が高い．

なお，皮膚硬化や肺線維化の軽い強皮症症例で，経過とともに抗 Scl-70 抗体が陰性化したという報告もあるが，患者の大多数は，診断時に陽性であれば，経過を通じて陽性であり，また陰性例が陽性化することもほとんどない．さらに，抗体価が疾患活動性を反映することもない．したがって，定期的にフォローアップすべき抗体ではない．

## 関連検査

同じく強皮症患者に見いだされる抗セントロメア抗体は，CREST 症候群など限局皮膚硬化型の症例に陽性になることが多い．この抗体は，蛍光抗体法では特徴的な散在斑点型(discrete speckled pattern)を呈する ANA として検出される．

ただし，抗セントロメア抗体が抗 Scl-70 抗体と共存することは稀で，抗 Scl-70 抗体陽性例のうちの 0.5%しか抗セントロメア抗体を持っていなかったという統計もある．

## 検査費用と保険請求

保険適用あり(保険点数は免疫拡散法，ELISA 法ともに 170 点)．

### 文献

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# 44 治療戦略 バリエーション①：悪性関節リウマチ（血管炎合併）

## ■ポイント

◎血管炎をはじめとする関節外症状を認め，難治性もしくは重篤な臨床病態を伴う関節リウマチ（RA）を悪性関節リウマチ（MRA）と定義する。

◎全身動脈型（Bevans型）と末梢動脈型（Bywaters型）に分けられる。

◎血管閉塞に起因する組織障害を管理することが治療上重要である。

## ■定義，概念

1954年にBevansが激しい関節外症状（胸膜炎，心外膜炎，肺の肉芽腫病変，腎病変など）と全身の壊死性血管炎を認め，急激に死に至った2例のRA患者をMRAとして報告した（Bevans M：*Am J Med* 16：197-211，1954）。その後，欧米では，MRAという用語はほとんど使われなくなり，こうした症例はrheumatoid vasculitisとして扱われている。本邦では1973年より厚生省（現厚生労働省）研究班により，調査研究が進められ，「血管炎をはじめとする関節外症状を認め，難治性もしくは重篤な臨床病態を伴うRA」と定義されている。

## ■病因，疫学

RAと同様に本症の病因は明らかでない。RAの家族歴が12％にみられ，RAよりも強くHLA-DR4との相関を認めることより，発症に遺伝的素因の関与が推定される。MRAでは，リウマトイド因子の陽性率が高く，免疫複合体が高値で，低補体血症を示すことが指摘され，免疫異常が強く病因と関与すると考えられてきた。免疫グロブリンクラス別リウマトイド因子では，IgGクラスリウマトイド因子が高率で，血管炎への関与が示唆されている。

本邦でのMRAの頻度は，RAの0.6～0.8％とされ，1993年の全国疫学調査による推定患者数は，4200人である。男女比は1：2とRAに比して男性に多く，年齢は50～60歳とRAに比して高齢である。MRAは罹病期間の長いRAに多い。

## ■症　状

MRAの臨床病型は，全身動脈型（Bevans型），末梢動脈型（Bywaters型）と肺臓炎型に分類される（**表1**）。全身動脈型（Bevans型）は，発熱，体重減少，浮腫，皮下結節，紫斑，筋痛，筋力低下，胸膜炎，心膜炎，多発性単神経炎，消化管出血，上強膜炎など，全身の諸臓器を

〈表1〉MRAの臨床病理学的分類

| | | 病理学的特徴 | 臨床的特徴 | 予後 |
|---|---|---|---|---|
| 血管炎型 | A. 全身動脈型 | 内臓を系統的に障害 | 胸膜炎，心膜炎<br>肺臓炎，心筋炎 | 不良 |
| | B. 末梢動脈型 | 四肢末梢および皮膚を障害 | 多発性神経炎，皮膚潰瘍<br>指壊疽，上強膜炎<br>皮下結節，皮膚出血 | 良好 |
| 非血管炎型 | C. 肺臓炎型 | 肺臓を障害 | 肺臓炎，間質性肺炎 | 不良 |
| | D. 全身性感染症その他 | | | 不良 |

（京極方久 他：リウマチ 15：483-487，1975より改変）

〈表2〉RAとMRAの臨床像の比較

| 症　状 | RA (*n*=227) | MRA (*n*=169) | 有意差 (*P*) |
|---|---|---|---|
| 女性頻度 | 78.9 | 71.6 | |
| definite以上RA | 99.6 | 99.4 | |
| 滲出性胸膜炎 | 2.8 | 28.7 | $P<0.01$ |
| 心嚢炎 | 0.5 | 15.3 | $P<0.01$ |
| 心筋炎 | 0 | 3.3 | |
| 肺臓炎，間質性肺炎，肺線維症 | 14.2 | 48.2 | $P<0.01$ |
| 筋萎縮，筋力低下 | 18.6 | 35.2 | $P<0.05$ |
| 臓器梗塞（腸，心筋など） | 0.9 | 15.0 | $P<0.01$ |
| 多発性単神経炎 | 0.9 | 37.3 | $P<0.01$ |
| 皮膚梗塞 | 0 | 18.5 | $P<0.01$ |
| 皮膚潰瘍 | 0.5 | 33.7 | $P<0.01$ |
| 指趾壊疽 | 0 | 15.1 | $P<0.01$ |
| 皮下結節 | 17.0 | 67.9 | $P<0.01$ |
| 紫斑，出血 | 5.5 | 34.5 | $P<0.01$ |
| 上強膜炎 | 0.9 | 26.5 | $P<0.01$ |
| 虹彩炎 | 0 | 7.1 | $P<0.025$ |
| 発熱，体重減少，下腿浮腫 | 26.6 | 73.3 | $P<0.01$ |

（厚生省（現厚生労働省）系統的脈管障害調査研究班 1986年度研究報告書．p33より）

系統的に急速に障害し，予後不良である。組織学的には，結節性多発動脈炎型血管炎（Kussmaul-Maier型血管炎）を示す。末梢動脈型（Bywaters型）は，皮膚梗塞，皮膚潰瘍，指尖部壊疽，末梢神経炎などを認める。肺臓炎型は，緩徐進行性の間質性肺炎および肺線維症を特徴とする（表2）。薬剤性肺障害を鑑別する必要がある。

## ■検　査

RAと同様に赤沈亢進，CRP上昇，高ガンマグロブリン血症を認める。白血球数と血小板数は増加し，貧血がみられる。RAに比してリウマトイド因子の陽性率，力価とも高く，IgM型に加え，IgG型リウマトイド因子も認める。免疫複合体は高値で，血清補体価は低下する。ラクトフェリンなど非特異的ANCAと本症が関連するとの報告もある。

## ■診断および鑑別診断

厚生省（現厚生労働省）特定疾患調査研究班により，MRAの改訂診断基準が示されている（表3）。

## ■薬物治療の考え方

MRA治療の基本方針は，①DMARDsを中心としたRAに対する治療は継続する，②関節機能保全の進行に留意する，③MRAが寛解するまで入院治療を原則とし，その上で血管炎などによる関節外症状の治療を行う（松岡康夫：難治性血管炎の診療マニュアル．厚生省（現厚生労働省）難治性血管炎に関する調査研究班，2002，p35-40）。治療反応性の評価は，臨床症状や炎症反応の改善，血清免疫学的異常所見（リウマトイド因子高値，免疫複合体上昇，低補体血症）の改善などに基づいて行う。

### 1）ステロイド

全身動脈型の諸症状に対しては，プレドニゾロン（PSL）40～80mg/日，末梢動脈型では，PSL 20～40mg/日で治療を開始する。血管炎による重篤な臓器症状や進行性間質性肺炎に対しては，ステロイドパルス療法も考慮する。