Multimeric Forms of Tyr–Ile–Gly–Ser–Arg (YIGSR) Peptide Enhance the Inhibition of Tumor Growth and Metastasis

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Introduction

Laminin is a large heteromeric glycoprotein (M₉ 900,000) located in the basement membrane extracellular matrix (1, 2). Laminin has multiple biological activities including promotion of cell adhesion, growth, differentiation, migration, neurite outgrowth, tumor metastasis, and collagenase IV induction. Several active sites on laminin chains were identified using synthetic peptides or proteolytic fragments (3–6). The YIGSR² sequence located on the B1 chain (positions 929–933) has been shown to promote cell adhesion and migration and to inhibit angiogenesis (3, 7–9). The peptide has also been shown to reduce experimental metastasis and s.c. tumor growth (8–13). Recently, a mouse melanoma B16-F10 variant, which was established by selection on YIGSR-coated dishes and adhered more strongly to YIGSR, was shown to form more lung colonies after i.v. injection and larger tumors after s.c. injection than the parent B16-F10 cells (14). These findings suggest that the YIGSR sequence on laminin may regulate tumor growth due to its effects on both angiogenesis and direct tumor cell interactions.

The YIGSR peptide is a potential candidate for development of anticancer and antimetastasis agents, and many modifications of YIGSR peptides have been reported to enhance its activity. Polymerized YIGSR peptides were shown by Murata et al. (12) to more effectively inhibit experimental metastasis than the monomeric peptides. The activity of YIGSR has been also increased by coupling to polyethylene glycol (13). These results suggest that molecular weight of the compound containing the active peptides might be important for enhancement of its activity. On the other hand, the cyclic YIGSR was shown to have increased effectiveness (15), and conformational studies by nuclear magnetic resonance and computer modeling suggest that the turn structure of the peptide may be an important criterion for activity (16). It is not yet clear whether these modifications directly enhance the potency of YIGSR and/or maintain a longer half-life in the circulatory system.

Recently, Tam et al. (17, 18) established the MAP system in which the antigen peptide is assembled on a lysine tree. The branched core lysine structure is located in the interior of the molecule allowing numerous active site peptides on the surface to be accessible for interactions. The MAP approach is suitable for direct preparation of high molecular weight products which can be used as an immunogen without further conjugation procedures. For example, the MAP method has been used successfully for development of many vaccines (18). In addition, MAP peptides seem to possess favorable molecular shapes as synthetic macromolecular mimics.

Using the MAP method, we designed multimeric YIGSR peptides, (CH₃CO–Tyr–Ile–Gly–Ser–Arg–Gly)₁₆–Lys–Lys–Lys–Lys–Gly [(Ac-YIGSRY₂)₁₆, K₉K₉K₉G₂] (designated Ac-Y₁₆), (Ac-YIGSRY₂)₂K₉K₉G (Ac-Y₈), and (Ac-YIGSRY₂)₂K₉K₉G (Ac-Y₄), and related peptides, Ac-(YIGSRY₂)₂NH₂ (Ac-Y₂) and Ac-YIGSRY-NH₂ (Ac-Y₁) and evaluated their biological activities in inhibiting tumor growth and metastasis. Coinjection of 0.2 mg/mouse of Ac-Y₁₆ i.v. with B16-F10 mouse melanoma cells inhibited lung colony formation by 97%, whereas 0.2 mg/mouse of Ac-Y₁ inhibited by 50%. The larger the peptide (Ac-Y₁₆ > Ac-Y₈ > Ac-Y₄ > Ac-Y₁), the more inhibitory effect there was on lung metastasis. Ac-Y₁₆ also inhibited the growth of s.c.-injected B16-F10 tumors. These data demonstrate that the multimeric YIGSR peptides strongly enhanced the activity of YIGSR in inhibiting tumor growth and metastasis and suggest that these compounds are potentially useful for clinical applications.

Materials and Methods

Synthesis of Peptides. The linear peptides [Ac-(YIGSRY₂)₂NH₂ and Ac-Y₁] were synthesized by the solid-phase method using an Applied Biosystems 431 automated peptide synthesizer on tert-butyloxy carbonyl strategy. Deprotection and cleavage from the resin were achieved by treatment with anhydrous HF, and the crude peptides were purified by gel filtration and reverse phase high performance liquid chromatography. The branched peptides (Ac-Y₁₆, Ac-Y₈, Ac-Y₄, H-Y₁₆, and Ac-R₁₆) were synthesized manually by 9-fluorenylmethyloxycarbonyl strategy on /r-v-butyloxycarbonyl strategy. Deprotection and cleavage from the resin were achieved by treatment with trimethylsilyl bromo-thioanisole in trifluoroacetic acid (0°C, 2 h) (19). The crude peptides were purified by either gel filtration or reverse phase high performance liquid chromatography. The branched peptides were examined by sodium dodecyl sulfate-polyacrylamide gel electrophoresis and a major band of the expected molecular size was observed. The identity of the peptides was confirmed by amino acid analysis. The peptides used in this paper are summarized in Fig. 1, and the structure of Ac-Y₁₆ is schematically shown in Fig. 1b.

Cell Culture. B16-F10 mouse melanoma cells (20) (a gift of Dr. I. J. Fidler, M. D. Anderson Hospital, Houston, TX) were cultured in Eagle’s minimum essential medium (GIBCO Laboratories, Grand Island, NY) containing 9% (vol/vol) fetal calf serum (HyClone, Logan, UT), 100 units/ml penicillin, and 100 µg/ml streptomycin (GIBCO).
in a dose-dependent manner (Fig. 3). Coinjection of only 0.2 mg/mouse of Ac-Y16 reduced the number of lung colonies by more than 97%. In contrast, Ac-Y1 (monomeric YIGSR) reduced the number of lung colonies by 50% at the same dose. The increase in the number of YIGSR sequences in the peptides paralleled the inhibitory effect on lung metastasis. A much larger multimere peptide containing 32 YIGSR sequences, however, showed activity comparable to that of Ac-Y16 (data not shown). Therefore, Ac-Y16 seems to have a sufficient number of YIGSR sequences to be maximally effective. The NH₂-terminal acetylated and free multimere peptides, Ac-Y16 and H-Y16, showed similar inhibitory activity suggesting that the NH₂-terminal group of multimere molecules (CH₃CO- or H-) did not affect this activity. Ac-R16 showed a weak inhibitory effect on tumor metastasis when compared to Ac-Y16. This result is identical to a previous study using a GRGDS peptide (8).

Next we studied the antitumorigenic activity of Ac-Y16 and Ac-Y1 in a s.c. tumor model. Ac-Y16 significantly inhibited the s.c. growth of B16-F10 melanoma cells when 0.5 mg/mouse of this peptide was injected i.p. each day for 9 days (Fig. 4). However, Ac-Y1 did not show a significant inhibitory effect at this concentration. Previously, Cys-Asp-Pro-Gly-Tyr-Ile-Gly-Ser-Arg-NH₂ (CDPGYIGSR-NH₂) was shown to inhibit the growth of solid tumors when it was injected at 3 mg/day for 4 days (10). Ac-Y1, therefore, can significantly inhibit the growth of solid tumor if greater amounts are injected. It was previously suggested that this inhibition of tumor growth was due to the antiangiogenic effect of the peptide (10). The enhanced antitumor effect of this multimere YIGSR peptide is also likely caused in part

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**Tumor Inhibition by Multimeric YIGSR Peptides**

(a) Ac-Y16: (Ac-YIGSR)₁₆K₈K₄K₂KG-OH  
H-Y16: (Ac-YIGSR)₁₆K₈K₄K₂KG-OH  
Ac-Y8: (Ac-YIGSR)₈K₄K₂KG-OH  
Ac-Y4: (Ac-YIGSR)₄K₂KG-OH  
Ac-Y₄L: Ac-(YIGSR)₄-NH₂  
Ac-Y1: Ac-YIGSR-NH₂  
Ac-R16: (Ac-GRGDSG)₁₆K₈K₄K₂KG-OH

(b) Ac-Y16

Fig. 1. List of synthetic peptides and multimere YIGSR peptide (a) List of synthetic peptides used. Ac-Y16. (b) Schematic representation of Ac-Y16.

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**Fig. 2. Inhibitory effect of synthetic peptides on the formation of lung tumors.** B16-F10 cells (1 × 10⁶) and a synthetic peptide (0.2 mg) were coinjected into the tail vein of a mouse (C57BL6/N). Seventeen days later, the number of B16-F10 cell colonies in the lung was counted. The number was an average from 5 mice. Bars, SD.

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**Fig. 3. Inhibitory effect of Ac-Y16 at various concentrations on the formation of lung tumors.** Various amounts of Ac-Y16 were coinjected with B16-F10 cells (1 × 10⁶) into the tail vein of a mouse and the number of the tumor colonies was counted as described in Fig. 2. Bars, SD. * values at 0.2 mg/mouse differ significantly from 0.1 mg/mouse (P < 0.05) and 0.05 mg/mouse (P < 0.01).

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**Fig. 4. Effect of Ac-Y16 and Ac-Y1 on growth of tumor after s.c. injection.** B16-F10 cells (1 × 10⁶) were injected s.c. into the right lower back of C57BL6/N mice (day 0). On day 1 to day 9, each peptide (0.5 mg/mouse/day) was injected i.p. daily. On day 10, mice were sacrificed, and the tumors were weighed.

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**Results and Discussion**

Three sizes of multimere YIGSR peptide containing 4, 8, and 16 YIGSR sequences with either free NH₂-terminal amino or NH₂-terminal acetyl group were synthesized and assembled on a lysine tree using the MAP method (17, 18). A glycine residue was used as a spacer between the active sequence and the lysine tree. The Ac-Y16 has a high molecular weight (M₇ 12,554) and is highly branched, most probably with a globular shape (Fig. 1). For comparison with the multimere YIGSR peptides, GRGDS (21) were prepared using the MAP method [(Ac-GRGDSG)₁₆K₈K₄K₂KG (Ac-R16)].

We examined the effect of the multimere peptides on experimental metastasis (Fig. 2). Ac-Y16 inhibited experimental tumor metastasis
by an inhibition of vessel formation. In related work, we have also reported that this peptide binds directly to certain highly malignant tumor cells (14), suggesting additional activities of this peptide on tumor cells.

When the multimeric YIGSR peptides were tested for cell attachment activity using B16-F10 cells, they were more active than the monomeric peptide (Ac-Y1; data not shown). Multimeric peptide, Ac-Y16, also had enhanced attachment activity compared to Ac-Y8, Ac-Y4, and Ac-Y1. Fassina et al. (22) reported that a multimere complementary peptide, which was synthesized using the MAP method, could enhance the binding affinity with the target native peptides by several orders of magnitude.

In this paper, we have described multimere YIGSR peptides prepared by the MAP method and found that these peptides have greater antitumor activities than the original monomeric YIGSR peptide. The MAP approach is advantageous, because the synthetic process is brief and the molecular size is easily controlled. One potential drawback is that the MAP structures may be antigenic but the idea has not been tested yet for the YIGSR peptide. Recently, many active sequences have been identified within large intercellular matrix proteins (e.g., laminin, fibronectin, collagen, thrombospondin, entactin, etc.) (23, 24). Unfortunately, the biological activities of synthetic peptides of active site segments have been often shown to be weak and sometimes too low to be recognized in in vivo experiments. The branched multimere peptide approach described here is useful to enhance the activities of short cell adhesive peptides and to clarify their in vitro and in vivo activities. Furthermore, the multimere YIGSR compounds described here are potentially useful for therapeutic applications as antitumor growth and metastasis agents.

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References

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