Interleukin-18 Synergism with Interleukin-2 in Cytotoxicity and NKG2D Expression of Human Natural Killer Cells

Yuan-Ying Qi, Chao Lu, Ying Ju, Zi-E Wang, Yuan-Tang Li, Ya-Juan Shen*, Zhi-Ming Lu*

Abstract

Natural killer (NK) cells play an important role in anti-tumor immunity. Interleukin (IL)-18 is an immunoregulatory cytokine that induces potent NK cell-dependent anti-tumor responses when administered with other cytokines. In this study, we explored the effects of combining IL-18 and IL-2 on NK cytotoxicity as well as expression levels of the NK cell receptor NKG2D in vitro. Freshly isolated PBMCs were incubated for 48 h with IL-18 and IL-2, then CD107a expression on CD3-CD56+ NK cells was determined by three-colour flow cytometry to evaluate the cytotoxicity of NK cells against human erythroleukemia K562 cells and human colon carcinoma HT29 cells. Flow cytometric analysis was also employed to determine NKG2D expression on NK cells. The combined use of IL-18 and IL-2 significantly increased CD107a expression on NK cells compared with using IL-18 or IL-2 alone, suggesting that the combination of these two cytokines exerted synergistic enhancement of NK cytotoxicity. IL-18 also enhanced NKG2D expression on NK cells when administered with IL-2. In addition, blockade of NKG2D signaling with NKG2D-blocking antibody attenuated the up-regulatory effect of combining IL-18 and IL-2 on NK cytolysis. Our data revealed that IL-18 synergized with IL-2 to dramatically enhance the cytolytic activity of human NK cells in a NKG2D-dependent manner. The results appear encouraging for the use of combined IL-18 and IL-2 in tumor immunotherapy.

Keywords: Interleukin-18 - interleukin-2 - natural killer cells - NKG2D - cytotoxicity

Asian Pac J Cancer Prev, 15 (18), 7857-7861
of IL-18 to patients with advanced cancer can generate a relatively limited anti-tumor efficacy but with no apparent toxicities (Robertson et al., 2008; Tarhini et al., 2009). Because of their divergent but complementary properties, the combination of IL-18 and IL-2 is considered as a viable strategy to induce NK cell-mediated anti-tumor responses (Son et al., 2001). However, the exact regulatory mechanism of combining IL-18 and IL-2 on NK cell function is still not well understood.

In the present study, we investigated the effects of combining IL-18 and IL-2 on cytolytic activity and NKG2D expression of human NK cells in vitro. We assayed NK cytotoxicity by multi-parameter flow cytometry using a marker, lysosomal-associated membrane protein-1 (LAMP-1 or CD107a), which can be expressed on the cell surface following degranulation. We also examined the expression of NKG2D on NK cells by using flow cytometry. We found that IL-18 synergized with IL-2 to promote the cytotoxicity and NKG2D expression of NK cells. The synergistic enhancement of NK cytolysis by both cytokines was significantly attenuated by NKG2D blockade. Therefore, we concluded that IL-18 acted synergistically with IL-2 to enhance NK cell activity at least partly via NKG2D pathway.

Materials and Methods

Cytokines and antibodies

Recombinant human IL-18 (rhIL-18) was purchased from R&D systems (Minneapolis, MN, USA) and rhIL-2 was from Shanghai Sangon Biotech Co., Ltd (Shanghai, China). Both cytokines were reconstituted in sterile distilled water and were endotoxin free. PE-conjugated mouse anti-human CD3, APC-conjugated mouse anti-human CD56, and FITC-conjugated mouse anti-human CD107a monoclonal antibodies were products of BD Pharmingen (San Diego, CA, USA). Alexa Fluor® 488-conjugated mouse anti-human NKG2D monoclonal antibody (mAb) and neutralizing antibody against NKG2D (anti-human NKG2D-blocking mAb, mouse IgG1) were purchased from R&D systems (Minneapolis, MN, USA).

PBMCs isolation and cytokine stimulation

Peripheral blood samples were obtained from healthy donors. Peripheral blood mononuclear cells (PBMCs) were isolated from heparinized venous blood in sterile by Ficoll-Histopaque density gradient centrifugation (Tianjin Haoyang, China). These cells were washed two times with RPMI 1640 medium (Hyclone, Logan, UT, USA) and were resuspended at a density of 1×10⁶ cells/ml in RPMI 1640 medium containing 10% fetal bovine serum (FBS), 100 U/ml streptomycin and 100 U/ml penicillin. The cells were placed in a 96-well sterile cell culture plate (Costar, Corning, NY, USA) and stimulated with various concentration combinations of rhIL-18 (0, 100, 200 ng/ml) plus rhIL-2 (0, 100, 200 U/ml) for 48 h. Three replicate wells were used. All cultures were maintained in a humidified incubator with 5% CO₂ at 37°C.

Assay of CD107a degranulation

Freshly isolated or cytokine-stimulated PBMCs were cocultured with human erythroleukemia K562 cells or human colon carcinoma HT29 cells in a 96-well cell culture plate with an effector/target (E:T) ratio of 10:1. The final volume was 100 µl in each well. The cells were then stained with FITC-conjugated anti-CD107a mAb and incubated for 5 h in a humidified incubator with 5% CO₂ at 37°C. Monensin (eBioscience, San Diego, CA, USA) was added to each well at a final concentration of 2 µmol/l during the last 4 h of the culture to prevent the degradation of CD107a from NK cell surface and ensure the detectability of this marker after stimulation. After 5 h incubation, the cells were stained with PE-conjugated anti-CD3 mAb and APC-conjugated anti-CD56 mAb. CD107a expression on CD3 CD56⁺ NK cells was determined on a FACS Calibur flow cytometer (BD Bioscience, San Jose, CA, USA).

To verify the relationship between NK cytolytic enhancement and NKG2D expression on NK cells, untreated or stimulated PBMCs were pre-incubated with NKG2D-blocking mAb or isotype control IgG for 1 h before the coculture with target cells. Then, CD107a degranulation assays were performed.

Flow cytometric analysis of NKG2D expression

After different stimulations, cells were collected, washed and resuspended in 100 µl staining buffer (PBS with 0.5% BSA and 0.1% sodium azide) at 1×10⁶ cells/ml. Subsequently, these cells were incubated with PE-conjugated anti-CD3 mAb, APC-conjugated anti-CD56 mAb, and Alexa Fluor® 488-conjugated anti-NKG2D mAb at 4°C in the dark for 30 min, washed twice, resuspended in 300 µl staining buffer directly for flow cytometric analysis. NKG2D expression on CD3 CD56⁺ NK cells was examined on a FACS Calibur flow cytometer (BD Bioscience, San Jose, CA, USA).

Statistical analysis

Student’s t test was used to analyze whether there were significant differences in cytotoxicity and NKG2D expression of NK cells between the combined use of cytokines (IL-18 and IL-2) and either cytokine alone (IL-18 or IL-2). A value of p<0.05 was regarded as statistically significant. Statistical analyses were performed by using GraphPad Prism 5 (GraphPad Software, USA).

Results

IL-18 synergized with IL-2 to improve CD107a degranulation of human NK cells in vitro

When cytotoxicity assay was performed against K562 cells, both IL-18 and IL-2 clearly promoted the expression of CD107a on CD3 CD56⁺ NK cells. Compared with using IL-18 or IL-2 alone, the combination of IL-18 (200 ng/ml) and IL-2 (100 U/ml) significantly increased the percentage of CD107a positive NK cells (24.89% versus 4.18% and 5.63%, respectively; p<0.01; Figure 1A). Similar results were also observed when using HT29 cells as targets of cytotoxicity test (Figure 1A). Besides, CD107a expression on the surface of NK cells was up-regulated by IL-18 plus IL-2 in a dose-dependent manner (Figure 1B). Although NK cells might have different sensitivity to K562 and
HT29 cells, our results revealed that IL-18 dramatically enhanced the cytolytic activity of NK cells against these two tumor cells when combined with IL-2.

**IL-18 and IL-2 did not affect the proliferation of human NK cells**

Isolated PBMCs were cultured for 48 h in the presence of IL-18 (200 ng/ml) plus IL-2 (100 U/ml), or either cytokine alone. We observed the effect of combining IL-18 and IL-2 on the expansion of NK cells in vitro by flow cytometric analysis of CD3-CD56+ cell population. As shown in Figure 2, we did not observe significant increases in the percentage of CD3-CD56+ NK cells following different cytokine stimulations. The combined use of IL-18 and IL-2 did not affect the proliferation of human NK cells.

**IL-18 synergized with IL-2 to increase NKG2D expression on human NK cells**

To explore the regulatory mechanism of combining IL-18 and IL-2 on NK cytolysis, we also observed the expression level of NKG2D receptor, which plays a critical role in NK-mediated cytolysis of target cells. Isolated PBMCs were incubated for 48 h with IL-18 (200 ng/ml), IL-2 (100 U/ml) or a combination of both cytokines. Flow cytometric analysis showed that the combined administration of IL-18 and IL-2 significantly enhanced the expression of NKG2D on CD3-CD56+ NK cells in comparison with either IL-18 or IL-2 alone (76.15% versus 59.88% and 65.60%, respectively; p<0.05; Figure 3A and B).

The up-regulatory effect of combining IL-18 and IL-2 on

---

**Figure 1. IL-18 Synergized with IL-2 to Increase CD107a Expression on NK Cells.** (A) Representative graphs of CD107a expression on gated CD3-CD56+ NK cells following no stimulation, stimulation with IL-18 (200 ng/ml), IL-2 (100 U/ml) or a combination of both cytokines. NK cytolysis was assayed against K562 and HT29 cells, respectively. Similar results were observed in three independent experiments. (B) The line charts represent the expression pattern of CD107a on NK cells after the culture with different dose combinations of IL-18 and IL-2. Data are given as the mean±SD from three independent experiments

**Figure 2. IL-18 and IL-2 Did Not Affect the Proliferation of Human NK Cells.** Flow cytometric analysis of the expansion of CD3-CD56+ NK cells following no stimulation, stimulation with IL-18 (200 ng/ml), IL-2 (100 U/ml) or a combination of both cytokines. Representative results of three independent experiments are shown here

**Figure 3. IL-18 Synergized with IL-2 to Enhance NKG2D Expression on NK Cells.** NKG2D expression levels on NK cells determined by flow cytometry were compared following no stimulation, stimulation with IL-18 (200 ng/ml), IL-2 (100 U/ml) or a combination of both cytokines. (A) Representative graphs of NKG2D expression on gated CD3-CD56+ NK cells. (B) The bar graphs represent the expression pattern of NKG2D on NK cells after different stimulations. Data are given as the mean±SD of three independent experiments (*P<0.05 and **P<0.01)
NK cytolysis was NKG2D-dependent

We next blocked NKG2D pathway with anti-NKG2D antibody to investigate the role of NKG2D in the regulation of NK cytotoxicity by IL-18 and IL-2. We observed that the blockade of NKG2D receptor significantly inhibited NK cell-mediated lysis of target cells. The up-regulatory effects of combining IL-18 and IL-2 on NK cytolyis against K562 and HT29 cells were dramatically attenuated by NKG2D blockade (Figure 4). These results suggested that IL-18 synergized with IL-2 to improve the cytolytic activity of NK cells at least partly via NKG2D pathway.

Discussion

NK cells are increasingly considered as potential targets for tumor immunotherapy. Syngeneic IL-12/IL-15/IL-18-pretreated NK cells can proliferate rapidly in tumor tissue and induce sustained anti-tumor effects after adoptive transfer to tumor-bearing mice (Ni et al., 2012). Infusion of continuously growing NK92 cells into patients with lung cancer appears to have some anti-tumor responses without significant side effects (Tonn et al., 2013). Thus, it is necessary to implement a viable strategy to improving NK cell activities so as to strengthen human’s anti-tumor responses.

Both IL-18 and IL-2 are potent activators of NK cell effector function. Although IL-2 has ever been widely used for treatment of patients with advanced cancer, its clinical utility has been greatly limited by the emergence of significant toxicities associated with high-dose or long-term therapy (Atzpodien and Reitz, 2005; Clark et al., 2013). IL-18 is a relatively nontoxic cytokine (Robertson et al., 2008) that promotes the proliferation of activated T cells, activation of NK cells and cytokine production (Srivastava et al., 2013). Du et al. (2012) have constructed a human IL18-IL2 fusion protein and confirmed that this protein can induce significant NK cell-dependent anti-tumor reponses in different tumor-bearing mice models.

To further illuminate the role of combining IL-18 and IL-2 in the regulation of NK cell activity, we first investigated the effects of these two cytokines on NK cytotoxicity. Instead of traditional isotope-release assay, NK cytolyis was determined by flow cytometric analysis of the percentage of CD107a positive NK cells after pre-incubation of isolated or stimulated cells with anti-NKG2D mAb. Data represent the mean±SD of three independent experiments. *P<0.01 versus IgG isotype control group.

Figure 4. NK Cytolytic Enhancement by IL-18 Plus IL-2 was Dependent on the Up-regulatory Expression of NKG2D. NK cytolyis against K562 (A) and HT29 (B) cells was determined by flow cytometric analysis of the percentage of CD107a positive NK cells after pre-incubation of isolated or stimulated cells with anti-NKG2D mAb. Data represent the mean±SD of three independent experiments. *P<0.01 versus IgG isotype control group.

NK cytotoxicity was NKG2D-dependent

We next blocked NKG2D pathway with anti-NKG2D antibody to investigate the role of NKG2D in the regulation of NK cytotoxicity by IL-18 and IL-2. We observed that the blockade of NKG2D receptor significantly inhibited NK cell-mediated lysis of target cells. The up-regulatory effects of combining IL-18 and IL-2 on NK cytolsis against K562 and HT29 cells were dramatically attenuated by NKG2D blockade (Figure 4). These results suggested that IL-18 synergized with IL-2 to improve the cytolytic activity of NK cells at least partly via NKG2D pathway.

Discussion

NK cells are increasingly considered as potential targets for tumor immunotherapy. Syngeneic IL-12/IL-15/IL-18-pretreated NK cells can proliferate rapidly in tumor tissue and induce sustained anti-tumor effects after adoptive transfer to tumor-bearing mice (Ni et al., 2012). Infusion of continuously growing NK92 cells into patients with lung cancer appears to have some anti-tumor responses without significant side effects (Tonn et al., 2013). Thus, it is necessary to implement a viable strategy to improving NK cell activities so as to strengthen human’s anti-tumor responses.

Both IL-18 and IL-2 are potent activators of NK cell effector function. Although IL-2 has ever been widely used for treatment of patients with advanced cancer, its clinical utility has been greatly limited by the emergence of significant toxicities associated with high-dose or long-term therapy (Atzpodien and Reitz, 2005; Clark et al., 2013). IL-18 is a relatively nontoxic cytokine (Robertson et al., 2008) that promotes the proliferation of activated T cells, activation of NK cells and cytokine production (Srivastava et al., 2013). Du et al. (2012) have constructed a human IL18-IL2 fusion protein and confirmed that this protein can induce significant NK cell-dependent anti-tumor reponses in different tumor-bearing mice models.

To further illuminate the role of combining IL-18 and IL-2 in the regulation of NK cell activity, we first investigated the effects of these two cytokines on NK cytotoxicity. Instead of traditional isotope-release assay, NK cytolyis was determined by flow cytometric analysis.
Interleukin-18 Synergism with Interleukin-2 in Cytotoxicity and NKG2D Expression of Human Natural Killer Cells

In summary, IL-18 acted synergistically with IL-2 to improve the cytolytic activity of human NK cells in vitro. Substantial up-regulation of NKG2D expression on the surface of NK cells may partly explain the synergistic enhancement of NK cytotoxicity by both cytokines. Our findings provide an important experimental basis for cancer immunotherapy. Appropriate administration of IL-18 and IL-2 might be a viable approach to induce therapeutic NK cell-mediated anti-tumor responses.

Acknowledgements

This study was supported by grants from Shandong Natural Science Foundation (No. ZR2013HM057) and Shandong Medicine and Health Technology Development Program (No. 2009QZ2022). We declare that we have not any conflicts of interest. We also thank the participants in this work for their involvement and cooperation.

References


