Short communications

Title;
Defective Efferocytosis by Alveolar Macrophages in IPF patients

Key words: idiopathic pulmonary fibrosis, efferocytosis, BAL, idiopathic interstitial pneumonia

Konosuke Morimoto¹, William J. Janssen², Mayumi Terada¹

¹Department of Clinical Medicine, Institute of Tropical Medicine, Nagasaki University, Japan.
²Division of Pulmonary Medicine, Department of Medicine, National Jewish Health, Denver, Colorado, USA

Address Correspondence to :
Konosuke Morimoto, M.D.
Department of Clinical Medicine, Institute of Tropical Medicine, Nagasaki University
1-12-4, Sakamoto, Nagasaki, 852-8523, Japan.
Email: komorimo@nagasaki-u.ac.jp
Fax: +81-95-819-7843    Phone: +81-95-819-7842

Word count: 994
**Abstract:**

**Rationale:** Idiopathic pulmonary fibrosis (IPF) is a chronic, progressive fibrosing interstitial pneumonia. The pathogenicity of IPF has been widely investigated but still remains to be clarified. Efferocytosis, the specialized recognition and ingestion of apoptotic cells by phagocytes, is essential for the resolution of inflammation in the lungs and repair of injured tissues. Impaired efferocytosis contributes to the pathogenesis of chronic lung diseases such as emphysema and cystic fibrosis. We hypothesized that efferocytosis would also be reduced in alveolar macrophages isolated from subjects with IPF.

**Methods:** Efferocytosis was evaluated using Wright-Giemsa stained cell preparations isolated from the bronchoalveolar lavage (BAL) fluid of patients with IPF (n=5), nonspecific interstitial pneumonitis (n=6), cryptogenic organizing pneumonia (n=4) and eosinophilic pneumonia (EP) (n=5).

**Results:** Uningested apoptotic cells were significantly higher in BAL fluid from patients with IPF compared to other forms of interstitial lung disease. Macrophages isolated from patients with eosinophilic pneumonia had significantly fewer phagocytic ingestions than macrophages from the other three groups.

**Conclusion:** Efferocytosis by alveolar macrophages was significantly lower in subjects with IPF compared to subjects with other interstitial pneumonia. Dysregulated efferocytosis may contribute to the pathogenesis of IPF.
**Introduction**

Efferocytosis, the specialized recognition and ingestion of apoptotic cells by phagocytes, has been shown to down-regulate inflammation by decreasing inflammatory mediator production via production of TGF-β1, PGE2 and IL-10(1). At the same time, efferocytosis drives tissue repair by upregulating cellular production of growth factors such as hepatocyte growth factor (HGF) (2). Impaired efferocytosis has been documented in a number of chronic respiratory diseases (e.g. COPD, cystic fibrosis and asthma) and contributes directly to their pathogenesis by enhancing inflammation and impairing epithelial repair. (3, 4). Abnormal accumulation of inflammatory cells and dysregulated epithelial repair have been suggested to contribute to the development of fibrotic lung diseases. Accordingly, we sought to determine if efferocytosis was impaired in patients with idiopathic pulmonary fibrosis (IPF) and less-fibrotic idiopathic interstitial pneumonias (IIPs) such as nonspecific interstitial pneumonia (NSIP) and cryptogenic organizing pneumonia (COP) (5).

**Methods**

Efferocytosis, was evaluated using Dif-Quik™ stained cell preparations isolated from the bronchoalveolar lavage (BAL) fluid of patients with IPF (n=5), NSIP (n=6), COP (n=4) and eosinophilic pneumonia (EP) (n=5). We analyzed BAL from EP because it is rapidly reversible non-fibrotic lung disease. All BAL were performed at the time of diagnosis of IIP or EP. IPF was diagnosed according to ATS/ERS criteria(5) or UIP pattern by surgical biopsy. NSIP and COP were diagnosed by surgical biopsy or transbronchial lung biopsy. EP was diagnosed by
clinical findings including BAL and TBLB. We excluded cases in which collagen vascular
diseases, infection or pneumoconiosis were present. Patient characteristics are available as
online supplementary data. Macrophages containing apoptotic bodies and apoptotic cells with
condensed nuclei (3) were identified as shown in Figure1a. Efferocytosis was quantified using
the following formulas:

\[
\text{Phagocytic index (PI)} = \frac{\text{number of phagocytosed cells}}{\text{number of AMs}} \times 100
\]

\[
\text{Apoptotic cells(\%)} = \frac{\text{number of apoptotic cells}}{(\text{total cells} - \text{number of AMs})} \times 100
\]

\[
\text{Defective index (DI)} = \frac{\text{apoptotic cells(\%)}}{\text{PI}}
\]

**Results**

Phagocytic indexes were significantly lower in BAL obtained from patients with IIPs compared
to EP (figure1b). In addition, higher percentages of apoptotic cells were present in BAL from
IPF patients (figure1c) with corresponding elevation of the defective index (figure 1d),
suggesting that clearance of apoptotic cells by AMs may be defective in IPF compared to other
forms of IIP that have better clinical outcomes.

**Discussion**

Efferocytosis of dying cells is critical for the resolution of inflammation and repair of injured
tissues. Efficient removal of apoptotic cells prevents the release of potentially toxic intracellular
contents from the dying cells and enhances the production of growth factors and cytokines by
the phagocyte, including TGF-β and HGF. The anti inflammatory effects of efferocytosis (i.e.
through TGF-β production) may be considered of paramount importance in resolving inflammation in lung diseases where leukocyte infiltration plays a role, such as EP, COP and NSIP. On the other hand, sustained production of TGF-β may lead to fibrosis. In comparison, HGF enhances epithelial cell repair and may counteract the pro-fibrotic effects of TGF-β. Thus in non-inflammatory injury processes (such as IPF) the production of HGF may be of greater importance in driving epithelial repair. In other words, the normal resolution of inflammation and the initiation of lung repair almost certainly require a delicate balance between the production of anti-inflammatory factors (TGF-β) and molecules that stimulate repair (HGF). In this context, both the nature of the underlying disease and the timing of apoptotic cell clearance may be critical, such that impaired efferocytosis during early lung injury may delay the resolution of inflammation whereas during later phases, failure to clear apoptotic cells may result in disordered repair.

Alveolar macrophages are the most abundant leukocytes in the airspaces and are the major cell responsible for efferocytosis. Their programming (or activation) is highly dependent on the environment in which they reside. Accordingly, macrophages that exist in a Th1 environment are generally pro-inflammatory and “classically activated.” Conversely, a Th2 environment promotes the development of “alternatively activated” macrophages that produce molecules implicated in mesenchymal repair and fibrosis. It is therefore not surprising that AMs taken from patients with IPF exhibit features of alternative activation (6). As such, it has been suggested that they may contribute to fibrosis by producing TGF-β and CCL18 (6). Indeed,
intentional depletion of alveolar macrophages in animal models of IPF abrogates the
development of fibrosis (7). Similar results have been achieved by inhibiting alternative
macrophage activation (8). Interestingly, debris from dead or dying cells that have not been
effectively cleared may promote alternative activation of macrophages (9). This raises the
intriguing possibility that the presence of apoptotic cells drives alternative activation of
macrophages, which in turn enhances fibroproliferation.

Nuclear condensation, cytoplasmic membrane blebbing, and reduced cell volume are
morphologic hallmarks of apoptosis. Unfortunately, these changes make it difficult to
distinguish the source (or origin) of apoptotic bodies. Therefore we cannot be sure whether the
apoptotic cells identified in our study are effete leukocytes or sloughed epithelial cells. Since
neutrophils and macrophages isolated from BAL of patients with IPF are resistant to apoptosis
(10, 11) we favor the latter, especially since lung tissue from patients with IPF contains high
numbers of apoptotic epithelial cells (12).

Increased apoptotic cell numbers may result from accelerated cell death or defective apoptotic
cell removal. Since under most circumstances, clearance of apoptotic cells from injured tissues
is incredibly efficient, we suggest that our results reflect the latter. For example, during bacterial
pneumonia there are over $10^6$ neutrophils per mm$^3$ of lung tissue, yet clearance of dying
neutrophils is so efficient that less than 0.3% are apoptotic (13). On the other hand, impaired
clearance of apoptotic cells has been suggested as a mechanism to explain the high levels of
apoptotic cells noted in the parenchyma and airspaces in patients with COPD(4). While our study suggests that efferocytosis may be impaired in IPF, prospective research using primary cells taken from patients with IIPs is required to clarify this finding and determine the mechanisms that underlie this defect.

Acknowledgement: We thank Dr. Masahiko Mori at Nagasaki University for data analysis.
References


**Figure Legends**

Figure 1

a); Representative findings of Dif-Quik™ stained cell preparations isolated from the bronchoalveolar lavage (BAL) fluid. b–d); Phagocytic indexes (PI) (b), percentages of apoptotic cells (c) and defective index (DI) (d) in BAL cells from patients with IIPs and EP. Statistical analysis was performed by two-way ANOVA, followed by Student Newman Keuls test for multiple comparisons.
Figure 1

(a) Images showing apoptotic cells.
(b) Box plot of PI values across different groups: UIP/IPF, NSIP, COP, EP.
   *p<0.01 for comparisons indicated by asterisks.
(c) Bar chart showing percentage of apoptotic cells across groups.
   *p<0.01, *p<0.05 for comparisons indicated by asterisks.
(d) Bar chart showing DI values across groups: UIP/IPF, NSIP, COP, EP.
   *p<0.01 for comparisons indicated by asterisks.
## Supplementary Table

### Patients characteristic

<table>
<thead>
<tr>
<th></th>
<th>IPF</th>
<th>NSIP</th>
<th>COP</th>
<th>EP</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>5</td>
<td>6</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Male/Female</td>
<td>5 / 0</td>
<td>3 / 3</td>
<td>3 / 1</td>
<td>3 / 2</td>
</tr>
<tr>
<td>age (mean±SD)</td>
<td>62.8±9.7</td>
<td>59.3±5.1</td>
<td>68.75±2.6</td>
<td>60.2±22.1</td>
</tr>
<tr>
<td>smoking history</td>
<td>5</td>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>BAL total cells</td>
<td>2.6±1.6</td>
<td>4.9±2.3</td>
<td>4.4±1.4</td>
<td>5.0±4.4</td>
</tr>
<tr>
<td>BAL macrophages</td>
<td>2.2±1.2</td>
<td>2.8±1.4</td>
<td>2.5±0.5</td>
<td>1.2±0.8</td>
</tr>
<tr>
<td>BAL neutrophils</td>
<td>0.07±0.08</td>
<td>0.27±0.43</td>
<td>0.27±0.07</td>
<td>0.14±0.27</td>
</tr>
<tr>
<td>BAL lymphocytes</td>
<td>0.2±±0.2</td>
<td>1.8±1.9</td>
<td>1.6±1.0</td>
<td>0.52±0.55</td>
</tr>
<tr>
<td>BAL Eosinophils</td>
<td>0.06±0.09</td>
<td>0.050.07</td>
<td>0.091.12</td>
<td>3.0±5.0*</td>
</tr>
<tr>
<td>serumKL-6(U/ml)</td>
<td>1175±551.3</td>
<td>1497.8±822.3</td>
<td>726±309.1**</td>
<td>269.3±132.2**</td>
</tr>
</tbody>
</table>

*Number of cells in Bronchial alveolar lavage (BAL) fluid (x10⁵/ml); * significantly higher than IPF, NSIP and COP; ** significantly lower than NSIP

Definition of abbreviations: IPF = Idiopathic pulmonary fibrosis; NSIP = nonspecific interstitial pneumonia; COP = cryptogenic organizing pneumonia; EP = eosinophilic pneumonia