ROCKing pulmonary fibrosis

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Clinical vignette: A 76-year-old man consults you for increasing shortness of breath over the past two years and an increasing requirement for home oxygen. A video-assisted thoracoscopic lung biopsy shows findings of usual interstitial pneumonitis, and he has no identifiable cause for pulmonary fibrosis, so he is considered to have idiopathic pulmonary fibrosis (IPF).

They describe a pathway through which tissue stiffness, in the setting of pulmonary fibrosis, promotes the differentiation and survival of pulmonary myofibroblasts. This pathway requires the activity of Rho-associated kinases (ROCK), which is necessary for contraction and force generation in fibroblasts and for downstream actin polymerization. The authors demonstrate that ROCK-induced actin polymerization leads to nuclear translocation of the transcriptional coactivator, MKL1, which itself plays important roles in promoting the differentiation and survival of myofibroblasts. Enhanced survival is mediated at least in part by induction of the well-characterized survival factor B cell lymphoma 2 (BCL-2). These results suggest several steps that could be targeted to break the feed-forward circuit connecting tissue stiffness with fibrosis progression.

Recent work from a number of experimental systems has implicated tissue stiffness as an important determinant of multiple cell behaviors. In one of the most striking examples, mesenchymal stem cells plated onto soft substrates differentiate into brain cells, cells plated on substrates of intermediate stiffness differentiate into muscle, and cells plated on the stiffest substrates differentiate into bone (1). These findings suggest that cells must have precise mechanisms to detect and appropriately respond to changes in the stiffness of their immediate surroundings. Previous work has identified examples of this phenomenon of “mechanotransduction” that are relevant to tissue fibrosis. For example, lung fibroblasts plated on artificial soft substrates are resistant to differentiation into myofibroblasts and make substantially less collagen than fibroblasts plated on artificial stiff substrates (2). Furthermore, stiff substrates have been shown to facilitate cellular activation of latent TGF-β through integrins expressed on fibroblasts or epithelial cells (3, 4). The recently solved crystal structure of the latent complex of TGF-β provides a compelling explanation of how mechanical force applied through integrins by contracting fibroblasts or epithelial cells could cause release of the active TGF-β cytokine from the embrace of its own carboxyterminal fragment, and how tissue stiffness likely facilitates this process (5). These findings indicate that increased tissue stiffness in the lungs could contribute to fibrosis.

Knowledge gap

Recent work from a number of experimental systems has implicated tissue stiffness as an important determinant of multiple cell behaviors. In one of the most striking examples, mesenchymal stem cells plated onto soft substrates differentiate into brain cells, cells plated on substrates of intermediate stiffness differentiate into muscle, and cells plated on the stiffest substrates differentiate into bone (1). These findings suggest that cells must have precise mechanisms to detect and appropriately respond to changes in the stiffness of their immediate surroundings. Previous work has identified examples of this phenomenon of “mechanotransduction” that are relevant to tissue fibrosis. For example, lung fibroblasts plated on artificial soft substrates are resistant to differentiation into myofibroblasts and make substantially less collagen than fibroblasts plated on artificial stiff substrates (2). Furthermore, stiff substrates have been shown to facilitate cellular activation of latent TGF-β through integrins expressed on fibroblasts or epithelial cells (3, 4). The recently solved crystal structure of the latent complex of TGF-β provides a compelling explanation of how mechanical force applied through integrins by contracting fibroblasts or epithelial cells could cause release of the active TGF-β cytokine from the embrace of its own carboxyterminal fragment, and how tissue stiffness likely facilitates this process (5). These findings indicate that increased tissue stiffness in the lungs could contribute to fibrosis.

Research advances

In this issue of the JCI, Zhou et al. provide new insight into how fibrosis, once established, can beget more fibrosis (6). They describe a pathway through which tissue stiffness, in the setting of pulmonary fibrosis, promotes the differentiation and survival of pulmonary myofibroblasts. This pathway requires the activity of Rho-associated kinases (ROCK), which is necessary for contraction and force generation in fibroblasts and for downstream actin polymerization. The authors demonstrate that ROCK-induced actin polymerization leads to nuclear translocation of the transcriptional coactivator, MKL1, which itself plays important roles in promoting the differentiation and survival of myofibroblasts. Enhanced survival is mediated at least in part by induction of the well-characterized survival factor B cell lymphoma 2 (BCL-2). These results suggest several steps that could be targeted to break the feed-forward circuit connecting tissue stiffness with fibrosis progression.

One of the most exciting possibilities, which was directly tested by Zhou et al. (6), is that pulmonary fibrosis could be treated by inhibition of ROCK. Several potent ROCK inhibitors are already available, and one of these, fasudil, has been approved for clinical use in Japan and China and has already been given to a large number of patients for prevention of vasocstriction after brain injury. Another ROCK inhibitor, Y-27932, was previously shown to prevent pulmonary fibrosis in response to bleomycin (7), but in that study, the drug was administered before bleomycin and might have protected against acute lung injury and inflammation. These steps are important in the bleomycin model, but less relevant to patients with ongoing fibrosis. Zhou et al. showed that fasudil could prevent fibrosis even when administered 14 days after bleomycin (6), at which time inflammation has largely resolved and fibrosis is already present.

ROCK inhibitors such as fasudil could be effective for treating pulmonary fibrosis by more than one mechanism. These drugs have been previously shown to prevent the contraction of lung epithelial cells that is required for activation of TGF-β by the epithelial αvβ6 integrin.

Conflict of interest: The author is co-owner of patents for treatment of pulmonary fibrosis with antibodies blocking the αvβ6 integrin and has a sponsored research agreement with Biogen/Ideo to study the efficacy of anti-integrin antibodies for treatment of tissue fibrosis.

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ROCK-dependent fibroblast contraction has also been shown to be important for TGF-β activation by other αv-containing integrins present on myofibroblasts, which link mechanotransduction to feedforward circuits that promote fibrosis progression. By targeting multiple parallel feed-forward circuits, ROCK inhibitors could be especially promising as antifibrotic drugs.

Implications and future directions
One important caveat could limit the utility of ROCK inhibitors for treatment of fibrotic diseases. ROCK activity is critical for contraction of vascular smooth muscle and thus contributes to the homeostatic vascular smooth muscle contraction required for the maintenance of normal blood pressure. Depending on the relative degrees of ROCK inhibition required to prevent pathologic tissue fibrosis and relax vascular smooth muscle, the utility of systemically administered ROCK inhibitors could be limited by the induction of hypotension. One strategy that deserves further consideration for the treatment of pulmonary fibrosis is chemical modification of ROCK inhibitors to slow absorption into the bloodstream and increase systemic metabolism — modifications that could enrich for pulmonary effects if the drugs are administered by aerosol directly into the lung. Such a strategy might allow effective treatment of pulmonary fibrosis while minimizing the risk of systemic toxicity.

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