Scleroderma

- Chronic multisystemic disease characterized by vasculopathy, variable degree of inflammation, and fibrosis
- Incidence 3.7-22.8 cases/million
- Female:male 5:1
- Pulmonary fibrosis common, severe in 16%. Pulmonary hypertension occurs in 50% of cases and can lead to cor pulmonale. Pulmonary complications are the leading cause of death in this disease.

Clinical Features of Scleroderma (Systemic sclerosis; SSc)

Typical facial features in advanced SSc

Digital ulceration from vascular damage

CREST: Calcinosis, Raynaud’s phenomenon, Sclerodactyly, Esophageal dysmotility, Telangiectasias

Sclerodactyly
Calcinosis
Raynaud’s phenomenon
Telangiectasias

Organ Involvement in Scleroderma

Cardiac, renal, lung and gut complications are the main causes of SSc-related mortality.

From: Denton and Black. Trends Immunol. 26:596, 2005

Pulmonary Manifestations of Scleroderma

Normal Pulmonary Hypertension Pulmonary Fibrosis

Major Clinical Sub-types of Scleroderma

Limited cutaneous SSc (60% of cases)

- No skin sclerosis proximal to knees or elbows.
- Longstanding Raynaud’s phenomenon is typical.
- Most commonly associated autoantibody is anti-centromere Ab (ACA).
- A subgroup of these patients has manifestations of CREST (calcinosis, Raynaud’s, esophageal dysmotility, telangiectasia).
- Isolated pulmonary hypertension and gastrointestinal tract dysmotility are the most common severe manifestations. Lung fibrosis, renal and cardiac involvement occur less often than in dcSSc.
Major Clinical Sub-types of Scleroderma

Diffuse cutaneous SSc (30% of cases)
- The cardinal feature is skin sclerosis proximal to the knees and elbows.
- Raynaud’s phenomenon is universal but might manifest simultaneously or shortly after the development of skin sclerosis.
- Inflammatory features are prominent during the first 3 years of disease. Skin involvement often diminishes within two years.
- ACA is rarely present, anti-Scl-70 (topoisomerase-1) or anti-RNA polymerase is typical.
- There is a high frequency of interstitial lung disease, renal crisis and cardiac involvement.

Scleroderma overlap syndromes
- Their features include those of limited or diffuse cutaneous SSc, together with those of one or more additional autoimmune rheumatic diseases, such as polyarthritis, myositis or SLE.
- Often associated with anti U1-ribonucleoprotein (U1-RNP), U3-RNP or polymyositis-scleroderma (PM-Scl) autoantibody reactivity.

Localized scleroderma
- Morphea scleroderma causes patches of hard skin that can persist for years.
- Linear scleroderma causes bands of hard skin across the face or an extremity, rarely involving muscle or bone.
- Typically carries a good prognosis.

Genetics of Scleroderma
- Family history associated with increased risk of developing disease, but risk is only 1% for any individual.
- Concordance for both mono- and dizygotic twins is 5%. However, gene expression profiling of cultured dermal fibroblasts from monozygotic twins of an index case show a similar pro-fibrotic “signature” 46% of the time.
- Genetic studies indicate an association of scleroderma with polymorphisms in the promoters of the TNF, MCP-1, and CD19 genes.
- Although genetic studies have suggested an association of the HLA-DRB1*01 allele with anti-centromere antibodies, association of ACA with polymorphisms in the TNF promoter was even stronger, suggesting linkage disequilibrium.

The Role of B Cells in Scleroderma

In the blood of patients with scleroderma, naive B cells are increased in number, while memory B cells and plasmablasts/early plasma cells are diminished. Memory B cells express higher levels of CD80 and CD86, and thus are chronically activated, possibly due to CD19 over-expression. CD95 expression is also increased on memory B cells, leading to augmented CD95-mediated apoptosis. The continuous loss of memory B cells and plasmablasts/early plasma cells may increase naive B-cell production in bone marrow to maintain the B-cell homeostasis in systemic sclerosis. From: Fujimoto and Sato: Curr. Opin. Rheumatol. 17:746, 2005.

Do B Cells and Autoantibodies Play a Causative Role in Scleroderma?

Autoantibodies to the PDGF Receptor Stimulates Production of Reactive Oxidants

Oxidant production triggered by sera-derived IgG upon incubation with fibroblasts over-expressing the PDGF receptor. N, normal controls; SSc, scleroderma; PRP, primary Raynaud’s phenomenon; SLE, systemic lupus erythematosus; RA, rheumatoid arthritis; ILD, interstitial lung disease; AG 1296, PDGFR kinase inhibitor. From: Baroni et al., New Engl. J. Med. 354:2667, 2006.

Scleroderma-derived Antibodies to the PDGF Receptor Stimulate Cell Signaling and Collagen Production

Legend: FCS, fetal calf serum; AG1478, EGFR tyrosine kinase inhibitor; AG1296, PDGFR kinase inhibitor


Potential Therapeutics for Scleroderma Based on Insight Into its Pathogenesis


Auto-antibodies to the PDGF Receptor: The Pathogenesis of Scleroderma Revealed?

Unlike normal fibroblasts, fibroblasts in scleroderma increase the expression of PDGFR in response to TGF-β, rendering the cells more sensitive to PDGF. The Ras–ERK1/2–ROS signaling pathway is triggered by PDGF or anti-PDGFR, which then activates NADPH oxidase (NOX1) to produce reactive oxygen species (ROS). These, in turn, activate extracellular signal-regulated kinases 1 and 2 (ERK1/2), which induce the H-ras gene. This signaling loop is present in normal fibroblasts but is relatively amplified in fibroblasts in patients with scleroderma. From: Tan, New Engl. J. Med. 354:2709, 2006.

If chronic over-stimulation of the PDGFR is required for the development and/or progression of scleroderma, then inhibition of PDGFR kinase activity (AG 1296), Ras post-translational processing (FTI 277), or ERK MAP kinase (PD 98059) may prove therapeutic.


Therapeutic Approach to the Treatment of Scleroderma

From: Denton and Black, Trends Immunol. 26:596, 2005
Fibrosis Can Occur in Any Organ and Can Lead to Irreversible Organ Damage

- Various theories have been proposed for the pathogenesis of fibrosing diseases. One view is that fibrosis represents a pathological variant of wound healing.
- An alternate view is that fibrosis is due to "unresolved inflammation."
- Another view is that fibrosis results from an "imbalance" in the activities of proteases and anti-proteases.
- Regardless of the precise etiology of fibrosis, the pathological deposition of collagen and other components of the extracellular matrix results from persistence of mesenchymal cells assuming a fibroblastic or myofibroblastic phenotype, producing copious amounts of components of the ECM.

Examples of Fibrosis

- Normal glomerulus
- Hepatitis C cirrhosis
- Glomerulosclerosis
- Retroperitoneal fibrosis
- Idiopathic Pulmonary Fibrosis (IPF)

Three questions worth pondering...

1. What cells and molecules participate in fibrosis?
2. What is the pathogenesis of fibrosis?
3. Can we intervene therapeutically and retard or reverse fibrosis?

Fibrosis Results from the Inappropriate Deposition of Extracellular Matrix

- Normal
- IPF

Two Engaging Members of the ECM

- Fibronectin
- Laminin
Diversity in Cells and Component of the ECM

<table>
<thead>
<tr>
<th>Collagen</th>
<th>Anchor</th>
<th>Proteoglycan</th>
<th>Cell-Surface Receptor</th>
<th>Cells</th>
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<tr>
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<td>chondroitin and dermatan sulfates</td>
<td>integrin</td>
<td>fibroblasts</td>
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<td>heparan sulfate and heparin</td>
<td>integrin</td>
<td>quiescent hepatocytes, regenerating hepatocytes</td>
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Fibrosis is triggered by growth factors, cytokines, and peptides

Important Pro-fibrotic Growth Factors

Growth factors
- TGF-β, PDGF, FGF-2 (basic FGF), IGF-I
- Connective tissue growth factor (CTGF), EGF

Cytokines
- Th2 cytokines (IL-4, IL-13); IL-1, IL-6

Peptides
- Endothelin I, Ang-II

Chemokines
- C-C chemokines

Activation of Latent TGF-β: Not So Simple

TGF-β is synthesized by virtually all types of cells, in the form of an inactive homodimeric propeptide, pro-TGF-β. After TGF-β is cleaved from the propeptide, additional downstream events control the extent to which TGF-β is available. The small latent complex, composed of TGF-β and its latency-associated peptide, and the large latent complex, composed of TGF-β, latency-associated peptide, and the latent TGF-β binding protein control where and when active TGF-β is made available. The matrix protein thrombospondin-1 binds to the latency-associated peptide, which results in the activation of TGF-β, an essential step for the binding of TGF-β to its receptors. Plasmin, some MMPs, and two members of the integrin family also activate the latent complexes of TGF-β. From: Ugur and Sahin-Altan, N. Engl. J. Med. 354: 2721, 2006.

Basic Paradigm of TGF-β Signal Transduction

Enhanced neointimal hyperplasia and reduced matrix deposition in the arteries of Smad3-null mice upon injury. Photomicrographs showing representative cross sections of hematoxylin/eosin-stained (A and B) and Masson’s trichrome-stained (C and D) femoral arteries from wild-type (A and C) and Smad3-null (B and D) mice 3 weeks after endothelial injury by photochemically induced thrombosis method. Arrows indicate the positions of the internal elastic lamina. L, vascular lumen. From: Circ Res 96:904, 2005.
The Myofibroblast, a Collagen-producing Contractile Cell Involved in Wound Healing

α-smooth muscle actin

The Hepatic Stellate Cell is the "Myofibroblast-equivalent" in Cirrhosis


What are the cellular origins of fibroblasts and myofibroblasts?

• Local proliferation of mesenchymal cells
• Influx of blood-borne fibroblast precursors (often termed "fibrocytes")
• Epithelial-mesenchymal transformation (EMT)

Use of Bone Marrow Chimeras to Determine the Cellular Origin of Fibroblasts

Representative lung sections from bleomycin (BLM)-treated (a–c) or saline-treated (d–f) GFP BM chimeric mice were evaluated at day 21 after BLM or saline treatment. The histology within each mouse was determined in four fields (magnification x400) and each field was assigned a score from 0 (normal lung) to 4 (severe fibrosis). In saline-treated mice, lung architecture was normal (a–c). In contrast, field-stained lung sections from saline-treated GFP BM chimeric mice showed normal lung architecture at x40 and x200, respectively, with a few scattered (GFP+) cells visualized by fluorescence microscopy (d–f). Inset in c and f showed the light-microscopic appearance of the respective sections stained by fluorescence microscopy (x200). From: Hashimoto et al., J. Clin. Invest. 113:243, 2004.


GFP+ Col I+ Cells Derived from the Bone Marrow Populate Lungs During Experimental Pulmonary Fibrosis in Mice

Epithelial-mesenchymal Transformation (EMT)

(a) Schematic of EMT: Epithelial cells (in blue) adhere to each other through adherent junctions, using E-cadherin (E-cad), and their desmosomes (tight junctions) constitute by various proteins such as desmoplakin (Dp). Epithelial cells (in red) are neither adherent nor apically polarized and have low expression of E-cadherin and desmoplakin. The intermediate filament protein vimentin (Vim) is induced in mesenchymal cells (b–g). EMT in a human squamous cell carcinoma line. Prior to EMT (b), and after EMT (c–g). E-cadherin (red) and Vim (green) (b and g) and E-cadherin (blue) and Vim (red) (c–f) immunostaining in epithelial cells (b–d) and mesenchymal cells following EMT (e and g). Adapted from Carral and Ballestero, Oncogene 24:7443, 2005.
E-Cadherin Appears to be a Critical Regulator of EMT

Is repression/disruption of E-cadherin expression sufficient to induce EMT?

The "Canonical" Wnt Pathway Leads to Activation of a Subset of Genes Important in Development

Repressing E-Cadherin Triggers EMT

Summary

1. Scleroderma is an autoimmune disease involving multiple organs. It is characterized by a vasculopathy, varying degrees of inflammation, and fibrosis. Several major clinical variants of scleroderma have been described.

2. Pulmonary complications of scleroderma are common and severe in substantial minority. Death is due to severe pulmonary hypertension, pulmonary fibrosis, or both, ultimately leading to cor pulmonale.

3. Autoantibodies play an important role in the pathogenesis to scleroderma. Agonistic autoantibodies against the PDGFR have been isolated from patients with scleroderma.

4. Various theories of fibrogenesis have been proposed. Regardless of the precise etiology, fibrosis is due to the excessive deposition of ECM by the major collagen-producing cells in the body, fibroblasts and myofibroblasts.

5. Fibroblasts arise from a combination of local proliferation of resident mesenchymal cells, EMT, and influx of fibroblast precursors from the bone marrow.

6. Among the various pro-fibrogenic growth factors, TGF-β usually plays an important role in fibrosis. TGF-β triggers increased production of ECM proteins, induces EMT, and typically induces proliferation (rather than cell cycle arrest) in fibroblasts.