Members of the L6 family of membrane proteins, a branch of the tetraspanin superfamily, are overexpressed in tumor cells from many types of cancers. However, direct evidence of their oncogenic activity has not been previously shown. In this issue of the JCI, Lee et al. demonstrate that overexpression of the tetraspanin superfamily member TM4SF5 in human hepatocellular carcinoma cells causes cellular phenotypic changes that resemble classical descriptions of epithelial-mesenchymal transition (EMT), with some unique aspects (see the related article, doi:10.1172/JCI33768). They also show that these TM4SF5-mediated effects trigger tumor formation when these cells are injected into mice. The study implicates TM4SF5, for the first time to our knowledge, in EMT oncogenic pathways of cancer progression.

Over many years, cancer researchers have attempted to unlock the secrets of cancer cells by comparing the gene expression of tumor cells to that of their normal cellular counterparts. The genes so identified have in many cases proven to be important mediators of the transformed phenotype and have led in a few cases to the development of clinically useful therapeutics, such as antibodies directed against EGFR (implicated in many types of epithelial cancers) or human EGFR 2 (HER2/neu; often overexpressed in breast cancer). In 1997, Gress et al. performed a large-scale screen for differentially expressed genes in tissue from individuals with pancreatic cancer compared with tissue from individuals with chronic pancreatitis and identified transmembrane 4 L6 family member 5 (TM4SF5) as a gene upregulated in pancreatic tumors (1). TM4SF5 was noted to be homologous to the integral membrane protein L6 that is also overexpressed in a variety of malignant tissues (2).

**The tetraspanin superfamily**

TM4SF5 and L6 form a four-member homology group of membrane proteins that are structurally similar to tetraspanins. All members of the L6 family have four transmembrane domains. The N and C termini are cytoplasmic, as is one of the regions between the second and third transmembrane domains. This structure creates two extracellular loops between the transmembrane domains and is superficially similar to other tetraspanins that also have four transmembrane domains. However, the main extracellular domain of L6 and the tetraspanins are highly divergent, and the L6 family lacks a characteristic pattern of cysteines found in the tetraspanins (3). Hence the four L6 proteins are sometimes referred to as members of a tetraspanin superfamily.

While there is much biochemical and cell biological information about the tetraspanins, there is little information available about the L6 family. We do know that both L6 and TM4SF5 have been found to be overexpressed in some cancers, including gastric, prostate, breast, and pancreatic cancer, and that L6 has been associated with tumor cell invasion and motility in lung cancer (4, 5). Members of the tetraspanin family have also been shown to be tightly associated with integrins, which modulate cell shape, cell migration, and signal transduction in many cell types.

**The mechanism of epithelial cell plasticity**

The internal and external surfaces of the body, lining of blood vessels, and other small cavities are covered with a layer of epithelial cells that are held in formation via adhesive complexes between adjacent cells. These cells use the binding of cell-surface receptors, known as integrins, to extracellular matrix proteins to attach to the basement membrane (Figure 1A). When epithelial cells undergo transformation and become cancerous, they use these integrins to direct tumor cell invasion and cancer spread. Integrin engagement with extracellular ligands results in complex multiprotein structures that link the ECM to stress fibers that form the cytoplasmic actin cytoskeleton. The flow of signals from the ECM to the actin cytoskeleton is under the control of protein tyrosine kinases such as focal adhesion kinase (FAK) and members of the Rho family of GTPases and impacts the dynamics between cell adhesion and movement.

During normal embryonic development, a process known as epithelial-mesenchymal transition (EMT) involves the disaggregation of epithelial cells and the reshaping of these cells for movement (6). An analogous process is proposed to play an important role in the migration and metastasis of epithelial cancers (7–10). A better understanding of the factors that control epithelial cell organization may lend insight into how noninvasive, cancerous epithelial cells can dissociate from neighboring cells, invade adjacent tissue, and acquire the ability to move throughout the body and form metastases.

The interaction of various tetraspanins with integrins can regulate some of these processes. For example, tetraspanin family member CD151 has been found in complexes with β1 integrins (11). This association increases the avidity of β1 integrin binding to its ligand (12) and has also been shown to affect melanocyte motility in the skin (13). Expression of CD151 has also been shown to alter tumor metastasis, although the detailed mechanisms through which it mediates this effect are not yet clear (14). There is also evidence that tetraspanins modulate intracellular signaling (11).
EMT induced by tetraspanin TM4SF5

In their current study in this issue of the JCI, Lee et al. (15) build on their earlier study and unravel in part the molecular mechanisms by which TM4SF5 contributes to cancer progression. In a previous report, Lee et al. demonstrated that TM4SF5 is associated with the integrin α2 subunit and modulates actin organization and FAK signaling in Cos7 cells after serum stimulation (16), functions perhaps analogous to those of other tetraspanins. The authors have now taken their previous work further by showing that TM4SF5 overexpression in human hepatocarcinoma SNU449 cells brings about phenotypic changes in these cells that resemble EMT. This has pathological relevance because they also show that TM4SF5 is upregulated in human hepatocarcinoma tissues. The cells show elongated morphology, cell-cell contact loss, continuous growth, aberrant actin bundling, and a shift from epithelial cell marker to mesenchymal cell marker expression, i.e., downregulation of the tumor suppressor and epithelial cell adhesion molecule E-cadherin (independent of Snail1, a transcriptional repressor of E-cadherin), downregulation of the actin-binding protein zonula occludens–1 (ZO-1), and upregulation of α-SMA (Figure 1, B and C). They suggest that TM4SF5 enhances the expression and cytosolic stabilization of the cyclin-dependent kinase inhibitor p27Kip1, likely via kinase interacting with stathmin– (KIS-) and/or Akt-mediated phosphorylation. This results in RhoA inhibition and subsequent changes in cell morphology resembling EMT. The authors observed decreased expression of ZO-1 and E-cadherin (the latter occurring in a Snail1-independent manner) and increased α-SMA expression. Loss of cell-cell contact leads to loss of contact inhibition between cells and uncontrolled multilayer growth. Importantly, this uncontrolled growth could be blocked by suppression of TM4SF5 or p27^kip1, Rho activation, or E-cadherin reexpression in these cells. Upon subcutaneous injection of TM4SF5-overexpressing SNU449 cells into nude mice, Lee et al. observed tumor formation. Figure modified from ref. 15.
but in the current study (15), TM4SF5-induced EMT of SNU449 cells appeared to be independent of Snail1. Moreover, in NMuMG cells, RhoA was found to function as an upstream effector of Akt activation in response to TGF-β, the inducer of EMT in this cell system (23), which is in contrast to the effect of Akt as the upstream effector to inhibit RhoA as reported here (15). The current study by Lee et al. therefore highlights a previously unidentified mechanism for inducing EMT with relevance for hepatocellular carcinoma. Furthermore, it describes a variant EMT phenotype induced by the tumor-specific antigen TM4SF5.

Address correspondence to: Ruth J. Muschel, Radiation Oncology and Biology, The Radiobiology Research Institute, Churchill Hospital, University of Oxford, Oxford OX3 7LJ, United Kingdom. Phone: 44-0-1865-857-427; Fax: 44-0-1865-857-533; E-mail: ruth.muschel@rob.ox.ac.uk.


## Table 1
Overview of different EMT models

<table>
<thead>
<tr>
<th>Epithelial cell type</th>
<th>EMT inducers</th>
<th>Signaling pathways</th>
<th>Epithelial markers</th>
<th>Mesenchymal markers</th>
<th>Actin cytoskeleton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eph4 (normal mouse mammary gland cell line)</td>
<td>Cooperation of Ha-RAS and TGF-β; c-Jun; c-Fos</td>
<td>Autocrine TFG-β and ERK/MAPK, PI3K; β-catenin/LEF</td>
<td>E-cadherin, ZO-1 downregulation</td>
<td>N-cadherin, vimentin upregulation</td>
<td>Actin stress fibers</td>
</tr>
<tr>
<td>NMuMG (normal murine mammary gland cell line)</td>
<td>TGF-β; TjRI/Smds</td>
<td>TFG-β; PI3K; p38 MAPK; ERK/MAPK</td>
<td>E-cadherin, ZO-1, β-catenin downregulation</td>
<td>Fibronectin upregulation</td>
<td>Actin stress fibers</td>
</tr>
<tr>
<td>Mouse primary hepatocytes</td>
<td>TGF-β</td>
<td>TGF-β</td>
<td>E-cadherin downregulation</td>
<td>Vimentin, collagen type I upregulation</td>
<td>Actin stress fibers</td>
</tr>
<tr>
<td>AML12 (normal mouse hepatocyte cell line)</td>
<td>TGF-β</td>
<td>TGF-β; PKA; STAT3</td>
<td>E-cadherin, ZO-1 downregulation</td>
<td>Vimentin, collagen type I upregulation</td>
<td>Actin stress fibers</td>
</tr>
<tr>
<td>MMH-D3 (immortalized murine hepatocyte cell line)</td>
<td>Cooperation of Ha-RAS and TGF-β</td>
<td>Autocrine TFG-β and ERK/MAPK, PI3K</td>
<td>E-cadherin, ZO-1, desmoplakin, β-catenin downregulation</td>
<td>Fibronectin upregulation</td>
<td>Actin stress fibers</td>
</tr>
<tr>
<td>SNU449 (human primary hepatocellular carcinoma cells)</td>
<td>TM4SF5</td>
<td>TM4SF5, integrins/FAK/RhoA (inactive)</td>
<td>E-cadherin, ZO-1, desmoplakin, β-catenin downregulation</td>
<td>α-SMA upregulation</td>
<td>Ablerrant actin bundling</td>
</tr>
</tbody>
</table>

Data are from refs. 17–24. FAK, focal adhesion kinase; LEF, lymphoid enhancer binding factor; TjRI, TGF-β receptor I.