

## Viewpoint

# Regulation of cancer stem cells by p53

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### Abstract

The hypothesis that cancer stem cells are responsible for the chemoresistant and metastatic phenotypes of many breast cancers has gained support using cell-sorting strategies to enrich the tumor-initiating population of cells. The mechanisms regulating the cancer stem cell pool, however, are less clear. Two recent publications suggest that loss of p53 permits expansion of presumptive cancer stem cells in mouse mammary tumors and in human breast cell lines. These results add restriction of cancer stem cells as a new tumor suppressor activity attributed to p53.

workers demonstrate that p53 binds to the promoter of *CD44* [2], a commonly used marker of cancer stem cells [3], and represses CD44 expression. Constitutive expression of CD44 blocked p53-dependent apoptosis and rendered cells resistant to doxorubicin. Conversely, suppression of CD44 expression restricted tumor-initiating cells.

### Enrichment of tumor-initiating cells in p53-deficient mammary tumor models

The recent identification and characterization of stem cells in a variety of adult tissues has led to renewed interest in the role of stem cells in cancers. Cancer stem cells are hypothesized to be a small population of cells within a tumor that are capable of self-renewal and that can undergo differentiation to generate the phenotypic heterogeneity observed in tumors. Contemporary methods for studying cancer stem cells have most often used cell surface markers to enrich the subset of cells capable of initiating a tumor upon transplantation into an appropriate host. Molecular pathways that limit expansion of the tumor-initiating cell population could be targeted to eradicate tumors.

These results link the loss of p53 function to increased expression of CD44, which promotes expansion of tumor-initiating cells purified in tumors. The p53 protein appears to play a similar role in embryonic stem cells, where p53 represses expression of Nanog – which limits the pool of pluripotent cells [4,5]. In contrast, loss of p53 extends the repopulating activity of tissue-specific stem cells [6,7]. Disruption of *BRCA1* also allows expansion of breast stem cells [8]. The restriction of stem cells may therefore be a fundamental pathway for tumor suppression.

### Reading between the cell lines

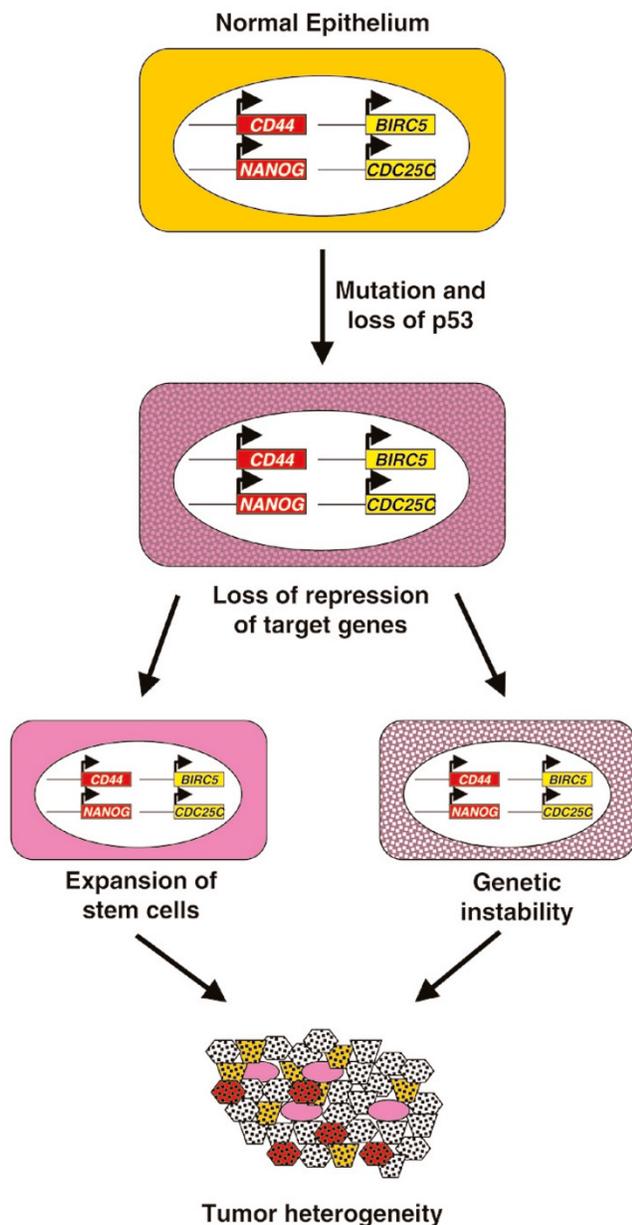
While expansion of the tumor-initiating cell population in p53-deficient mammary epithelial cells is consistent in both mouse mammary and human breast epithelial cells, the role of CD44 is not. Although loss of p53 expression resulted in increased levels of CD44 protein in BPEC-T cells and in basal mammary epithelium of *Trp53*<sup>-/-</sup> mice [2], there was no enrichment for tumor-initiating cells within the CD44<sup>+</sup>/CD24<sup>-</sup> population in BALB/c-*Trp53*<sup>-/-</sup> mammary tumors [1]. This apparent discrepancy points to heterogeneity in the expression of markers among cancer stem cells. In mammary tumors from *Brca1*<sup>ΔExon11</sup>/*Trp53*<sup>+/-</sup> mice, two discrete tumor-initiating populations were identified that express either CD44<sup>+</sup>/CD24<sup>-</sup> or CD133<sup>+</sup> [9]. As coexpression of CD44 and CD133 was not detected in these pools of cells, it appears that CD44 is not essential for sustaining the pool of cancer stem cells.

Using mammary tumors arising spontaneously from transplants of BALB/c-*Trp53*<sup>-/-</sup> mammary epithelium, Zhang and coworkers show that cells expressing markers of mouse mammary stem cells (*lin*<sup>-</sup>/CD29<sup>hi</sup>/CD24<sup>hi</sup>) had a greater tumor-initiating frequency [1]. This observation was consistent among tumors with heterogeneous expression of markers for the luminal epithelium and the basal epithelium. The *lin*<sup>-</sup>/CD29<sup>hi</sup>/CD24<sup>hi</sup> population shared additional features of mammary stem cells, including radiation resistance and the formation of secondary mammospheres.

But how might loss of p53 lead to formation or expansion of the tumor-initiating pool? Using a unique culture model of luminal breast epithelial cells (BPEC-T), Godar and co-

Indeed, p53 represses expression of more than 20 target genes [10] that may contribute to maintenance of the pool of tumor-initiating cells. Genes such as Nanog may have direct actions in supporting self-renewal of cancer stem cells, allowing the pool to expand. Loss of p53 would also allow

Figure 1



Loss of p53 function and effects on tumor heterogeneity. In normal epithelia, p53 represses expression of potential oncogenes (for example, *CD44*, *NANOG*, *BIRC5*, *CDC25C*) as well as transcriptionally activating tumor suppressor pathways [10]. Loss of p53 allows genetic instability as well as expansion or acquisition of stem cell features during carcinogenesis. These pathways combine to generate the phenotypic heterogeneity and plasticity observed in tumors.

increased expression of the multidrug-resistance gene (*ABCB1* or *MDR1*) that renders cells resistant to chemotherapies. Similarly, both increased proliferation and decreased apoptosis would be expected to result from de-repression of *CDC25C* and *BIRC5/Survivin* when p53

function is disrupted. *CD44* may therefore be only one mechanism by which p53 may act to restrict the tumor-initiating population of cancer cells.

### Cancer stem cells: puppet or puppeteer?

It is clear that that p53 plays a pivotal role in tumor suppression. Mutation and loss of function of p53 are among the most common alterations in epithelial cancers [11], and gene expression signatures associated with dysfunctional p53 have been shown to predict patient survival [12,13]. The p53 protein regulates a variety of pathways (cell cycle arrest, apoptosis, DNA repair, senescence and autophagy) that can contribute to suppression of tumors. The publications by Zhang and colleagues and by Godar and colleagues now add suppression of cancer stem cells as an additional activity by which p53 can inhibit tumors [1,2]. So which of these pathways dominate? The answer will have significant impact on therapeutic strategies.

On the one hand, loss of p53 may promote genetic instability – resulting in plasticity of phenotypes due to random mutations and clonal evolution (Figure 1). In this model, the behavior of the p53-deficient cancer cells would be stochastic and would require therapeutics targeting multiple oncogenic pathways. If the apparent phenotypic plasticity of p53-deficient breast tumors is due to the expansion of the cancer stem cell pool, however, therapies targeting the self-renewal pathways may be extremely effective. Loss of p53 function in breast tumors is strongly correlated with the basal-like gene expression signatures [14,15]. This suggest that either these tumors originate from breast stem cells or that loss of p53 allows cancer cells to acquire characteristics of stem cells. These results favor the possibility that p53 deficiency allows expansion of cancer stem cells and that the expression profiles of tumor-initiating cells will identify effective therapeutic targets.

### Competing interests

The authors declare that they have no competing interests.

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