Generation of retinal ganglion-like cells from reprogrammed mouse fibroblasts

Mengfei Chen,1,2 Qin Chen,1 Xuering Sun,1 Wenjuan Shen,2 Bingqian Liu,1 Xiufeng Zhong,1,4 Yunxia Leng,1 Chunmei Li,1 Weizhong Zhang,1 Fang Chai,1 Bing Huang,1 Qianying Gao,1 Andy Peng Xiang,2 Yehong Zhuo1 and Jian Ge1

1State Key Laboratory of Ophthalmology, Zhongshan Ophthalmic Center, Sun Yat-sen University, 2Center for Stem Cell Biology and Tissue Engineering, Sun Yat-sen University, Guangzhou 510080, China, 3Department of Pathophysiology, Medical College of Jinan University, Guangzhou 510632, China, 4Department of Ophthalmology, Johns Hopkins University, Baltimore, MD, USA

Correspondence: Jian Ge, State Key Laboratory of Ophthalmology, Zhongshan Ophthalmic Center, 54 Xian Lie Nan Road, Guangzhou, 510060, China, E-mail: gejian@mail.sysu.edu.cn

Neeru Jindal
Neuroscience Research Lab, Department of Neurology, Post Graduate Institute of Medical Education and Research, Chandigarh, INDIA

Background
Retinal neuron degeneration results in irreversible loss of vision. Neuroprotective strategies are effective for the early stage of degeneration, but cannot prevent the cell death in advanced stage. Stem cell transplantation into injured retina has potential to restore the vision and provide treatment of advanced stages of retinal degeneration.1,2 Embryonic stem (ES) cells have been identified as a viable source of retinal progenitors. The embryonic retinal stem cells/progenitors are however, not available in sufficient quantity for clinical application. These cells also possess limited self-renewal besides ethical issues because of their embryonic/fetal origin.

Recently, the direct reprogramming of somatic cells to a pluripotent state attracted the attention of scientists as these could be used for treating degenerative diseases without ethical concerns.1 Induction of pluripotent stem cells from mouse embryonic or adult fibroblasts was introduced with the help of four factors namely, Oct3/4, Sox2, c-Myc, and Klf4, under ES cell culture conditions.3–6 The purpose of the study was to determine whether induced pluripotent stem (iPS) cells express retinal progenitor cell (RPC) related genes, and whether iPS cells can directly differentiate into retinal ganglion cells (RGCs).

Study Design
Mouse iPS cells were induced from tail-tip fibroblasts (TTFs) by the four factors (Oct3/4, Sox2, Klf4 or c-Myc) through retrovirus-mediated transient gene transfer. 12 to 14 days after infection, iPS colonies were picked up and transferred onto mitomycin C-inactivated MEF feeder cells. Two iPS cell lines, including iPS clone 6 (iPS-C6) and GFP-iPS clone 5 (GFP-iPS-C5), were used in this study.

Undifferentiated iPS-C6 cells displayed ES-like morphology when cultured on MEF and expressed endogenous Sox2. FACS analysis showed that approximately 20% iPS cells were positive for SSEA-1 (surface marker of ES cells). The reprogramming factor Sox2 participates in eye development and cross-regulates with Pax6 and Otx2. Authors first analyzed whether undifferentiated iPS cells express RPC related marker genes. Mouse brain tissue RNA was isolated on E11.5 and served as a positive control. The results of real-time PCR and immunofluorescence revealed that both undifferentiated iPS-C6 and GFP-iPS-C5 cells expressed RPC-related genes, including Pax6, Rx, Otx2, Lhx2, and Nestin, but not Six6, Chx10, or Six3. All these markers were not observed in TTFs and ES. These results demonstrated that iPS cells (induced by four factors) inherently express RPC-related genes and present potential differentiation into retinal neurons.

To cause iPS cells to differentiate toward RGCs, mouse iPS-C6 cells were expanded on MEF feeders, and EBs were generated by suspension-cultured iPS cells in EB medium for 2 to 3 days. iPS cells were induced to differentiate into RGCs by DL (Dkk1+ Lefty A) or DN (Dkk1+Noggin). Neuronal morphology was displayed by many cells on day 8. Real time PCR demonstrated that RPC-related genes except Pax6 were decreased after differentiation. DL or DN significantly upregulated the expression of Pax6 compared with control. Immunofluorescence assay showed the expression of MAP2 (neuron marker) and GFAP (glia marker) in DN induced neuron-like cell. Although Pax6 acts as a Math5 upstream gene and directly activates Math, the expression of RGC markers, including Brn3b, Islet-1, and Thy1.2, was not detected. These results indicated that DL or DN upregulated Pax6 but did not sufficiently differentiate iPS toward RGCs.

To directly differentiate iPS cells into RGCs, authors upregulated Pax6 by DN, overexpressed Math5, and further inhibited Hes1 with DAPT (γ-secretase inhibitor) in iPS cells. After 72 hours of transfection of Math5, many iPS-C6 cells displayed RGC morphology with long, straight synapse like structures. Double-immunostaining analysis demonstrated that RG-like cells stained positive for typical markers of RGC precursors, including Math5, Brn3b, and Islet-1. 96 hours after transfection approximately 15% of cells stained positive for Math5, 10% of cells expressed Brn3b, and 5% cells were positive for Thy1.2.

RG-like cells derived from GFP-iPS cells were transplanted into the vitreous chamber of normal mice after differentiation by DN + DAPT and Math5 transfection. After 2 weeks, most GFP
expressing cells were found to be concentrated near the injection site and rarely engrafted into the host retina, because intact normal retinal environment presents a barrier to graft integration. Authors also found teratoma formation in both eyes of one mouse (12 in total mice) after transplantation of the differentiated iPS cells (induced differentiation at passage 9). These results indicated the risk for tumorigenesis after the transplantation of virus-induced iPS cells into the retina.

Implications
Reprogramming somatic cells to pluripotent stem cells and then directly differentiating them into RG-like cells represents a strategy of artificial change of cell fate by transcription factors. iPSCs represent a renewable, reliable, and robust source of retinal progenitors that may be used to formulate stem cell approaches to understand and treat a wide range of retinal degenerative diseases.

References
1. Singh T, Prabhakar S, Gupta A, et al. Recruitment of stem cells into the injured retina after laser injury. Stem cell Dev 2011; May 11.
2. Sharma NK, Prabhakar S and Anand A. Age related macular degeneration – advances and trends. Annals of Neurosciences 2009; 16(3): 62–71.
3. Osakada F, Jin ZB, Hirami Y, et al. In vitro differentiation of retinal cells from human pluripotent stem cells by small-molecule induction. J Cell Sci 2009; 122: 3169–3179.
4. Takahashi K and Yamanaka S. Induction of pluripotent stem cells from mouse embryonic and adult fibroblast cultures by defined factors. Cell 2006; 126: 663–676.
5. Takahashi K, Tanabe K, Ohnuki M, et al. Induction of pluripotent stem cells from adult human fibroblasts by defined factors. Cell 2007; 131: 861–872.
6. Yu J, Vodyanik MA, Smuga-Otto K, et al. Induced pluripotent stem cell lines derived from human somatic cells. Science 2007; 318: 1917–1920.

doi: 10.5214/ans.0972.7531.1118207