

## ORIGINAL ARTICLE

# Transforming Growth Factor Beta-Induced Factor 2-Linked X (TGIF2LX) Regulates Two Morphogenesis Genes, Nir1 and Nir2 in Human Colorectal

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**Abstract-** A member of homeodomain protein namely TGIF2LX has been implicated as a tumor suppressor gene in human malignancy as well as in spermatogenesis. However, to our knowledge, dynamic functional evidence of the TGIF2LX has not yet been provided. The aim of the present study was to investigate the human TGIF2LX target gene(s) using a cDNA-AFLP as a differential display method. A pEGFP-TGIF2LX construct containing the wild-type TGIF2LX cDNA was stably transfected into SW48 cells. UV microscopic analysis and Real-time RT-PCR were used to confirm TGIF2LX expression. The mRNA expressions of TGIF2LX in transfected SW48 cells, the cells containing empty vector (pEGFP-N), and untransfected cells were compared. Also, a Real-time PCR technique was applied to validate cDNA-AFLP results. The results revealed a significant down-regulation and up-regulation by TGIF2LX of Nir1 and Nir2 genes, respectively. The genes are engaged in the cell morphogenesis process. Our findings may provide new insight into the complex molecular pathways underlying colorectal cancer development.

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**Keywords:** cDNA-AFLP; *TGIF2LX*; Transcription factor; Tumor suppressor; Target genes; Colorectal cancer

## Introduction

Homeodomain transcription factors play fundamental roles in cellular proliferation, differentiation as well as cell fate (1). The homeobox genes are a diverse group of genes characterized by a conserved 180 base-pair motif encoding a homeodomain with three structurally conserved helices (2). These genes have a particular DNA sequence, the homeobox, which encodes a very variable protein domain named homeodomain. Many homeodomain proteins are transcription factors with important roles in embryonic

development and cell differentiation, several of which are involved in human disease and congenital abnormalities (3,4).

One subfamily of homeobox genes encodes proteins with atypical homeodomain referred to as three amino acid loop extension (TALE) which are described by the presence of three extra amino acids between helix 1 and helix 2(3,5). The third helix has a major role in DNA-binding site recognition (5). TALE homeodomain proteins are crucial transcription factors for embryonic progress and early development (6,7). Four TALE classes have been identified in animals: *PBC*, *MEIS*,

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*TGIF* and *IRO* (Iroquois) (8).

*TGIF* (referred to as transforming growth factor- $\beta$ -induced factor 5'-TG-3' interacting factor) genes encode *TALE*-class homeodomain proteins including *TGIF1*, *TGIF2*, *TGIF2LX* (transforming growth factor- $\beta$ -induced factor 2-like, X-linked) and *TGIF2LY* (transforming growth factor- $\beta$ -induced factor 2-like, Y-linked), that act as multifunctional repressors of TGF- $\beta$  signaling. These transcription factors function in normal and abnormal developments (3,9-11).

*TGIF2* is frequently expressed in human tissues, with especially high expression in the heart, kidney, and testis (1).

The human *TGIF2LX* gene is located on X-chromosome (Xq21.3) and is suggested to have originated from the retrotransposition of autosomal *TGIF2*. The *TGIF2LX* has 2 exons with a 96 base-pair intron. Although *TGIF2* and *TGIF2LX* show extensive variations, they share conservatively within the homeodomain, and the C-terminus region (12).

An abnormal expression of *TGIF2LX* gene in some prostate tumors, but not in normal and benign prostate hyperplasia, has been shown (13). Moreover, a possible association of *TGIF2LX/Y* mRNA expression with human azoospermia has been reported in the Iranian patients affected by infertility (14). Another study showed that *TGIF2LX* gene is differentially expressed in glioblastoma and astrocytoma cell lines suggesting a potential function of this gene in brain tumorigenesis (15).

The present study aimed at identifying potential human *TGIF2LX* target gene(s) using cDNA-AFLP as a differential display method.

## Materials and Methods

### Cell culture

The colon adenocarcinoma cell line, SW48, was grown in RPMI-1640 medium (Gibco, Germany) containing 25 mM D-glucose, 4 mM L-glutamine and 1 mM sodium pyruvate and supplemented with 5% (v/v) heat-inactivated fetal bovine serum (FBS) (Gibco, Germany) 2 mM glutamate (Gibco, Germany), 100 units/ml penicillin, 100  $\mu$ g/ml streptomycin and 250 ng/ml amphotericin (Gibco, Germany) in culture flask 25 cm<sup>2</sup> (SPL Life Sciences, South Korea). The cells were incubated at 37°C in a humidified 95% atmosphere, 5% CO<sub>2</sub> atmosphere incubator designated as the culture at a steady-state condition (16,17).

### Cell transfection

In our previous study, we designed and cloned the entire coding region of *TGIF2LX* into the pEGFP-N1 vector (15). We transfected subcultured SW48 cells using X-treme GENE siRNA Transfection Reagent (Roche, Applied Science, and Germany) either with pEGFP carrying *TGIF2LX* cDNA sequence or empty pEGFP plasmid according to the manufacturer's instructions. After 24 to 48 hours, transfection was examined using an Olympus fluorescent inverted microscope. The following day, the cells were cultured in the presence of 800  $\mu$ g/mL G418 (Life Technologies) for 21 days to select highly expressing GFP cells. As a maintenance dose, the cells were cultured in the presence of 200  $\mu$ g/mL of G418 (Life Technologies).

### RNA extraction and cDNA synthesis

Total RNA was extracted by the TriZol reagent (Invitrogen, USA) following the manufacturer's instructions. The quality and quantity of total RNA were verified by gel electrophoresis and optical density reading with a NanoDrop (ThermoScientific2000, USA). Total RNA was treated with *DNaseI* (Invitrogen, USA). Then, 5  $\mu$ g of total RNA was used to synthesize cDNA fragments using random sequence hexamer primers and OligodT with a cDNA synthesis system kit (Vivantis, USA), according to the manufacturer's protocol.

### cDNA-AFLP

A modified cDNA-AFLP procedure was performed as described previously (18-20). Double-stranded cDNA (dscDNA) was synthesized at 16 °C for 2 h with *DNA polymeraseI* (Thermo Scientific, USA). The resulting double-stranded cDNA was then digested with 5 U *EcoRI*, (Fermentas, Canada) at 37 °C for 2 h and PCR templates were generated. Subsequently, the adaptors were ligated to *T4-DNA ligase* (Vivantis, USA) overnight at 16°C, and one-tenth of this reaction volume was used for pre-amplification with *PrEcoRI* primers (Table1) in a 50  $\mu$ l reaction volume.

The PCR condition was as following steps: initial denaturation at 95°C for 5 min followed by 30 amplification cycles at 94°C for 40 s, 60°C for 40 s, and 72°C for 1.5 min, and a final extension at 72°C for 7 min. The sensitive amplification was also carried out by sensitive primers. These primers contained adaptor sequences plus one variable nucleotide at the 3' end. The products resulting from sensitive amplifications were separated on 10% non-denaturing polyacrylamide gel

electrophoresis (PAGE) and stained with silver nitrate according to the protocol (21). Finally, the gels were scanned and checked for the presence of differentially expressed transcription-derived fragments (TDFs).

**Isolation, cloning, and sequence analysis of transcript-derived fragments**

Based on their intensity of up-regulation and down-regulation, the bands that were obviously changed were selected and cut from the gels with a surgical blade. The gel was dissolved in 100 µl sterile water with vigorous vortexing for 1 min, and incubated in boiling water for 30 min. A 5 µl portion of each dissolved band was re-amplified using appropriate, sensitive adaptors. After checking PCR products on 1.5% agarose gel, they were cloned into a *pTZ57R/T* Vector (Thermo scientific, USA). There combinant plasmid containing the TDF of interest was subjected to sequencing using universal primers (*M13* (-20) forward and reverse primer) (Fermentase,USA); this was done to identify the isolated TDFs. Sequence data were analyzed in a non-redundant nucleic and protein databases, namely BLAST (Basic Local Alignment Search Tool) (<http://www.ncbi.nlm.nih.gov/BLAST>).

**Real-time RT-PCR analysis**

Real-time RT-PCR was conducted to confirm the differences in expression patterns of TDF-derived genes, For expression analysis, specific primers were designed using the NCBI primer-BLAST program (<http://www.ncbi.nlm.nih.gov/primer-BLAST>). A

quantitative Real-time PCR was performed in a total volume of 20 µl that contained 2 µl cDNA, 10 µl of *SYBR Green I Taq Mix* (Takara, Dalian, China), 1 µl (0.2 mM) of each primer, and 6 µl ddH<sub>2</sub>O. Experiments were performed in triplicate using a CFX96™ Real-Time System (C1000™ Thermal Cycler) (Bio-Rad, Hercules, CA, USA). The PCR condition followed this steps: initial denaturation at 95°C for 3 min followed by 45 amplification cycles containing denaturation at 95°C for 10 s, annealing at 60°C for 32 s and extension at 72° for 1.5 min, and a final extension at 72°C for 7 min. The amplification products were heated to 95°C to determine their melting curves and confirm their specificity. Glyceraldehyde 3-phosphate dehydrogenase (*GAPDH*) gene expression was used as a housekeeping gene to normalize data. The cycle thresholds (CTs) of the identified genes were compared with that of the house keeping gene (*GAPDH*), the relative expression level of each target gene was analyzed by using the 2<sup>-ΔΔCT</sup> method (22,23).

**Results**

The entire coding region of *TGIF2LX* was cloned into the *pEGFP-N1* vector. The *TGIF2LX* expression was detected by RT-PCR. Plasmids containing the correct sequence were transfected into SW48 cell line, and the *TGIF2LX-GFP* fusion protein is expressed. The fluorescent microscopic study revealed that the *TGIF2LX-GFP* was mainly localized to nuclei (Figure 1).



**Figure 1.** *TGIF2LX* gene expression detected by fluorescent microscopy. SW48 cells 21 days after post-transfection with a light microscope (A). SW48 cells transfected with empty plasmid *pEGFP* (B), and with plasmid *pEGFP-TGIF2LX* (C) under a fluorescent microscope (×20).

cDNA-AFLP analyses were carried out on SW48 with either *pEGFP* plasmid with *TGIF2LX* cDNA sequence or *pEGFP* plasmid without *TGIF2LX* cDNA sequence; this was done to investigate target gene(s) of the *TGIF2LX*. The cDNA AFLP products from different primer combinations were resolved on 10% non-denaturing PAGE (Figure 2) different bands containing TDFs were extracted from PAGEs, amplified and subcloned into T-vector for sequencing so that it was possible to detect *TGIF2LX* target genes. The sequence

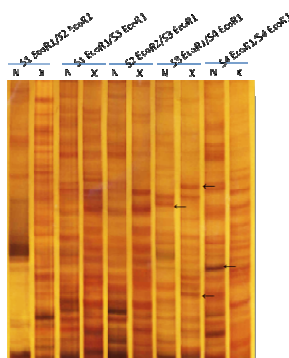
obtained for each TDF was compared with the Gen Bank non-redundant public sequence database BLAST program (24).

In this study, different mRNA expression levels of *Nir1* and *Nir2* genes, and two other unknown genes were detected in SW48 cells containing plasmid *pEGFP-TGIF2LX* compared to cells containing the empty *pEGFP* plasmid.

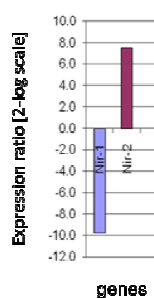
**Validation of cDNA AFLP results using real time PCR**

After identification by cDNA-AFLP, gene expression was further investigated in order to identify two TDFs using qRT-PCR by specific primers (Table 1). These TDFs were selected based on the expression

intensity and differential patterns of expression in the cDNA-AFLP experiment. According to the qRT-PCR results, *Nir1* and *Nir2* were found to be down-regulated and up-regulated, respectively (Figure 3).



**Figure 2.** The pattern of TDFs extracted from cDNA-AFLP PAGE. Sensitive amplification of cDNA-AFLP on a PAGE from different primer combinations: S1 *EcoRI* /S2 *EcoRI*, S1 *EcoRI* /S3 *EcoRI*, and S2 *EcoRI* /S3 *EcoRI*, and S3 *EcoRI* /S4 *EcoRI*, and S4 *EcoRI* /S4 *EcoRI*. The arrows indicate extracted TDFs. N: SW48 cells transfected with empty plasmid *pEGFP*, X: SW48 cells transfected with *pEGFP-TGIF2LX*.



**Figure 3.** Relative expression pattern of *Nir1* and *Nir2* genes by real time RT-PCR. *Nir2* gene showed increased expression level, and *Nir1* gene showed decreased expression level after normalization with internal control (*GAPDH*) ( $P < 0.001$ ).

**Table 1. Sequences of adaptors and primer used in this study**

Primer name	Sequences	PCR product size (bp)	Primer name
Housekeeping	GAPDH-F	5'-CACCAGGGCTGCTTTTAAC-3'	190 bp
	GAPDH-R	5'-ATCTCGCCTCCTGGAAGAT-3'	
	AdL <i>EcoR</i> 1	5'-ACCGACGTCGACTATCCATGAAG -3'	
	AdS <i>EcoR</i> 1	5'- AATTCTTCATGG -3'	
cDNA AFLP Adaptors and Primers	Pr <i>EcoR</i> 1	5'- ACCGACGTCGACTATCCATGAAGAATTC -3'	--
	S1 <i>EcoR</i> 1	5'- ACCGACGTCGACTATCCATGAAGAATTC -3'	--
	S2 <i>EcoR</i> 1	5'- ACCGACGTCGACTATCCATGAAGAATTCG -3'	--
	S3 <i>EcoR</i> 1	5'- ACCGACGTCGACTATCCATGAAGAATTCA -3'	--
	S4 <i>EcoR</i> 1	5'- ACCGACGTCGACTATCCATGAAGAATTCT -3'	--
Target Gene	Nir 1 – F	5'- TATCGGATCGCCAAGTTGCT-3'	169 bp
	Nir 1 – R	5'-TTGAGAATCACCCAAAGC-3'	
	Nir 2 – F	5'- GTAGAACTGAACATCGTGGCCG-3'	
	Nir 2 – R	5'- CCACATAGCCGTCTGACAGGA-3'	

## Discussion

Colorectal cancer is one of the common malignancies worldwide, with one million new cases

each year. Determination of new target genes as molecular markers is useful for the cancer prognosis and helps to select therapeutic strategies (25,26).

The present study was conducted to identify

downstream genes regulated by *TGIF2LX*. It is possible that *TGIF2LX*, like the majority of homeobox genes, activates or represses downstream target gene(s) via direct or indirect manners. It was found in the present study that *Nir1* (also known as *PITPNM3*) and *Nir2* act as two *TGIF2LX* target genes. It was also revealed that *Nir1* was down-regulated while *Nir2* was up-regulated.

The *Nir* family members have been favorably conserved during evolution. *PITPNM3* contains 20 exons spanning approximately 101 kb of genomic sequence and encodes a protein belonging to phosphatidylinositol transfer protein (*PITP*) family. *Nir* proteins show tissue-specific expression pattern. The *Nir1* gene is expressed in the human retina, brain, spleen, ovary and breast cancer cells (27-29). Whereas *Nir2* is expressed in various tissues and cell types, including neuronal, epithelial, and hematopoietic cells (30). Evidence suggests that *Nir2* is an important regulator of cell morphogenesis and its ectopic expression remarkably affects cell morphology (31). It has been revealed that *Nir2* is essential for cytokinesis; blocking of *Nir2* function by *PITPNM1* antibody injection results in the production of multinucleated cell formation. Overall, any changes in *Nir2* structure lead to an abnormal cytokinesis (32).

It has been demonstrated that *Nir1* is a functional receptor for CCL18 (a Tumor-associated macrophage-derived cytokine). Expression and functional role of *PITPNM3* in breast cancer cells support the correlation of CCL18-expressing TAM count with prognosis due to increased CCL18 production that may have a stronger metastasis-promoting effect on breast cancer cells. CCL18 promotes breast cancer invasion, metastasis, and reduces patient survival; whereas *PITPNM3* suppression would reverse these effects (33). In contrary, *PITPNM3* is scarcely detected in gastric cancer cells (34).

It has been documented that *Nir1* and *Nir2* have different expression patterns in retinal cells. Their characteristic and expression pattern may indicate several roles in cellular processes. While *Nir1* is predominantly expressed in premature cells, *Nir2* is homogeneously distributed in undifferentiated neuroblasts and ganglion cells at birth but later becomes distinctly distributed in newly differentiated neuronal cells (35). The results obtained in the present study are in agreement with the results of the above-mentioned study except that in the present study *Nir2* as a *TGIF2LX* target was up-regulated in colorectal adenocarcinoma grade 4 which resulted in the increased in tissue differentiation and decrease in cancerogenesis. On the other hand, lack of *TGIF2LX* expression leads to

carcinogenesis. Therefore, it seems that *TGIF2LX* acts as tumor suppressor gene, but *Nir1* is a proto-oncogene.

Overall, the present study identified two target genes of *TGIF2LX*, which would be involved in the cell morphogenesis processes. These findings may provide new insight into the complex molecular pathways underlying colorectal cancer development.

## References

1. Imoto I, Pimkhaokham A, Watanabe T, et al. Amplification and overexpression of TGIF2, a novel homeobox gene of the TALE superclass, in ovarian cancer cell lines. *Biochem Biophys Res Commun* 2000;276(1):264-70.
2. Hu Y, Yu H, Shaw G, et al. Differential roles of TGIF family genes in mammalian reproduction. *BMC Dev Biol* 2011;11:58.
3. Holland PW, Booth HA, Bruford EA. Classification and nomenclature of all human homeobox genes. *BMC Biol* 2007;5:47.
4. Reza Raoofian, Mohammad Reza Noori-Dalooi, Samira Saeed-Rad, et al. Differential expression of human homeodomain TGIFLX in brain tumor cell lines. *Acta Med Iran* 2013;51(12):834-41.
5. Bertolino E, Reimund B, Wildt-Perinic D, et al. A novel homeobox protein which recognizes a TGT core and functionally interferes with a retinoid-responsive motif. *J Biol Chem* 1995;270(52):31178-88.
6. Melhuish TA, Gallo CM, Wotton D. TGIF2 interacts with histone deacetylase 1 and represses transcription. *J Biol Chem* 2001;276(34):32109-14.
7. Powers SE, Taniguchi K, Yen W, et al. Tgif1 and Tgif2 regulate Nodal signaling and are required for gastrulation. *Development* 2010;137(2):249-59.
8. Burglin TR. Analysis of TALE superclass homeobox genes (MEIS, PBC, KNOX, Iroquois, TGIF) reveals a novel domain conserved between plants and animals. *Nucleic Acids Res* 1997;25(21):4173-80.
9. Hyman CA, Bartholin L, Newfeld SJ, et al. Drosophila TGIF proteins are transcriptional activators. *Mol Cell Biol* 2003;23(24):9262-74.
10. Wang Y, Wang L, Wang Z. Transgenic analyses of TGIF family proteins in Drosophila imply their role in cell growth. *J Genet Genomics* 2008;35(8):457-65.
11. Yu YY, Pan YS, Zhu ZG. Homeobox genes and their functions on development and neoplasm in gastrointestinal tract. *Eur J Surg Oncol* 2007;33(2):129-32.
12. Blanco-Arias P, Sargent CA, Affara NA. The human-specific Yp11.2/Xq21.3 homology block encodes a potentially functional testis-specific TGIF-like retroposon.

- Mamm Genome 2002;13(8):463-8.
13. Ousati Ashtiani Z, Ayati M, Modarresi MH, et al. Association of TGIFLX/Y mRNA expression with prostate cancer. *Med Oncol* 2009;26(1):73-7.
  14. Aarabi M, Ousati-Ashtiani Z, Nazarian A, et al. Association of TGIFLX/Y mRNA expression with azoospermia in infertile men. *Mol Reprod Dev* 2008;75(12):1761-6.
  15. Raoofian R, Noori-Dalooi MR, Saee-Rad S, et al. Differential expression of human homeodomain TGIFLX in brain tumor cell lines. *Acta Med Iran* 2013;51(12):834-41.
  16. Akbari A, Amanpour S, Muhammadnejad S, et al. Evaluation of antitumor activity of a TGF-beta receptor I inhibitor (SD-208) on human colon adenocarcinoma. *Daru* 2014;22:47
  17. Akbari A, Ghahremani MH, Mobini GR, et al. Down-regulation of miR-135b in colon adenocarcinoma induced by a TGF-β receptor I kinase inhibitor (SD-208). *Iran J Basic Med Sci* 2015;18(9):856-61.
  18. Saffari M, Dinehkabodi OS, Ghaffari SH, et al. Identification of novel p53 target genes by cDNA AFLP in glioblastoma cells. *Cancer Lett* 2009;273(2):316-22.
  19. Elham Kazemi-Rad MM, Mohammad Bagher Khadem-Erfan, Mojtaba Saffari, et al. Identification of antimony resistance markers in *Leishmania tropica* field isolates through a cDNA-AFLP approach. *Exp Parasitol* 2013;135(2):344-9.
  20. Bagher Khadem Erfan M, Mohebal M2, Kazemi-Rad E, et al. Downregulation of Calcineurin Gene Is Associated with Glucantime Resistance in *Leishmania infantum*. *Iran J Parasitol* 2013;8(3):359-66.
  21. Bassam BJ, Caetano-Anolles G, Gresshoff PM. Fast and sensitive silver staining of DNA in polyacrylamide gels. *Anal Biochem* 1991;196(1):80-3.
  22. Livak KJ, Schmittgen TD. Analysis of relative gene expression data using real-time quantitative PCR and the 2(-Delta Delta C(T)) Method. *Methods* 2001;25(4):402-8.
  23. Akbari A, Mobini GR, Maghsoudi R, et al. Modulation of transforming growth factor-β signaling transducers in colon adenocarcinoma cells induced by staphylococcal enterotoxin B. *Mol Med Rep* 2016;13(1):909-91.
  24. Altschul SF, Madden TL, Schaffer AA, et al. Gapped BLAST and PSI-BLAST: a new generation of protein database search programs. *Nucl Acids Res* 1997;25(17):3389-402.
  25. Shen A, Chen H, Chen Y, et al. Pien Tze Huang Overcomes Multidrug Resistance and Epithelial-Mesenchymal Transition in Human Colorectal Carcinoma Cells via Suppression of TGF-beta Pathway. *Evid Based Complement Alternat Med* 2014;2014:679436.
  26. Yang J, Fu M, Ding Y, et al. High SHIP2 Expression Indicates Poor Survival in Colorectal Cancer. *Dis Markers* 2014;2014:218968.
  27. Krohn S, Garin A, Gabay C, et al. The Activity of CCL18 is Principally Mediated through Interaction with Glycosaminoglycans. *Front Immunol* 2013;4:193.
  28. Lev S. Molecular aspects of retinal degenerative diseases. *Cell Mol Neurobiol* 2001;21(6):575-89.
  29. Ocaka L, Spalluto C, Wilson DI, et al. Chromosomal localization, genomic organization and evolution of the genes encoding human phosphatidylinositol transfer protein membrane-associated (PITPNM) 1, 2 and 3. *Cytogenet Genome Res* 2005;108(4):293-302.
  30. Lev S, Hernandez J, Martinez R, et al. Identification of a novel family of targets of PYK2 related to *Drosophila* retinal degeneration B (rdgB) protein. *Mol Cell Biol* 1999;19(3):2278-88.
  31. Tian D, Litvak V, Toledo-Rodriguez M, et al. Nir2, a novel regulator of cell morphogenesis. *Mol Cell Biol* 2002;22(8):2650-62.
  32. Litvak V, Tian D, Carmon S, et al. Nir2, a human homolog of *Drosophila melanogaster* retinal degeneration B protein, is essential for cytokinesis. *Mol Cell Biol* 2002;22(14):5064-75.
  33. Chen J, Yao Y, Gong C, et al. CCL18 from tumor-associated macrophages promotes breast cancer metastasis via PITPNM3. *Cancer Cell* 2011;19(4):541-55.
  34. Leung SY, Yuen ST, Chu KM, et al. Expression profiling identifies chemokine (C-C motif) ligand 18 as an independent prognostic indicator in gastric cancer. *Gastroenterology* 2004;127(2):457-69.
  35. Tian D, Lev S. Cellular and developmental distribution of human homologues of the *Drosophila* rdgB protein in the rat retina. *Invest Ophthalmol Vis Sci* 2002;43(6):1946-53.