Targetome Analysis Revealed Involvement of MiR-126 in Neurotrophin Signaling Pathway: A Possible Role in Prevention of Glioma Development

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Abstract

Objective: For the first time, we used molecular signaling pathway enrichment analysis to determine possible involvement of miR-126 and IRS-1 in neurotrophin pathway.

Materials and Methods: In this prospective study, validated and predicted targets (targetome) of miR-126 were collected following searching miRtarbase (http://mirtarbase.mbc.nctu.edu.tw/) and miRWalk 2.0 databases, respectively. Then, approximate expression of miR-126 targeting in Glioma tissue was examined using UniGene database (http://www.ncbi.nlm.nih.gov/unigene). In silico molecular pathway enrichment analysis was carried out by DAVID 6.7 database (http://david.abcc.ncifcrf.gov/) to explore which signaling pathway is related to miR-126 targeting and how miR-126 attributes to glioma development.

Results: MiR-126 exerts a variety of functions in cancer pathogenesis via suppression of expression of target gene including PI3K, KRAS, EGFL7, IRS-1 and VEGF. Our bioinformatic studies implementing DAVID database, showed the involvement of miR-126 target genes in several signaling pathways including cancer pathogenesis, neurotrophin functions, Glioma formation, insulin function, focal adhesion production, chemokine synthesis and secretion and regulation of the actin cytoskeleton.

Conclusion: Taken together, we concluded that miR-126 enhances the formation of glioma cancer stem cell probably via down regulation of IRS-1 in neurotrophin signaling pathway.

Keywords: EGFL7, Glioma, IRS-1, MiR-126, Neurotrophin

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Introduction

MicroRNAs (miRNAs) are defined as endogenous small and non-coding RNAs that are approximately 18-24 nucleotides in length and play a significant role in the regulation of gene expression (1). These non-coding RNAs are negative regulators of gene expression (2). MiRNAs may have roles not only as oncogenes but also as tumor suppressors, further suggesting them as therapeutic targets (3). The interaction between miRNAs and 3’-nontranslatable regions of target mRNAs by complementarity, triggers mRNA degradation or prevents its translation (2, 4). As of today, more than 2000 different miRNAs have been characterized (2). MiRNAs could be considered as a valuable diagnosis or prognosis biomarker to predict the likely outcome of certain diseases such as cancer (5).

Glioma as one of the main central nervous system (CNS)-related cancers, comprises nearly 30% of all brain and CNS tumors and 80% of all malignant brain tumors (6). miR-126 is found on chromosome 9 within intron 7 of epidermal growth factor like domain 7 (EGFL7) gene (Fig.1) (7). miR-126 is one of the most important miRNAs that has significant roles in cellular biology, including cancer biology. Schmidt and colleagues showed that miR-126 is mainly involved in angiogenesis and inflammation, and briefly reviewed that miR-126 may play crucial roles in several human cancers (8).

In this regard, a number of miR-126 target genes has already been characterized. EGFL7 is the host gene of miR-126, which is also the major target of miR-126. Transcription of EGFL7 and miR-126 occurs simultaneously and mature miR-126 matches with a complementary sequence within the host gene EGFL7, causing a decrease in EGFL7 protein levels and
activating a negative feedback mechanism. EGFL7 affects cell migration pathways by interfering with tissue invasion and angiogenesis. Negative feedback mechanism of miR-126 shows that one of the main functions of miR-126 is regulating EGFL7 protein formation, leading to reduction of angiogenesis and cell migration (9).

Another target of miR-126 is insulin receptor substrate-1 (IRS-1) as upregulation of miR-126 can significantly inhibit the expression of IRS-1 (10). IRS-1 is able to modify PI3K/Akt signalling through neurotrophin pathway which is one of the major pathways involved in neural cell differentiation (11). Furthermore, V-Ki-ras2 Kirsten rat sarcoma viral oncogene (KRAS) is considered another target gene of miR-126. KRAS is involved in cellular differentiation via PI3K/Akt pathway (12). Interestingly, Ras and PI3K proteins are associated with the glioma cancer cells formation through Notch, Hedgehog (Hh), Wnt/beta-catenin, and focal adhesion pathways (13). Therefore, upregulation of miR-126 may suppress IRS-1 and subsequently trigger the formation of glioma cancer stem cell (14).

Cancer progression needs permanent formation of blood vessels to nourish the cancer cells. Thus, controlling this factor is of immense importance in inhibition of cancer progression (15). Furthermore, miR-126 can affect many cellular mechanisms involved in cancer pathogenesis via suppressing translation of numerous validated target gene such as PI3K, KRAS, EGFL7, CRK, ADAM9, HOXA9, IRS-1, SOX-2, SLC7A5 and VEGF in colorectal, gastric, oesophageal, oral, pancreatic, liver, thyroid, breast, cervical, ovarian, prostate, bladder, renal, and lung cancers as well as melanoma, osteosarcoma and leukemia (16). We here used molecular signaling pathway enrichment analysis to determine possible associations between miR-126 and IRS1 within neurotrophin pathway, for the first time.

Materials and Methods

In this prospective study, all miRNA-mRNA prediction analyses were conducted by miRWalk 2.0 database (zmf.umm.uni-heidelberg.de/apps/zmf/mirwalk2/) which is an integrative mRNA-miRNA prediction database (17). In order to find validated interactions, we implemented miRtarbase database (http://mirtarbase.mbc.nctu.edu.tw/) which provides experimentally validated mRNA-miRNA interactions from all previously performed studies (18).

Then, approximate expression of miR-126 targeting in glioma tissue was examined using UniGene database (http://www.ncbi.nlm.nih.gov/uniGene). Finally, in silico molecular pathway enrichment analysis was carried out by DAVID 6.7 database (http://david.abcc.ncifcrf.gov/) (19) to explore which signaling pathway is related to miR-126 targetome and how miR-126 attributes to the formation of glioma. This database utilized the P values associated with each annotation terms inside each cluster are exactly the same meaning/values as those (Fisher’s Exact/EASE Score) shown in the regular chart reported for the same terms.

Results

At the first step, in order to find the predicted target genes of miR-126, miRWalk 2.0 was implemented. Approximately 111 target genes were predicted to be the potential targets of miR-126. Moreover, 24 genes were also validated to be the target genes of miR-126. The predicted target could be the potential targets of miR-126 reported by miRWalk database. Checking DAVID database showed the involvement of miR-126 target genes in several signaling pathways indicated by the KEGG database including cancer pathway, neurotrophin signaling pathway, glioma, insulin signaling pathway, focal adhesion, chemokine signaling pathway and regulation of actin cytoskeleton (Table 1). Also, validated target genes of miR-126 were extracted from mirtarbase (Table 2) and predicted target genes of miR-126 were obtained from miRWalk 2.0 (Table 3).

Fisher’s exact test P values and enrichment scores [corresponding to false discovery rate (FDR)] were calculated to characterize the gene groups enriched in
the target list. According to the results, PIK3R2, KRAS, CRK and IRS1 were involved in the different pathways mentioned above and were targeted by miR-126. Furthermore, the target genes, were experimentally validated.

Our evaluation determined that some KEGG pathways (Table 1) including neurotrophin (Fig.2) and focal adhesion signaling pathways (Fig.3) are the ones that are most statistically associated with miR-126 targeting. Interestingly, four genes namely, KRAS, PIK3R2, IRS1 and CRK were influenced by miR-126. Among them, PIK3R2 and KRAS were shown to be the most effective genes in focal adhesion and neurotrophin pathways.

| Signaling pathway                              | Count | %     | P value  | FDR     | Genes                                      |
|-----------------------------------------------|-------|-------|----------|---------|--------------------------------------------|
| Neurotrophin signaling pathway                | 8     | 6.15  | 0.000035 | 0.036985| 1398, 10818, 2309, 3667, 3845, 8660, 4792, 5296 |
| Insulin signaling pathway                     | 6     | 4.61  | 0.0034   | 3.5688779| 1398, 7248, 3667, 3845, 8660, 5296          |
| Aldosterone-regulated sodium reabsorption     | 4     | 3.07  | 0.0036   | 3.798433 | 3667, 3845, 8660, 5296                      |
| Prostate cancer                               | 7     | 5.38  | 0.00005  | 0.052897 | 3480, 9134, 1869, 3845, 1027, 4792, 5296     |
| Chronic myeloid leukemia                      | 6     | 4.61  | 0.00024  | 0.252281 | 1398, 1869, 3845, 1027, 4792, 5296          |
| Small cell lung cancer                        | 6     | 4.61  | 0.0004   | 0.428764 | 9134, 1869, 1027, 4792, 3655, 5296          |
| Pathways in cancer                            | 10    | 7.69  | 0.00065  | 0.691123 | 1398, 3480, 9134, 1869, 7422, 3845, 1027, 4792, 3655, 5296 |
| Chemokine signaling pathway                   | 7     | 5.38  | 0.0027   | 2.838854 | 1398, 6387, 2309, 7852, 3845, 4792, 5296     |
| Non-small cell lung cancer                    | 4     | 3.07  | 0.0079   | 8.08554  | 1869, 2309, 3845, 5296                      |
| Glioma                                        | 4     | 3.07  | 0.012    | 12.1033  | 3480, 1869, 3845, 5296                      |
| Renal cell carcinoma                          | 4     | 3.07  | 0.016    | 15.78153 | 1398, 7422, 3845, 5296                      |
| Melanoma                                      | 4     | 3.07  | 0.017    | 16.34347 | 3480, 1869, 3845, 5296                      |
| Pancreatic cancer                             | 4     | 3.07  | 0.017    | 16.91404 | 1869, 7422, 3845, 5296                      |
| ErbB signaling pathway                        | 4     | 3.07  | 0.028    | 26.3737  | 1398, 3845, 1027, 5296                      |
| Type II diabetes mellitus                     | 3     | 2.3   | 0.05     | 41.96915 | 3667, 8660, 5296                            |
| Focal adhesion                                | 5     | 3.84  | 0.066    | 51.80995 | 1398, 3480, 7422, 3655, 5296                |
| Endometrial cancer                            | 3     | 2.3   | 0.066    | 48.06802 | 2309, 3845, 5296                            |
| Colorectal cancer                             | 3     | 2.3   | 0.14     | 78.64442 | 3480, 3845, 5296                            |
| Progesterone-mediated oocyte maturation       | 3     | 2.3   | 0.14     | 79.97993 | 3480, 3845, 5296                            |
| Regulation of actin cytoskeleton              | 4     | 3.07  | 0.23     | 93.51759 | 1398, 3845, 3655, 5296                      |

FDR: False discovery rate. miR-126 target genes in several signaling pathways such as pathways in cancer, neurotrophin signaling pathway, glioma, insulin signaling pathway, focal adhesion, chemokine signaling pathway and regulation of actin cytoskeleton, etc.
**Table 2: Targets of hsa-miR-126 validated by mirTarbase**

| Hsa-miR-126 | Entrez gene ID | Brain | Glioma |
|-------------|---------------|-------|--------|
| SPRED1      | 161742        | 36    | 37     |
| PLK2        | 10769         | 388   | 121    |
| CCNE2       | 9134          | 27    | 37     |
| RGS3        | 5998          | 69    | 74     |
| TOM1        | 10043         | 178   | 102    |
| CRK         | 1398          | 83    | 83     |
| VEGFA       | 7422          | 52    | 158    |
| PIK3R2      | 5296          | 70    | 279    |
| VCAM1       | 7412          | 20    | 0      |
| IRS1        | 3667          | 11    | 27     |
| E2F1        | 1869          | 18    | 55     |
| SOX2        | 6657          | 70    | 429    |
| TWF1        | 5756          | 38    | 55     |
| TWF2        | 11344         | 51    | 74     |
| DNMT1       | 1786          | 48    | 74     |
| KRAS        | 3845          | 32    | 9      |
| IGFBP2      | 3485          | 84    | 457    |
| PITPNC1     | 26207         | 34    | 46     |
| MERTK       | 10461         | 12    | 46     |
| EGFL7       | 51162         | 20    | 37     |
| SLC7A5      | 8140          | 48    | 65     |
| TEK         | 7010          | 40    | 0      |
| ADAM9       | 8754          | 21    | 37     |
| CXCL12      | 6387          | 44    | 0      |
| FOXO3       | 2309          | 80    | 121    |
| CXCR4       | 7852          | 34    | 27     |
| CD97        | 976           | 52    | 83     |
| TCF4        | 6925          | 187   | 93     |
| Cdkn1b      | 1027          | 173   | 46     |
| RHOU        | 58480         | 58    | 93     |
| LRP6        | 4040          | 19    | 9      |
| ADM         | 133           | 42    | 158    |
| NFKBIA      | 4792          | 48    | 167    |

*; Transcripts per million (TPM).

**Table 3: A part of targets of hsa-miR-126 predicted by mirWalk2**

| Gene          | EntrezID | Brain | Glioma |
|---------------|----------|-------|--------|
| PTPN9         | 5780     | 27    | 93     |
| SOX2          | 6657     | 70    | 429    |
| GOLPH3        | 64083    | 119   | 111    |
| PEX5          | 5830     | 73    | 55     |
| RGS3          | 5998     | 69    | 74     |
| UBQLN2        | 29978    | 57    | 102    |
| SPRED1        | 161742   | 36    | 37     |
| CRK           | 1398     | 48    | 37     |
| ITGA6         | 3655     | 31    | 27     |
| IRS1          | 3667     | 11    | 27     |
| LRP6          | 4040     | 19    | 9      |
| SLC7A5        | 8140     | 48    | 65     |
| HERPUD1       | 9709     | 86    | 167    |
| PLK2          | 10769    | 388   | 121    |
| SOX21         | 11166    | 13    | 74     |
| GATAD2B       | 57459    | 32    | 18     |
| ORMDL3        | 94103    | 37    | 83     |
| ANTXR2        | 118429   | 25    | 0      |
| PKD2          | 5311     | 21    | 9      |
| PLXNB2        | 23654    | 64    | 74     |
| FOXO3         | 2309     | 80    | 121    |
| IGF1R         | 3480     | 36    | 102    |
| QDPR          | 5860     | 374   | 65     |
| SDC2          | 6383     | 115   | 55     |
| IRS2          | 8660     | 37    | 121    |
| LARGE         | 9215     | 39    | 46     |
| TOM1          | 10043    | 178   | 102    |
| MGEA5         | 10724    | 182   | 83     |

*; Transcripts per million (TPM).
Fig. 2: miR-126 is involved in neurotrophin signaling pathway pathways including IRS1, PI3K and IκB, which their partial diagram collected from KEGG pathway is demonstrated. Red stars mark targets of miR-126.

Fig. 3: Involvement of miR-126 targetome in focal adhesion signaling pathway from KEGG is shown. miR-126 target genes are determined by red star marks.

Discussion

So far, MiR-126 is the only characterized miRNA that shows endothelial cell (EC)-specific expression and the first vascular miRNA that was knocked out in mice. Loss-of-function studies in mice and zebrafish showed that miR-126 possesses an important function in controlling vascular integrity and angiogenesis (17, 18). Previous studies indicated truncation of miR-126 in mouse as a pathogenic cause of leaky vessels, hemorrhage, and embryonic death, due to loss of vascular integrity and defective angiogenesis. MiR-126−/− mice demonstrated severely hindered vascularization during development of cranial vessel and retina. In addition, miR-126−/− showed defective angiogenesis in response to angiogenic factors (19).

Knockdown of miR-126 in zebrafish led to hemorrhage, and collapse of the dorsal aorta and primary cardinal veins, indicating a conserved function of miR-126. In vivo functional studies in mice and zebrafish showed a function for Egfl7 (as the host gene of miR-126) in EC migration and vasculogenesis (20, 21). Interestingly, edema, defective cranial vessel and retina vascularization were the signs for miR-126−/− mice as well as Egfl7-knockout mice. The molecule responsible for the observed phenotype has been discussed. However, in miR-126−/− mice, Egfl7 expression was not altered (21). Nonetheless, miR-126 expression in Egfl7-knockout mice was not reported (22). Recently, floxed alleles of Egfl7 (Egfl7flox) and miR-126 (miR-126flox) were generated (23).

Egfl7flox/flox mice, in which miR-126 expression is not affected, are phenotypically normal whereas miR-126−/− mice, in which Egfl7 is normally expressed, exhibit numerous previously explained embryonic and postnatal vascular phenotypes observed in Egfl7-knockout mice. These results indicated that miR-126 is an essential factor not only for angiogenesis but also for maintenance of vascular integrity. The in vivo functions of Egfl7 might be supported by its paralog Egfl8. This debate highlights the significance of minimally disruptive gene-targeting strategies because of the presence of intronic miRNAs in the genome. Neoangiogenesis is important for vascular regeneration in response to injury, such as myocardial infarction (MI).

miR-126−/− mice also exhibited reduced survival and defective cardiac neovascularization following MI, suggesting a significant role for miR-126 in neoangiogenesis (24). Previous reports have indicated that proangiogenic function of miR-126 is exerted through enhancement of MAP kinase and PI3K signaling in response to vascular endothelial growth factor (VEGF) and fibroblast growth factors (FGF) (20). Also, Saito et al. (25) examined alterations in epigenetic and expression levels of miR-126 in human cancer cells. Therefore, it seems that epigenetic modifications may control the expression of miR-126 as a tumor suppressor intronic miRNA through directly controlling the host target gene, EGFL7 (26). Apart from Spred-1, PIK3R2 and EGFL7, miR-126 targets vascular cell adhesion protein 1 (VCAM-1), thereby affects the regulation of the adhesion of leukocytes to the endothelium (27) defining another role for miR-126 in vascular inflammation. It was also reported that MiR-126 prevents tumorigenesis and is downregulated in many cancer lines (25, 26, 28).

Importantly, PIK3R2 and CT10 regulator of kinase (CRK) showed to be the targets for miR-126 in cancer cells (28). Evidence showing that PIK3R2 represses PI3K-AKT signaling in ECs but enhances PI3K-AKT signaling in cancer cells, is not sufficient. Nevertheless, these results indicate that miR-126 is a multi-functional miRNA with important roles in angiogenesis, tumor growth and invasion, and vascular inflammation (29). Another target of miR-126 was revealed by Zhang et al. (10). They showed that miR-126 prevented cell cycle progression in
breast cancer cells via targeting IRS-1 at 3'-U TR (8). Also, miR-126 targets HOXA9; the overexpression of HOXA9 is associated with poor prognosis in acute myelogenous leukemia (26). These studies showed that miR-126 plays a significant role in tumorigenesis, tumor progression and metastasis (22, 28).

Neurotrophins form a family of growth factors which play significant roles in neuronal development. This family has four members in mammals: i. Brain-derived neurotrophic factor (BDNF), ii. Nerve growth factor (NGF), iii. Neurotrophin-3 (NT3), and iv. Neurotrophin-4/5 (NT4/5) (30). Neurotrophins are synthesized as larger precursors which undertake proteolytical cleavage for production of mature neurotrophins. These factors perform multiple functions in the nervous system. As they may raise survival, differentiation, axon outgrowth or apoptosis (31, 32).

Barker indicated that depending on the type of neurotrophin and the expression pattern of neurotrophin receptors (NTRs), neurotrophin is triggered by binding to two different classes of cell surface receptors namely, p75NTR and Trk receptors. The Trk receptors (TrkA, TrkB, and TrkC) comprise a large family of receptor tyrosine kinases, whereas p75NTR is structurally a member of the Fas/TNF-R family (33, 34). In primary cultures of rodent superior cervical ganglion sympathetic neurones, the TrkA ligands, NGF and NT3 enhance survival and neurite outgrowth during embryonic development, whereas the p75NTR ligand, BDNF has been reported to induce apoptosis (35). Evangelopoulos et al. (36) showed that TrkB-Fc or TrkC-Fc receptors are useful tools for modification of the survival of neuroblastoma cells.

Ahn et al. (11) showed that glioma invasion mediated by the p75 neurotrophin receptor (p75NTR/CD271), requires regulated interaction with PDLIM1 (a member of the ALP subfamily of PDZ/LIM proteins). Wadhwa et al. (37) suggested that Trk A and Trk B are involved in early stages of tumor pathogenesis, giall proliferation, and progression of malignancy. Lawn et al. (38) and Forsyth et al. (39) proved that neurotrophin signaling pathway promotes the growth and proliferation of glioma cell line. Li et al. (40) confirmed that different mechanisms found for regulations of NDAP (neurotrophin-regulated neuronal development-associated protein) expression by neurotrophins, might be checkpoints for apoptosis during neuronal development.

Conclusion
Our results suggested a significant role for neurotrophin signaling pathway in gliomagenesis. According to our findings, overexpression of miR-126 may lead to downregulation of IRS-1 and subsequently formation of glioma cancer stem cell.

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Author’s Contributions
M.R., M.D.; Literature review, data collection, data analysis, and wrote final manuscript. K.G., M.P.; Supervising of project, interpretation of data and revising of manuscript. All authors read and approved the final manuscript.

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