Effect of Human Ovarian Tissue Vitrification/Warming on the Expression of Genes Related to Folliculogenesis

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ABSTRACT

Background: Ovarian tissue cryopreservation is an alternative strategy to preserve the fertility of women predicted to undergo premature ovarian failure. This study was designed to evaluate the expression of folliculogenesis-related genes, including factor in the germline alpha (FIGLA), growth differentiation factor-9 (GDF-9), follicle-stimulating hormone receptor (FSHR), and KIT LIGAND after vitrification/warming of human ovarian tissue. Methods: Human ovarian tissue samples were collected from five transsexual women. In the laboratory, the ovarian medullary part was removed by a surgical blade, and the cortical tissue was cut into small pieces. Some pieces were vitrified and warmed and the others were considered as non-vitrified group (control). Follicular normality was assessed with morphological observation by a light microscope, and the expression of FIGLA, KIT LIGAND, GDF-9, and FSHR genes was examined using real-time RT-PCR in both the vitrified and non-vitrified groups. Results: Overall, 85% of the follicles preserved their normal morphologic feature after warming. The percentage of normal follicles and the expression of FIGLA, KIT LIGAND, GDF-9, and FSHR genes were similar in both vitrified and non-vitrified groups (P > 0.05). Conclusion: Vitrification/warming of human ovarian tissue had no remarkable effect on the expression of folliculogenesis-related genes.

Keywords: Vitrification, Gene expression, Humans

INTRODUCTION

Ovarian tissue cryopreservation is an alternative strategy to preserve the fertility of women predicted to undergo premature ovarian failure due to cancer treatment, genetic disorders, or other certain diseases [1, 2]. This approach has the advantage of restoring both fertility and endocrine function [3] and may be the only acceptable method to preserve fertility for pre-pubertal girls [4], for women who cannot delay the start of cancer treatment and for women with hormone-sensitive malignancies [5].

There are two methods for cryopreservation of ovarian tissue: slow freezing and vitrification. Slow freezing, which was introduced earlier, is still available in clinical practice [6]; however, due to simplicity, safety, and inexpensiveness of vitrification technique, more attention has been recently given to this method [7].

Different studies have been conducted on the vitrification of human ovarian tissue and some of them have demonstrated the incidence of damage to the follicles [8-11]. Most studies, on the other hand, have reported that the majority of follicles in ovarian cortical tissue maintain their normal morphology and fine structure at the electron microscopy level after vitrification and warming [12-15].

The normal growth and development of follicles require the expression of specific genes involved in the folliculogenesis [16]. Factor in the germline alpha (FIGLA) gene plays an important role in the early stages of follicular development. It is exclusively expressed in primordial follicles and has a regulatory role in the expression of the zona pellucida genes and also in the formation of primordial follicles in the early events of folliculogenesis [17]. The mutation of this gene can cause early menopause [18]. In the later stages of development, growth differentiation factor-9...
(GDF-9) gene is expressed in the primary follicle oocytes. It has been proposed to be an important regulator of early follicular growth, supporting oocyte viability [19], recruitment of theca cells [20], and finally, transition of primary follicles to secondary follicles [19].

Some developmental genes are expressed in granulosa cells, including KIT LIGAND gene that is expressed in the granulosa cells of primordial follicles and causes the follicular transition from primordial to primary follicles [21]. Follicle-stimulating hormone receptor (FSHR) is another gene that is expressed in the granulosa cells of secondary follicles, and causes follicular transition from secondary to antral follicles [22].

There is a dearth of report regarding the expression of some genes after vitrification/warming of the ovarian tissue [23, 24]. Recently, Abdollahi et al. [23] has shown that the expression of some apoptosis-related genes is changed and some of them are unchanged after vitrification/warming of the ovarian tissue.

According to our knowledge, there is a lack of information on the expression of folliculogenesis-related genes involved in early follicular development after cryopreservation of human ovarian tissue. Thus, this study was designed to evaluate the expression of folliculogenesis-related genes, including FIGLA, KIT LIGAND, GDF-9, and FSHR after vitrification/warming of human ovarian tissue.

MATERIALS AND METHODS

All reagents and materials were obtained from Sigma-Aldrich (Germany) except mentioned otherwise.

Ovarian tissue collection. The ovarian tissue samples were collected from five transsexual women (female to male) aged 20-30 years old, suffering from gender identity disorder. The women were underwent sex reassignment surgery by hysterectomy and gender identity disorder. The women were undergo sex reassignment surgery by hysterectomy and then oophorectomy, under a protocol approved by the Ethics Committee of the Faculty of Medical Science of Shahid Beheshti University, Tehran, Iran (Ref. No.71). They were subsequently embedded in paraffin wax (routine protocol) and serially sectioned at 5 μm thickness. Every 10th section of each fragment was mounted on glass slides and stained with hematoxylin and eosin. Then each section was examined by a light microscope to count follicles (×10 objective). To avoid counting the follicles more than once, only those with a visible nucleus of oocytes were counted.

The follicles were classified as primordial, primary, secondary, and antral according to Lass et al. [25]. Primordial follicles contained one layer of flattened granulosa cells; primary follicles had one layer of cuboidal granulosa cells; secondary follicles had two or more layers of cuboidal granulosa cells; and antral follicles showed multiple layers of cuboidal granulose cells with antrum. Normal follicles contained round oocytes, surrounded by granulosa cells in a close contact to each other. The ooplasm was homogenous with finely granulated nucleus. Atretic follicles had pyknotic oocyte nucleus, shrunken ooplasm or disorganized granulosa cells.

RNA extraction and cDNA synthesis for molecular assessment. In vitrified and non-vitrified groups (at least 9 fragments in each group), three to five fragments from three different ovarian samples were stored at -80°C for subsequent molecular assessment. Total RNA was extracted from the vitrified and non-
vitrified ovarian tissues using TRIzol reagent (Invitrogen, USA) according to the manufacturer’s instructions. The RNA samples were treated with DNase to eliminate any genomic DNA contamination just prior to proceed with the cDNA synthesis. Then the RNA concentration was determined by spectrophotometry and adjusted to a concentration of 250 ng/μl. Finally, 1000 ng of the extracted RNA was used for cDNA synthesis using the commercial Kit (Thermo Scientific, EU) according to the manufacturer’s instructions. Using oligodT, the extracted RNA was reverse transcribed by Moloney murine leukemia virus reverse transcriptase. The cDNA-synthesis reaction was performed at 42°C for 60 min, and the obtained cDNA was stored at -20ºC until use.

Real-time RT-PCR. The primers for real-time RT-PCR were newly designed using the Gen Bank (http://www.ncbi.nlm.nih.gov) and online software such as Primer3 and Oligo Analyzer. As shown in Table 1, newly designed primers were ordered and synthesized at Generary Biotech Co. (China). One-step RT-PCR was performed using the Applied Biosystems (UK) real-time thermal cycler according to QuantiTect SYBR Green RT-PCR Kit (Applied Biosystems, UK, Lot no: 1201416). The housekeeping gene, β-ACTIN, was used as an internal control. One microliter of cDNA, 1 μl of the mixture of forward and reverse primers, and 10 μl of SYBR Green Master Mix were used per 20 μl of the reaction volume. After completing the PCR run, melt curve analysis was applied to confirm the amplified product and record the Ct values. A single, sudden decline of fluorescence during a melt curve at a high temperature indirectly indicates a specific amplicon being amplified during the PCR run; otherwise cDNA would be omitted and the cDNA of another fragment would be replaced. For each sample, the reference gene (β-ACTIN) and the target genes were amplified in the same run.

The real-time thermal condition included holding step at 95ºC for 5 min, cycling step at 95ºC for 15 s, 58ºC for 30 s, and 72ºC for 15 s, which was continued by a melt curve step at 95ºC for 15 s, 60ºC for 1 min, and 95ºC for 15 s. Then the relative quantification of target genes was determined using the Pfaffl method [26]. The real-time RT-PCR experiments were done in duplicate for each sample.

Statistical analysis. Statistical analysis was carried out with the SPSS 19.0 software. Quantitative variables were expressed as mean ± SE and percentage. The normality of data was assessed by Kolmogrov-Smirnov test, and the homogeneity of variance was assessed by Levene's test. The results of real-time RT-PCR were compared by independent samples t-test. P values less than 0.05 were considered as statistically significant.

RESULTS

Histological observation of ovarian tissue. The morphology of ovarian cortical sections in both the vitrified and non-vitrified groups is shown in Figure 1. The follicle contained round oocyte, surrounded by granulosa cells in close contact to each other. Stromal cells had spindle shaped nucleus with a finely diffused chromatin. After vitrification/warming, the follicular integrity and stromal tissue structures were preserved, however, detachment between oocyte and granulose cells were observed in some follicles (Fig. 1). No antral follicles were observed in any of the two groups.

Follicular counting of ovarian tissue. A total of 510 follicles were counted and analyzed in both the vitrified and non-vitrified tissues (200 follicles in the vitrified and 310 follicles in the non-vitrified tissues). The percentages of the morphologically normal follicles at different developmental stages in both groups are summarized in Table 2. Overall, 85% of the

Table 1. The characteristic of primers used in real-time RT-PCR assays

<table>
<thead>
<tr>
<th>Accession number</th>
<th>Target gene</th>
<th>Primer sequence</th>
<th>Product size (bp)</th>
</tr>
</thead>
</table>
| NM_001101.3      | β-ACTIN     | Forward: 5’ –TCAGAGCAAGAGAGGCAATCC- 3’  
Reverse: 5’ –GGTCATCTTCTACGGTTGG- 3’ | 187 |
| NM_001004311.3   | FIGLA       | Forward: 5’ –TCGTCCACTGAAAACCTCCAG- 3’  
Reverse: 5’ –TTCTTATCCGCTACGCTCC- 3’ | 76 |
| NM_000899.4      | KIT LIGAND  | Forward: 5’ –AATCTCTTCGCTAAAACCTGAAG- 3’  
Reverse: 5’ –CCATCTGCTTATCCACACTGA- 3’ | 163 |
| NM_005260        | GDF-9       | Forward: 5’ –TCCACCCACACACCTGAAAT- 3’  
Reverse: 5’ –GCAGCAAAAAACAAAGAGGG- 3’ | 147 |
| NM_181446.2      | FSHR        | Forward: 5’ –CTGCGAAGAGGAAATGAGTCC- 3’  
Reverse: 5’ –TGAGATGTGTACCCGATGATA- 3’ | 157 |

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follies preserved normal morphologic feature and 15% were degenerated after warming. Among normal follicles, the proportion of primordial, primary, and secondary follicles was 57.7%, 25.2%, and 2.1%, respectively. There was no significant difference in the percentage of normal follicles at different developmental stages between the two groups (\( P > 0.05 \)).

Expression of folliculogenesis-related genes in ovarian tissue. The expression ratio of several target genes (FIGLA, KIT LIGAND, GDF-9, and FSHR) to housekeeping gene (\( \beta \)-ACTIN) in the vitrified and non-vitrified tissues is shown in Figure 2. The expression level of FIGLA, KIT LIGAND, GDF-9, and FSHR to \( \beta \)-ACTIN in the vitrified tissues were \( 14 \times 10^{-4} \pm 0.9 \times 10^{-4} \), \( 7.3 \times 10^{-4} \pm 3.9 \times 10^{-4} \), \( 13 \times 10^{-4} \pm 1.8 \times 10^{-4} \), and \( 18.7 \times 10^{-4} \pm 0.3 \times 10^{-4} \), respectively. This ratio in the non-vitrified tissues were \( 18.4 \times 10^{-4} \pm 7.7 \times 10^{-4} \), \( 8.6 \times 10^{-4} \pm 2.9 \times 10^{-4} \), \( 17.3 \times 10^{-4} \pm 5.6 \times 10^{-4} \), and \( 24 \times 10^{-4} \pm 9.5 \times 10^{-4} \), respectively. There was no significant difference between the target genes expression in the vitrified and non-vitrified tissues (\( P > 0.05 \)).

**DISCUSSION**

Morphological observations in the present study showed that the majority of follicles in human ovarian cortical tissue maintained their normal structure after vitrification/warming. There was no significant difference in the percentage of intact follicles in the vitrified and non-vitrified tissues (\( P > 0.05 \)). In addition, the integrity of ovarian stromal tissue was well preserved; therefore, it seems that this procedure of vitrification can be a good alternative for human ovarian tissue cryopreservation. The competence of this method may be the result of using EG, DMSO, and sucrose as cryoprotectants. EG has low toxic effect, rapid cell diffusion, the high compatibility with other cryoprotectants, and the best survival rate of follicle [27]. Most protocols yielding successful results use solutions containing a mixture of DMSO and EG [12, 13, 15, 28, 29]. This cryoprotectant compound has also been effective in preserving the ovarian tissue integrity of other species [8, 12]. Moreover, adding sucrose assists dehydration, decreases the risk of intracellular crystallization and reduces the toxic effects of

<table>
<thead>
<tr>
<th>Group</th>
<th>Total no. of follicles</th>
<th>No. of normal follicles (%mean ± SE)</th>
<th>No. of primordial follicles (%mean ± SE)</th>
<th>No. of primary follicles (%mean ± SE)</th>
<th>No. of secondary follicles (%mean ± SE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vitrified</td>
<td>200</td>
<td>171 (85.0 ± 1.3)</td>
<td>115 (57.7 ± 3.4)</td>
<td>52 (25.2 ± 3.0)</td>
<td>4 (2.1 ± 0.2)</td>
</tr>
<tr>
<td>Non-vitrified</td>
<td>310</td>
<td>284 (90.4 ± 2.0)</td>
<td>199 (60.7 ± 7.1)</td>
<td>72 (25.0 ± 4.9)</td>
<td>13 (4.7 ± 1.8)</td>
</tr>
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</table>

There is no significant difference in the percentage of normal follicles at different developmental stages between the two groups (\( P > 0.05 \)).

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Few studies have been conducted regarding alteration in gene expression patterns after vitrification of ovarian tissue in other species [1, 24]. In contrast to our results, Choi et al. [24] have shown that angiogenic gene expression is increased significantly in mouse ovarian tissue after vitrification/warming. Also, the expression of GAPDH gene in bovine ovarian tissue was diminished after vitrification with ethyl vinyl acetate bag [1]. Abdollahi et al. [23] reported that the expression of some apoptosis-related genes was changed and some intact. This discrepancy between these results can be due to differences in the methods of vitrification or different subjects of species.

Therefore, to better understand the effect of vitrification/warming on the gene expression of human ovarian tissue, more additional studies after long term in vitro culture or xenograft transplantation of the vitrified tissues are needed.

In conclusion, our results, for the first time, demonstrated that in spite of some alterations in morphology of human ovarian tissue after vitrification using DMSO, EG, and sucrose, no remarkable effect was observed on the expression of folliculogenesis-related genes immediately after warming.

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