Fertility preservation in patients with BRCA mutations or Lynch syndrome

Giacomo Corrado, Claudia Marchetti, Rita Trozzi, Giovanni Scambia, Anna Fagotti

ABSTRACT
Guidelines and expert consensus are lacking on fertility preservation in BRCA mutation carriers and in patients with Lynch syndrome. The safety of fertility preservation in this setting is still a topic of debate and multiple factors need to be carefully considered. The aim of this review was to analyze the reproductive potential of women harboring a genetic mutation affecting the DNA repair system and explore the efficacy and safety of existing fertility preservation strategies in these patients.

INTRODUCTION
Hereditary breast and ovarian cancer syndrome, and Lynch syndrome (hereditary non-polyposis colorectal cancer), increase gynecological cancer risks. Both are inherited as autosomal dominant disorders. In particular, hereditary breast and ovarian cancer syndrome is characterized by pathogenic variants in the BRCA1 and 2 genes, but other genes involved in the DNA repair process might also be involved as damage of these genes increases the risk of breast and ovarian tumors but also of pancreatic and prostate cancer. Lynch syndrome is associated with pathogenic variants in a mismatch repair gene family and is associated with an increased risk of colorectal cancer, as well as endometrial, breast, and ovarian cancer. Primary and secondary prevention in women carrying these mutations is focused on early cancer detection and/or on prophylactic procedures.

As screening remains of limited value, at least in ovarian cancer, women may choose surgical options, such as risk reducing bilateral salpingo-oophorectomy, bilateral salpingectomy, or hysterectomy to reduce the risk of cancer. Since hereditary cancers are associated with a relatively young onset, risk reducing surgery is generally recommended between the ages of 35–45, or when childbearing is completed; however, these procedures lead to premature menopause and infertility.

In this review, we focus on fertility issues in women harboring a genetic mutation of DNA repair genes, in particular BRCA1 or BRCA2, or with Lynch syndrome.

FERTILITY PRESERVATION IN BRCA 1/2 MUTATION CARRIERS
We performed a literature review to summarize data on the assessment of fertility potential and response to in vitro fertilization techniques on BRCA mutation carriers. We searched PubMed with the key words ‘BRCA and fertility’ and found 98 articles between January 2000 and March 2020. We excluded non-English language articles, review articles, surveys, video articles, and non-pertinent articles. We obtained 13 articles reporting data on 3145 patients, of which 2211 were BRCA wild type, 599 BRCA mutated (335 BRCA1, 237 BRCA2, 4 heterozygous BRCA1/2 carriers, 5 mutation of unknown significance, 4 BRCA1–2 mutation, 14 non-specified BRCA mutation types). 245 patients were controls and 90 had an unknown mutation status.

BRCA Status and Fertility Potential
BRCA1 and 2 genes are key members of the kinase ataxia–telangiectasia mutated mediated DNA double strand break repair pathway. The prevalence of BRCA deleterious mutations is approximately 1:300–500 in the general population. Overall, BRCA mutations account for 17–65.5% of breast cancers and 16.2–40% of ovarian cancers. Of specific relevance for the present review is the fact that BRCA related malignancies are characterized by a precocious onset. A 20-year-old patient with a BRCA1 mutation has a 12% and 3.2% risk of developing breast and ovarian cancers, between the ages of 20 and 40 years, respectively. For a similar patient with a BRCA2 mutation, these risks are 7.5% and 0.7%, respectively. Considering the current trend to postpone pregnancy to later in life, especially in Western countries, it is anticipated that an increasing proportion of young women will be diagnosed with cancer before completing childbearing. The most effective measure to reduce the risk of ovarian cancer in BRCA mutated patients is risk reducing salpingo-oophorectomy at age 35–40, but this impairs fertility, inducing a premature menopause.

Moreover, BRCA mutations seem to directly influence the fertility potential of the mutation carrier. In fact, because BRCA genes play critical roles in the repair of double stranded DNA breaks, it is plausible that germline mutations of BRCA genes can lead to accelerated oocyte apoptosis as well as depletion. Titus and colleagues demonstrated in animal models that impairment in DNA double strand break repair caused by BRCA mutation results in accelerated loss of primordial ovarian follicles and ovarian aging.

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Anti-Müllerian Hormone

The anti-Müllerian hormone (AMH) is a member of the transforming growth factor-β (TGF-β) family, which is produced in the granulosa cells of ovarian follicles and can be detected in serum. Several studies have validated anti-Müllerian hormone as an index of ovarian reserve, which reflects the decline in reproductive capacity. In our search, we considered 11 studies evaluating anti-Müllerian hormone levels in BRCA mutation carriers compared with wild-type patients. We included studies that compared BRCA mutation carriers with wild-type patients due to several confounding factors, such as body mass index, age, and parity, which can influence AMH levels.

Table 1: Ovarian function and fertility assessment

<table>
<thead>
<tr>
<th>Article</th>
<th>Year</th>
<th>Study Type</th>
<th>Patients Included</th>
<th>BRCA Mutated</th>
<th>BRCA WT</th>
<th>Other</th>
<th>Cancer</th>
<th>Fertility Assessment: AMH Levels</th>
<th>Antral Follicular Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Porcu et al</td>
<td>2020</td>
<td>Prospective</td>
<td>227</td>
<td>32.2</td>
<td>31.5</td>
<td>33.2</td>
<td>32.5</td>
<td>32.4</td>
<td>22</td>
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<tr>
<td>Porcu et al</td>
<td>2020</td>
<td>Case-control</td>
<td>135</td>
<td>32.35</td>
<td>32.6</td>
<td>32.1</td>
<td>32.7</td>
<td>/</td>
<td>69</td>
</tr>
<tr>
<td>Oktay et al</td>
<td>2020</td>
<td>Longitudinal cohort</td>
<td>108</td>
<td>33.3</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>14.0</td>
<td>0</td>
</tr>
<tr>
<td>Son et al</td>
<td>2019</td>
<td>Retrospective</td>
<td>316</td>
<td>34</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>52</td>
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</tr>
<tr>
<td>Lambertini et al</td>
<td>2019</td>
<td>Retrospective</td>
<td>148</td>
<td>34</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>148</td>
<td>148</td>
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<tr>
<td>Grynberg et al</td>
<td>2019</td>
<td>Retrospective</td>
<td>329</td>
<td>31.7</td>
<td>31.8</td>
<td>31.9</td>
<td>32.3</td>
<td>52</td>
<td>52</td>
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<tr>
<td>Lambertini et al</td>
<td>2019</td>
<td>Retrospective</td>
<td>156</td>
<td>31</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>29</td>
<td>29</td>
</tr>
<tr>
<td>Gunata et al</td>
<td>2019</td>
<td>Retrospective</td>
<td>795</td>
<td>32.4</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>57</td>
<td>57</td>
</tr>
<tr>
<td>Lin et al</td>
<td>2017</td>
<td>Comparative laboratory study</td>
<td>30</td>
<td>36.5</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>18</td>
<td>18</td>
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<tr>
<td>Johnson et al</td>
<td>2017</td>
<td>Prospective</td>
<td>195</td>
<td>31.15</td>
<td>31.4</td>
<td>30.9</td>
<td>34.3</td>
<td>30.9</td>
<td>106</td>
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<tr>
<td>Michaelson-Other et al</td>
<td>2014</td>
<td>Prospective</td>
<td>365</td>
<td>33.2</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>41</td>
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</tr>
</tbody>
</table>

AMH, anti-Müllerian hormone; WT, wild-type.

In conclusion, data are controversial and do not provide reliable information in clinical practice. Furthermore, interpretation of studies results is complicated by confounding factors, such as small sample size, different recruitment criteria, and variability in study designs. Therefore, more research is needed to better understand the impact of BRCA mutations on ovarian function and fertility potential.
Evidence in the literature suggests that fertility treatments are not associated with an increased risk of ovarian or breast cancers, even in BRCA mutation carriers.33 Gronwald et al performed a matched case-control study on 94 pairs of BRCA1 or BRCA2 mutation carriers with and without a diagnosis of ovarian cancer adjusted for age, date of diagnosis, and type of mutation, and found no significant differences between the two groups.34 These results suggest that fertility treatments do not cause ovarian or breast cancer.

Table 2: Ovarian function and fertility preservation

<table>
<thead>
<tr>
<th>Article</th>
<th>Year</th>
<th>Type of study</th>
<th>Sample Cancer</th>
<th>Median age (years)</th>
<th>Fertility preservation</th>
<th>Total dose of gonadotropins</th>
<th>No. of oocytes cryopreserved</th>
<th>No. of oocytes retrieved</th>
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<td></td>
<td>Prospective</td>
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<td>32.3, 31.5, 32.2, 32.3</td>
<td>161 46</td>
<td>236, 226, 230.3, 199.7</td>
<td>277</td>
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*unknown.*

WT, wild-type.

**TREATMENTS**

BRCA MUTATED PATIENTS AND ASSISTED REPRODUCTIVE

**Oocyte and/or Embryo Cryopreservation**

Cryopreservation of oocytes is the first recommended fertility technique for patients with a hereditary risk of cancer. It is effective even in prepubertal girls because it requires ovarian stimulation.35 Cryopreservation allows patients to undergo cancer therapy and receive fertility treatments after treatment.36 Studies have shown that cryopreservation is feasible even in BRCA mutation carriers.37

**Antral Follicle Count**

Antral follicle count is the count of resting follicles found on both ovaries at the beginning of the proliferative phase of the menstrual cycle. It is a marker of ovarian reserve and of the primordial follicle number, even after adjustment for chronological age.38 An increase in antral follicle count has been proposed, but data are few and controversial.39 We identified four studies17 22 24 25 which investigated the relationship between antral follicle count and ovarian cancer risk.40

**Review**

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*unknown.*

WT, wild-type.
detecting significant differences.22 Recently, Porcu and colleagues performed a prospective study including 67 women affected by breast cancer who had undergone fertility preservation treatment compared with 181 healthy controls. They found that patients in the BRCA positive cohort, especially BRCA1 positive patients, needed a higher dose of gonadotropins, a longer duration of stimulation, and a statistically significant lower number of oocytes cryopreserved.17

In conclusion, there is growing evidence indicating that BRCA mutations may be associated with decreased ovarian reserve and premature menopause, especially for BRCA1 mutation patients. Therefore, some authors suggest systematic fertility preservation in this population. The cryopreservation of oocytes or embryos can be discussed, emphasizing that the chances of success decrease with increasing age. Hence if these strategies are considered, this should take place at an earlier age, for example, before age 30 years and ideally before cancer diagnosis.

**Ovarian Tissue Cryopreservation**

Ovarian tissue cryopreservation maintains both fertility and endocrine ovarian function but it is still considered an experimental technique. This method does not require ovarian stimulation and offers the opportunity of a spontaneous pregnancy. Ovarian tissue cryopreservation might be proposed to selected patients, including some cancer patients scheduled for highly gonadotoxic treatment, but in particular, if treatment initiation cannot be delayed, in the case of prior exposure to chemotherapy, when ovarian stimulation is a contraindication, or to prepubertal women.10 Ovarian tissue is surgically retrieved and cryopreserved. After being thawed, ovarian tissue is grafted back to the patient, on either the orthotopic (into the pelvic cavity) or heterotopic site (subcutaneous regions such as the forearm or abdominal wall).

In BRCA mutated women, younger than the recommended age for prophylactic bilateral salpingo-oophorectomy, the procedure might be feasible. Ovarian tissue can be transplanted into the remaining ovaries so that the gonads can be removed after completion of reproductive plans. Another strategy may be subcutaneous transplantation of ovarian tissue for better monitoring.23 In Lamber-tini et al’s study23 72 patients underwent ovarian tissue cryopreservation. Patients in the BRCA positive cohort tended to have a numerically lower number of oocytes per fragment (0.08 vs 0.14; p=0.19) than those in the BRCA negative cohort (0.14 number of oocytes per fragment). Currently, two cases of pregnancy obtained by ovarian tissue cryopreservation in BRCA mutated women have been published. In both cases, BRCA2 mutation carriers, previously treated for breast cancer, became pregnant after ovarian tissue transplantation 55 and 36 months following completion of chemotherapy. This suggests that cryopreservation might be a safe and effective option for BRCA mutated patients desiring fertility after cancer treatment.

**LYNCH SYNDROME**

Evidence regarding fertility issues and Lynch syndrome are limited, and even more so when searching for other genes involved in the DNA repair pathway. A systematic review was not possible due to the paucity and heterogeneity of the data. Nonetheless, we want to highlight some major issues, as this condition, although rare, has been diagnosed more frequently in recent years due to the greater attention and knowledge of hereditary cancer syndromes. Lynch syndrome (previously referred to as hereditary non-polyposis colorectal cancer) is an autosomal dominantly inherited cancer syndrome characterized by the development of colorectal, endometrial, and ovarian cancers and various other neoplasia frequently diagnosed at an early age. It is caused by pathogenic variants of the DNA mismatch repair system genes MLH1, MSH2, MSH6, and PMS2, which prevent the correction of acquired errors during DNA synthesis.39 Gynecological cancers are often the sentinel Lynch syndrome event in women and have an excellent prognosis.40 The risk of developing endometrial cancer is very high and equals or exceeds the risk of colorectal cancer among women with Lynch syndrome.41 The cumulative incidence of endometrial cancer for pathological MLH1, MSH2, MSH6, and PMS2 is 42.7%, 56.7%, 46.2%, and 26.4% at the age of 75 years, respectively.42 Typically, women affected by Lynch syndrome are younger than unaffected women: in fact, the average age at endometrial cancer diagnosis in women with Lynch syndrome was reported to be 47–49 years (range 26–87)42 which is more than 10 years younger than the general population affected by endometrial cancer.43 Lynch cancer is considered the third most common cancer among women with Lynch syndrome44; risk estimates of developing ovarian cancer in patients affected by Lynch syndrome are approximately 8–10%,6 compared with a 1.4% risk in the general population.45 The average age of Lynch syndrome patients developing ovarian cancer is between 40 and 47 years of age which is lower than the general population affected, but higher than BRCA1 mutation carriers who develop ovarian neoplasia.

In recent years, clinical practice and guidelines for gynecological surveillance and prophylactic surgery for female Lynch syndrome variants have been evolving. According to the National Comprehensive Cancer Network guidelines,9 total hysterectomy and bilateral salpingo-oophorectomy are options in women with Lynch syndrome who have completed childbearing, in order to reduce the risk of both endometrial cancer and ovarian cancer. The timing of risk reducing surgery may be individualized based on family history and comorbidities and is not standardized, as it is in BRCA mutation carriers. Noteworthy, women diagnosed with Lynch syndrome face both a higher risk of developing cancers and the need to undergo risk preventive procedures, which may adversely impact their fertility potential. In contrast with BRCA mutation carriers, it is unclear whether or not Lynch syndrome itself is associated with impairment of fertility potential. Although mismatch repair proteins are essential in DNA replication, no evidence in the current literature suggests that Lynch syndrome directly affects fertility.46 In the only study addressing this issue, Stupart et al47 proposed a model in which they found a decrease in lifetime fertility in patients with Lynch syndrome and affected by an early diagnosis of colorectal cancer, compared with those who developed colorectal cancer later in life. For example, women diagnosed with colorectal cancer between the ages of 20 and 24 gave birth to a mean of 1.2 children in their lifetime compared with women diagnosed with colorectal cancer after age 50 years who gave birth to a mean of 2.8 children in their lifetime. The reasons for reduced fertility after colorectal cancer in these patient groups were not investigated in the study, but cancer related mortality and morbidity, effects of surgery, chemotherapy and radiotherapy, and personal choice can all be expected to play a role. However, it should be emphasized that this
is the only experience suggesting this reduction and no biological explanations have been anticipated.

When considering Lynch syndrome and endometrial cancer risk, it should be considered that because endometrial cancer is detected at earlier ages, it is common that some patients might be diagnosed when still premenopausal and with an unresolved fertility desire. Therefore, the issue of conservative treatment becomes particularly challenging. In the overall population, accumulating evidence highlights that fertility sparing options might be offered to young women diagnosed with endometrial hyperplasia or cancers limited to the endometrium. Conservative treatment in most cases consists of progestin administered orally or via a levonorgestrel coated intrauterine device. Moving to atypical hyperplasia or limited endometrial cancer, fertility preservation is more complicated because endometrial lesions are caused by genetic mutations and the efficacy of fertility sparing hormonal treatment remains debatable. In fact, it should be noted that the molecular mechanisms causing disease in patients with Lynch syndrome differ from those occurring in sporadic cases. Therefore, progestin therapy, which is more commonly used in the latter group, may be ineffective in patients harboring a defect in mismatch repair genes. Accordingly, in the guidelines and expert consensuses discussing fertility sparing treatment for atypical hyperplasia and endometrial cancer in Lynch syndrome patients, this issue is still debated and the safety of fertility sparing treatment in Lynch syndrome patients remains unclear, if not unproven. Interestingly, in a recent survey among gynecological oncologists on this issue, the majority of clinicians did not support the choice of conservative management and fertility preservation in endometrial cancer with Lynch syndrome. The authors concluded that patients have to be counseled about the risk of developing disease recurrence/persistence. Additionally, as they are at a significantly higher risk of developing ovarian cancer, the importance of performing risk reducing surgery, after patients have completed childbearing, should be emphasized.

Additional Cancer Related Genes and Impact on Fertility

With regard to other genes involved in DNA repair, several have been investigated and are related to gynecological cancer occurrence. In particular, women carrying a germline pathogenic variant in BRIP1 have an 8–11-fold increased relative risk of developing ovarian cancer, without a significantly increased risk for breast cancer. Also, pathogenic variants in RAD51C and RAD51D are associated with an increased risk for ovarian cancer without a significantly increased risk for breast cancer. In contrast, pathogenic variants in TP53, CDH1, CHEK2, and ataxia–telangiectasia mutated are associated with an increased risk of breast cancer without a significantly increased risk of ovarian cancer. As for BRCA mutation carriers, these hereditary cancers are associated with a relatively younger age of onset, and risk reducing surgeries are generally considered as the best option to prevent cancer development and are recommended between the ages of 35 and 45, or when childbearing is complete. No data about fertility function are available in these women, probably due to the low incidence of these mutations in the general population, with few available reports and, consequently, limited guidelines. Accordingly, no data about assisted reproductive technology procedures or oocyte conservation have been presented.

ETHICAL ISSUES

Gamete or gonad storage for long periods generates ethical and moral questions deserving of attention, reflection, and discussion before a fertility preservation protocol is considered. One reason for such discussion is the existence of uncertainties curtailting the processes that involve routine and experimental strategies, as well as the future use of the preserved tissues and cells if the biological owner dies. Fertility preservation preceding antineoplastic treatment lays between medical indication, based on the intention of prevention, humanization, and a social statement based on the biopsychosocial impact of procreating. In the case of cancer patients with a potential risk of fertility loss, the main ethical issue is to furnish the best information about the potential risks and the currently available techniques for the preservation of their gametes. This will allow well informed patients and their families to make the right decisions with the necessary clarity, based on personal interest concerning the possibility of future fertility.

CONCLUSIONS

Genetic testing rates for BRCA mutations or Lynch syndrome have progressively increased during the past decades resulting in a growing population of young and healthy patients with genetic alterations. For these young women, fertility is an issue as their fertile window has reduced due to prophylactic surgery and cancer treatments, and likely a reduced fertility potential. Data on fertility preservation techniques are still scant in this populations and the aim of this review was to summarize the most up to date evidence on this emerging topic. Remarkably, there is emerging but not completely accepted evidence that BRCA mutations may cause a decrease in ovarian reserve, with premature menopause. Therefore, some have proposed fertility preservation techniques in this population, with some concern about a possible increased risk of cancer. Preventive intervention is mandatory; nonetheless, identification of these women, at a young age, would allow fertility counseling and a tailored approach. In particular, these women should be advised against delaying childbearing.

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Contributors GC and CM conceived the study, carried out the design of the study, participated in the sequence alignment, and drafted the manuscript. RT carried out the analysis and interpretation of the data, and helped draft the manuscript. GS gave final approval of the version to be published and revised the manuscript. AF participated in the study’s design and coordination, gave final approval of the version to be published, and revised the manuscript. All authors read and approved the manuscript.

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