Hereditary Cancer Risk Assessment: How Best can we Achieve it?

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Abstract

Hereditary cancer risk assessment (HCRA) is a multidisciplinary process of estimating probabilities of germ-line mutations in cancer susceptibility genes and assessing empiric risks of cancer, based on personal and family histories. It includes genetic testing and management of at-risk individuals so that they can make informed choices about cancer screening, surgical and chemo preventive options, as well as genetically targeted cancer therapies. Providing patients with pre- and post-test genetic counseling may help them to get better informed decision making. Following individuals at increased risk with surveillance protocols, reassuring those at low risk, and referring those at high risk of a hereditary cancer to a cancer genetics center with outpatient clinics may be the best suitable approach to HCRA.

Keywords: Hereditary; Cancer; Mutations; Genetic testing

Introduction

Within the last decade, emerging biomolecular technologies have been continuing to grow fast and have already achieved a great deal in our understanding of inherited cancer susceptibility. Meanwhile, important issues on the translation of this knowledge into clinical practice have been rapidly addressed. One essential component of these aspects refers to genetic counseling of families with hereditary cancer syndromes. The increased public awareness of the genetic aspects of cancer susceptibility has resulted in more requests from clinical and surgical oncologists for genetic evaluation of their patients so that appropriate management can be provided.

Five to 10% of all cancers are attributable to more than fifty Mundelein syndromes which are caused by highly penetrant germ-line mutations affecting tumor suppressor genes or proto-oncogenes mostly as an autosomal dominant inheritance (Tables 1 and 2). The cumulative risks of hereditary cancers are much higher and earlier than sporadic counterparts, which dramatically affect quality of life and decrease its expectancy. Other than an earlier than expected age of cancer diagnosis (e.g., colon cancer diagnosed before age 50 years), family history is the single most important indicator of strong hereditary cancer risk for which early recognition and intervention could be lifesaving.

This review aimed to describe a high-quality approach of delivering hereditary cancer risk assessment (HCRA) in the context of a multidisciplinary clinic.

Referrals for Hcra

Identifying the inherited risk factors of cancer in a given individual or family is complex requiring important psychological, social, and ethical issues. It requires knowledge of genetics, oncology, patient and family counseling skills and involves more provider time than most other clinical services. The American Society of Clinical Oncology (ASCO), the National Society of Genetic Counselors (NSGC), the Oncology Nursing Society (ONS), and other health care professional organizations have set forth guidelines outlining standards for the practice of cancer risk counseling, risk assessment, and genetic testing [1-3]. It also includes genetic testing as appropriate and management of at-risk individuals so that they can make informed choices about cancer screening and surgical and/or chemo preventive risk management options, as well as genetically targeted cancer therapies [4].

Components of the Hcra

The genetic risk assessment of an individual with cancer is based upon a careful analysis of personal history, a detailed family history of cancer and a physical examination when appropriate. It requires the confirmation of diagnosis in affected relatives, preferably through biopsies or, whenever possible, death certificates or autopsies. These are some important issues to be addressed in the HCRA process [4]:

1. Family pedigrees drawings with at least three generations in both sides of family
2. Patients and relatives:
   a. Current age, age at diagnosis, age at death, primary site, pathologic features, treatments
   b. Ancestry (especially if Ashkenazi Jewish)
   c. Previous surgeries, biopsies, diseases
   d. Endogenous risk factors: age at menarche, fertility history
   e. Exogenous risk factors: tobacco/alcohol use, food intake, hormones, exercises
   f. Cancer screening: mammography, gastrointestinal endoscopy, PSA
   g. Chemoprevention
3. Physical examination (when appropriate): skin, head circumference, tongue, thyroid, lungs, abdomen
4. Psychosocial and family dynamic
5. Basic principles of cancer genetics
6. Differential diagnosis
7. Mutation probabilities and empirical risks
8. Pre-test genetic counseling
   a. Indentify the best individuals to test
   b. Prioritize order of testing (germ-line, tumor)

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9. Post-test genetic counseling
   a. Disclosure and interpretation of results
   b. Address psychological and ethical concerns
   c. Identify at-risk family members
   d. Discuss communication of results to at-risk family members

10. Personalized risk management strategies
   a. Screening/surveillance exams
   b. Risk reduction, cancer prevention (surgeries, chemoprevention)
   c. Empiric strategies for uninformative results

### Predicting Germ line Mutations

Several models are available to estimate the likelihood of detecting a mutation in a cancer-susceptibility gene and each model is utilized selectively based on the characteristics of the patient's personal and family history.

If a mutation in the BRCA gene is suspected to be present in a hereditary breast and ovarian cancer family, there are several models available to predict the probability of an individual carrying such a mutation. These models include the Couch, Penn II, Myriad, BRCAPRO, Tyrer-Cuzick, and BOADICEA models [5-12]. Such models incorporate breast and ovarian cancer in first- and second-degree relatives, age of onset of cancer, Ashkenazi Jewish ancestry, and some are starting to incorporate other ethnic backgrounds.

There are similar models for predicting mutation in DNA mismatch repair (MMR) genes in suspected Lynch syndrome families, including MMRpro, Wijnen, MMRpredict, and PREMM1,2,6 [13-16]. However, in the HCRA of colon cancer families, it is more common to use established criteria as an indication for testing, including the Amsterdam I, Amsterdam II [17], or revised Bethesda Guidelines [18], which determine eligibility for tumor analysis to detect microsatellite instability that would help to lead to genetic testing of MMR genes.

Furthermore, there are established diagnostic criteria for Li and Fraumeni [19,20] and Cowden syndromes [21,22], as well as mutation probability models for hereditary melanoma and pancreatic cancer (Table 3).

The use of mutation predictability models is important for several reasons. First, calculating the likelihood of a germ-line mutation can help clinicians determine which family member is the best candidate for testing. Second, due to the high cost of genetic testing, numeric calculations of mutation probability may provide supportive evidence for insurance companies. Third, for psychosocial reasons, patients who are informed with a numeric estimation of a mutation may have more realistic expectations about the possibility of a positive result. Finally, for worried patients with a low probability of a mutation, the numeric presentation may provide substantial reassurance regarding screening guidelines based on empiric cancer risks. A recent study highlighted possible health benefits and the cost-effectiveness of primary genetic screening for Lynch syndrome in the general population [23].

Nevertheless, several models may underestimate mutation probability in certain situations such as a limited family structure or specific tumor characteristics [24]. Thus, probabilities predicted by a model must be interpreted in the context of an individual's personal and family history. The National Comprehensive Cancer Network (NCCN) in USA publishes guidelines annually in order to help clinicians to

<table>
<thead>
<tr>
<th>Syndrome(s)</th>
<th>Gene(s)</th>
<th>Inheritance</th>
<th>Principal tumors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hereditary breast and ovarian cancer</td>
<td>BRCA1, BRCA2</td>
<td>Autosomal dominant</td>
<td>Breast cancer, Ovarian cancer, Pancreatic cancer, Prostate cancer</td>
</tr>
<tr>
<td>Lynch syndrome (formerly HNPPC) includes Muir-Torre, Turcot syndrome</td>
<td>MLH1, MSH2, MSH6, PMS2, EPCAM</td>
<td>Autosomal dominant</td>
<td>Colorectal cancer, Endometrial cancer, Ovarian cancer, Gastric cancer, Urothelial/bilharzian tract cancer</td>
</tr>
<tr>
<td>Familial adenomatous polyposis (includes Gardner syndrome)</td>
<td>APC</td>
<td>Autosomal dominant</td>
<td>Gastrointestinal adenomas, Colorectal cancer, Duodenal cancer</td>
</tr>
<tr>
<td>MYH-associated polyposis</td>
<td>MUTYH</td>
<td>Autosomal recessive</td>
<td>Colorectal cancer</td>
</tr>
<tr>
<td>Li-Fraumeni syndrome</td>
<td>TP53</td>
<td>Autosomal dominant</td>
<td>Sarcoma, Adrenocortical cancer, Brain tumor (include chorioid plexus), Breast cancer</td>
</tr>
<tr>
<td>Cowden syndrome</td>
<td>PTEN</td>
<td>Autosomal dominant</td>
<td>Skin tumors, Breast cancer, Thyroid cancer, Endometrial cancer</td>
</tr>
<tr>
<td>Hereditary diffuse gastric cancer</td>
<td>CDH1</td>
<td>Autosomal dominant</td>
<td>Gastric cancer (diffuse), Breast cancer (lobular)</td>
</tr>
<tr>
<td>Peutz-Jeghers syndrome</td>
<td>STK1</td>
<td>Autosomal dominant</td>
<td>Colorectal, Small bowel, Breast cancer, Pancreatic cancer</td>
</tr>
<tr>
<td>Juvenile polyposis</td>
<td>SMAD4, BMPR1A</td>
<td>Autosomal dominant</td>
<td>Colorectal cancer, Pancreatic cancer</td>
</tr>
<tr>
<td>Melanoma syndromes</td>
<td>CDKN2A, CDK4</td>
<td>Autosomal dominant</td>
<td>Malignant melanoma, Pancreatic cancer</td>
</tr>
<tr>
<td>Neurofibromatosis</td>
<td>NF1, NF2</td>
<td>Autosomal dominant</td>
<td>Schwannoma (vestibular), Meningioma, Neurofibroma, Optic glioma</td>
</tr>
<tr>
<td>Tuberous sclerosis</td>
<td>TSC1, TSC2</td>
<td>Autosomal dominant</td>
<td>Renal angiomylipoma, Subependymoma, Astrocytoma (giant cell)</td>
</tr>
<tr>
<td>Von Hippel-Lindau syndrome</td>
<td>VHL</td>
<td>Autosomal dominant</td>
<td>Hemangioblastoma, CNS, retina, Renal cell cancer, Pheochromocytoma</td>
</tr>
<tr>
<td>Birt-Hogg-Dube syndrome</td>
<td>FLCN</td>
<td>Autosomal dominant</td>
<td>Renal cell cancer, Skin tumors</td>
</tr>
<tr>
<td>Papillary renal cancer syndromes</td>
<td>FH, MET</td>
<td>Autosomal dominant</td>
<td>Renal cell cancer</td>
</tr>
<tr>
<td>Retinoblastoma</td>
<td>RB1</td>
<td>Autosomal dominant</td>
<td>Retinoblastoma, Osteosarcoma</td>
</tr>
<tr>
<td>Hereditary Paraganglioma</td>
<td>SDHAX, SDHB, SDHC, SDHD</td>
<td>Autosomal dominant</td>
<td>Paraganglioma, Pheochromocytoma</td>
</tr>
<tr>
<td>MEN1, MEN2</td>
<td>MEN1, RET</td>
<td>Autosomal dominant</td>
<td>Pituitary adenoma, Parathyroid adenoma, Thyroid cancer (medullary)</td>
</tr>
</tbody>
</table>

### Table 1: Hereditary cancer syndromes.
Family history follows the information process of pre-test genetic counseling, which incorporates first-degree relatives with breast cancer along with hormone risk factors; although they may vary in which known breast cancer risk models are empirically derived, prospective research is needed to confirm the accuracy of these predictions and to evaluate the effectiveness of interventions based on individual genetic testing.

Because models used to convert genotypes into absolute risks are empirically derived, prospective research is needed to confirm the accuracy of these predictions and to evaluate the effectiveness of interventions based on individual genetic testing.

How should risks of developing cancer be communicated? They can be given as cancer risk per year, or before a certain age, or within a decade, or as an overall lifetime risk in comparison with the population risk in terms of relative risks. The individual perception of cancer risk improves outcome, a clear protocol for surveillance and/or preventive options should also be discussed and it must be stressed that no surveillance guideline is flawless, so individuals must bear in mind that abnormal symptoms should never be ignored between screening exams [32].

### Predicting Cancer Risks

In the absence of an identified gene mutation, counseling unaffected individuals about their empiric risk of cancer requires careful consideration of the patient's personal and family history. Most risk estimates for cancer development are empiric, based on the probability of a genetic component in the individual, and this risk estimate increases if the proband has several affected relatives on the same side of family with the same or related cancers, multiple or early onset cancers, or if the individual has clinical features of a hereditary cancer syndrome [27].

For breast cancer, there are several models that estimate empiric risks, including the Gail et al. [28], Claus et al. [29], BRCAPRO [8-10], Tyrer et al. [11] and BOADICEA [12] models. All of these models incorporate first-degree relatives with breast cancer along with hormone risk factors; although they may vary in which known breast cancer risk factors are incorporated. There are also some published tools available to assess risks for colon, ovarian, lung, melanoma, and other cancers, but few are validated [30]. Numeric estimates of cancer risk may guide recommendations for appropriate screening and preventive care.

Because models used to convert genotypes into absolute risks are empirically derived, prospective research is needed to confirm the accuracy of these predictions and to evaluate the effectiveness of interventions based on individual genetic testing.

### Pre-test Counseling

After establishing risks of identifying a pathogenic germ-line mutation in a family and indicating the best candidates to be tested, it follows the information process of pre-test genetic counseling, which requires informed consent for testing for a genetic cancer susceptibility gene (Table 4). It is an approach that explains to the affected relative the nature of the tests to be carried out, the possible results (positive, negative, undetermined, inconclusive), the emotional impact they may cause, and its relevance regarding employment and insurance. This approach must be non-directive, letting patients make their own decisions after viewing all possible scenarios [31]. In numerous cases, a pathogenic mutation will not be revealed but some genetic variants (e.g., single nucleotide polymorphisms) with unknown clinical significance and functional consequence, requiring further tests to clarify (e.g. segregation in family members). Therefore, it is important to plan the willing (or not) to communicate results to the family. When a known deleterious mutation is detected in a family member, and when the affected individual agrees to release his/her results to the family, predictive testing can be offered to at-risk relatives.

Predictive testing often requires two pre-test counseling interviews with up to three months between them, when family, emotional, employment and insurance issues are discussed, and as well the mode of inheritance and penetrance of the mutation are explained. Screening and preventive options should also be discussed and it must be stressed that no surveillance guideline is flawless, so individuals must bear in mind that abnormal symptoms should never be ignored between screening exams [32].

### Clinical criteria guidelines and mutation probability models utilized for Hereditary Breast and Ovarian Cancer

<table>
<thead>
<tr>
<th>Clinical criteria/cancer(s) included</th>
<th>Model(s)</th>
<th>Gene(s) included</th>
<th>Syndrome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breast cancer (age&lt;45, two primaries, male)</td>
<td>Couch [5]</td>
<td>BRCA1, BRCA2</td>
<td>HBOC</td>
</tr>
<tr>
<td>Ovarian cancer</td>
<td>Penn II [6]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pancreatic cancer</td>
<td>Myriad [7]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prostate cancer</td>
<td>BRCAPRO [8-10]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ashkenazi ancestry</td>
<td>Tyrer-Cuzick [11]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Family history</td>
<td>BOADICEA [12]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bethesda [18]</td>
<td>MMRpro [14]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Colonrectal cancer</td>
<td>MMRpredict [15]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Endometrial cancer</td>
<td>PREMM1,2,6 [16]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Classical [19]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chompret [20]</td>
<td>TPS5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adrenocortical, breast, sarcoma, brain cancer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Classic [21]</td>
<td>Cleveland clinic [22]</td>
<td>PTEN</td>
<td>Cowden</td>
</tr>
<tr>
<td>Melanoma</td>
<td>MELApri [23]</td>
<td>CDKN2A</td>
<td>Melanoma</td>
</tr>
</tbody>
</table>

**Table 3:** Clinical criteria guidelines and mutation probability models utilized for Hereditary Breast and Ovarian Cancer (HCRA).
Informed consent elements

1. information on the specific mutation(s) being tested, including whether the range of risk associated with the variant will impact medical care
2. implications of a positive and negative result
3. possibility that the test will not be informative
4. options for risk estimation without genetic testing
5. risk of passing a genetic variant to children
6. technical accuracy of the test including where required by law, licensure of the laboratory
7. fees involved in testing and counseling
8. psychological implications of test results (benefits and risks)
9. risks and protections against genetic discrimination by employers or insurers
10. confidentiality issues, including policies related to privacy and data security
11. possible use of DNA testing samples in future research
12. options and limitations of medical surveillance and strategies for prevention after genetic testing
13. importance of sharing genetic test results with at-risk relatives so that they may benefit from this information
14. plans for follow-up after testing

Table 4: Basic elements of informed consent for cancer susceptibility testing.

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In summary, HCRA is a multidisciplinary (with genetic counselors, trained genetic nurses, oncologists, psychologists and social workers) process of estimating probabilities of germ-line mutations in cancer susceptibility genes and assessing empiric risks of cancer based on personal and family histories in order to offer diagnostic and predictive gene testing. Providing patients with pre- and post-test genetic counseling can help them to get informed decision making. Following individuals at increased risk with surveillance protocols (such as from NCCN), reassuring those at low risk, and referring those at high risk of a hereditary cancer to a genetics center with outpatient clinics may be the best suitable approach to HCRA. Specialized nurses can be settled in district hospitals to undertake pedigrees and risk assessment so they can refer those patients with moderately increased risk for surveillance, those with highly increased risk to the local cancer genetics center and reassure patients with low risk [32].

In Brazil, a National Familial Cancer Network has been built in order to provide families with hereditary cancer prompt access to diagnosis, management and counseling of the most common hereditary cancer syndromes in a public health care setting [33].

Collaboration with cancer patients associations and non-governmental foundations would be extremely helpful to providing families with a better support and care.

References

3. Oncology Nursing Society. Role of the Oncology Nurse in Cancer Genetic Counseling.


