

## Tumour Review

Germline *TP53* pathogenic variants and breast cancer: A narrative review

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## ABSTRACT

Approximately 10% of breast cancers are associated with the inheritance of a pathogenic variant (PV) in one of the breast cancer susceptibility genes. Multiple breast cancer predisposing genes, including *TP53*, are responsible for the increased breast cancer risk.

Tumor protein-53 (*TP53*) germline PVs are associated with Li-Fraumeni syndrome, a rare autosomal dominant inherited cancer predisposition syndrome associated with early-onset pediatric and multiple primary cancers such as soft tissue and bone sarcomas, breast cancer, brain tumors, adrenocortical carcinomas and leukemias. Women harboring a *TP53* PV carry a lifetime risk of developing breast cancer of 80–90%.

The aim of the present narrative review is to provide a comprehensive overview of the criteria for offering *TP53* testing, prevalence of *TP53* carriers among patients with breast cancer, and what is known about its prognostic and therapeutic implications. A summary of the current indications of secondary cancer surveillance and survivorship issues are also provided. Finally, the spectrum of *TP53* alteration and testing is discussed.

The optimal strategies for the treatment of breast cancer in patients harboring *TP53* PVs poses certain challenges. Current guidelines favor the option of performing mastectomy rather than lumpectomy to avoid adjuvant radiotherapy and subsequent risk of radiation-induced second primary malignancies, with careful consideration of radiation when indicated post-mastectomy. Some studies suggest that patients with breast cancer and germline *TP53* PV might have worse survival outcomes compared to patients with breast cancer and wild type germline *TP53* status. Annual breast magnetic resonance imaging (MRI) and whole-body MRI are recommended as secondary prevention.

## Introduction

Breast cancer is the most common cancer diagnosis in women and the majority are considered sporadic cases [1]. Around 10% of breast

malignancies are associated with a germline pathogenic variant in one of the breast cancer susceptibility genes and family history is often the telltale of an underlying inherited predisposition [2,3]. *BRCA1* and *BRCA2* pathogenic variants are responsible for less than half of the

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variants involved in increased breast cancer risk and pathogenic variants in multiple other breast cancer predisposing genes, including *TP53*, are responsible for the remaining [4–6].

Tumor protein-53 (*TP53*) gene is a tumor suppressor which controls cell growth and division. It protects cells against genome changes resulting from DNA damage by suppressing proliferation or activating apoptosis [7]. *TP53* germline pathogenic variants are associated with heritable *TP53*-related cancer syndromes, classically named Li-Fraumeni syndrome (<https://www.omim.org/entry/151623>), a rare autosomal dominant inherited cancer predisposition syndrome historically associated with early-onset pediatric and multiple primary cancers such as soft tissue and bone sarcomas, breast cancer, brain tumors, adrenocortical carcinomas, gastrointestinal, lung, pancreatic and prostate cancers and leukemias [8–12]. More recently *TP53* pathogenic variants were associated also with an increased risk of prostate cancer [13]. The cumulative cancer risk associated with Li-Fraumeni syndrome has been estimated to be approximately 50% by the age of 40 years and up to 90% by the age of 60 years [14] with females reported to have a higher risk than males, mostly due to the increased risk of premenopausal breast cancer [15–17]. Indeed, healthy women harboring a *TP53* pathogenic variant carry a lifetime risks of developing breast cancer of around 80–90%, higher than the risk of healthy *BRCA* carriers (lifetime risk of around 60–85%) [18–21].

The aim of the present narrative review is to give a comprehensive overview of all the aspects to be considered during the counselling of women with a new diagnosis of breast cancer and carrying (or suspected to carry) a *TP53* pathogenic variant. Criteria for offering *TP53* testing, prevalence of *TP53* carriers among patients with breast cancer, prognostic and therapeutic implications are provided. Current indications of secondary cancer surveillance and survivorship issues are discussed. Finally, the spectrum of *TP53* alteration and testing is discussed.

### Criteria for offering *TP53* testing and prevalence of *TP53* carriers among patients with breast cancer

Different criteria for offering *TP53* testing have been proposed (Table 1).

The first Li-Fraumeni syndrome criteria were proposed by Li and Fraumeni in 1988 [22]. Subsequently, less stringent Li-Fraumeni-like criteria were proposed in order to expand the proband's cancer types to include childhood cancers, brain cancers, and adrenal cortical carcinoma, and to change the relatives' age at the time of diagnosis to < 60 years [23,24]. Broader criteria were proposed by Chompret and colleagues in 2001 and a modified version of the Chompret criteria was proposed by Bougeard and colleagues in 2015 with the recommendation to offer *TP53* testing to patients with breast cancer diagnosis before age 31, regardless of family history [25,26]. Sensitivity and specificity of these criteria have been estimated to be around 90% and 50% respectively [26,29–31]. However, *TP53* carriers could also be identified in families who do not fulfill these clinical criteria due to a wide variety of phenotypes within the same syndrome, different tumor spectrum, age at diagnosis or sporadic occurrence of a germline pathogenic variant [26,30]. Indeed, it is estimated that at least 14% of germline *TP53* carriers have a *de novo* pathogenic variant [32]. Thus, the lack of a positive family history does not exclude the possibility of the identification of a *TP53* pathogenic variant in the patient [33].

In 2020, the European Reference Network GENTURIS expanded the revised Chompret criteria. Children and adolescents with acute lymphoblastic leukemia, medulloblastoma or jaw osteosarcoma, as well as children with any type of cancer from southern and south-eastern Brazilian families and patients affected by second primary malignancy within the radiotherapy field of a first core *TP53* tumor were also considered eligible for *TP53* testing [27]. Despite the available evidence regarding the higher prevalence of human epidermal growth factor receptor 2 (*HER2*) positive breast cancer among *TP53* carriers [34], none of the above-mentioned criteria consider histopathological features of

**Table 1**  
Criteria for offering *TP53* testing.

Criteria	Year	General criteria
Classic Li-Fraumeni criteria [22]	1988	Proband with sarcoma diagnosed before 45 years AND First-degree relative with any cancer before 45 years AND First or second-degree relative with any cancer before 45 years or a sarcoma at any age
Birch criteria (LFL) [23]	1994	Proband with any childhood cancer, or a sarcoma, or a brain tumor or ACC before 45 years AND First or second-degree relative with a core LFS cancer (sarcoma, breast cancer, brain tumor, ACC or leukemia) at any age AND First or second-degree relative with any cancer before 60 years
Eeles criteria (LFL) [24]	1995	Two first- or second-degree relatives with core LFS malignancies (sarcoma, premenopausal breast cancer, brain tumor ACC, leukemia, lung [bronchoalveolar] cancer) at any age
Chompret criteria [25]	2001	Proband affected by a narrow spectrum cancer (i. e., sarcomas, brain tumors, breast cancer, and ACC) before 36 years and at least one first or second-degree relative affected by a narrow spectrum tumor (other than breast cancer if the proband is affected by breast cancer) before 46 years or multiple primary tumors OR Proband with multiple primary tumors; two of which belong to the narrow spectrum with the first of which occurred before 36 years OR Proband with ACC
Modified Chompret criteria [26]	2015	Proband with tumor belonging to LFS tumor spectrum (e.g., soft tissue sarcoma, osteosarcoma, brain tumor, breast cancer, ACC, leukemia, bronchoalveolar lung cancer) before 46 years and at least one first- or second-degree relative with an above LFS tumor (except breast cancer if proband has breast cancer) before 56 years or with multiple tumors at any age OR Proband with multiple tumors (except multiple breast tumors), two of which belong to LFS tumor spectrum and the first occurring before 46 years OR Patient with ACC, choroid plexus carcinoma, or rhabdomyosarcoma of embryonal anaplastic subtype, irrespective of family history OR Breast cancer before age 31 years
GENTURIS criteria* [27]	2020	Patient with a <i>TP53</i> core tumor (breast cancer, soft-tissue sarcoma, osteosarcoma, central nervous system tumor, ACC) before 46 years and at least one first- or second-degree relative with a core tumor before 56 years OR Patient with multiple tumors, including two <i>TP53</i> core tumors, the first of which occurred before 46 years, irrespective of family history OR Patient with ACC, choroid plexus carcinoma, or rhabdomyosarcoma of embryonal anaplastic subtype, irrespective of family history OR Breast cancer before age 31 years OR Children and adolescents with hypodiploid ALL or otherwise unexplained sonic hedgehog-driven medulloblastoma or jaw osteosarcoma OR Patients who develop a second primary tumor, within the radiotherapy field of a first core <i>TP53</i> tumor which occurred before 46 years

(continued on next page)

Table 1 (continued)

Criteria	Year	General criteria
Evans criteria* [28]	2020	OR
		Children with any cancer from southern and south-eastern Brazilian families <sup>a</sup>
		Invasive breast carcinoma or DCIS before 31 years
		OR
		Bilateral invasive breast carcinoma or DCIS or multifocal invasive breast carcinoma or HER2 + invasive breast carcinoma or phyllode tumor before 36 years
		OR
		Invasive breast carcinoma and a second TP53 core tumor in the patient before 46 years
		OR
		Invasive breast carcinoma before 46 years and one first- or second-degree relative with a TP53 core tumor before 56 years

Abbreviations: ACC, adrenocortical carcinoma; LFS, Li-Fraumeni syndrome; LFL, Li-Fraumeni-like; ALL, acute lymphoblastic leukemia; DCIS, ductal carcinoma in situ; HER2, human epidermal growth factor receptor 2.

\* Breast cancer-specific testing criteria, not formally tested for sensitivity and specificity.

<sup>a</sup> To be tested for the p.R337H Brazilian founder germline TP53 variant.

breast cancer. In breast cancer-specific testing criteria proposed by Evans and colleagues, different age thresholds are proposed for patients with HER2 positive breast cancer or phyllode tumor [28].

Recommendations about TP53 testing derive from several studies evaluating the prevalence of TP53 germline carriers in selected patients with breast cancer (Table 2).

In highly selected cohorts of patients around 5% harbor a TP53

germline pathogenic variant, including women with breast cancer who meet the criteria of heritable TP53-related cancer syndromes or even those who have a strong family history of breast cancer [26,30,36,37,41,42,51–53]. Whereas the frequency of TP53 germline carriers in unselected patients with breast cancer is less than 0.5% [5,6,54]. In two population-based study that aimed to estimate the cancer risk related to different breast cancer susceptibility genes, TP53 pathogenic variant were identified in 19 (0.06%) out of 32,247 unselected patients with breast cancer (CARRIERS consortium) and in 7 (0.01%) out of 48,826 unselected patients with breast cancer (Breast Cancer Association Consortium) [5,6].

In a cohort of 364 female patients from the Netherlands diagnosed with breast cancer before the age of 30 years, 8 (2.2%) patients harbored a (likely) pathogenic TP53 variant [33]. Among them, 6 patients had a personal or familial history suggestive of Li-Fraumeni syndrome [33]. In an Australian population-based cohort of invasive breast cancers, TP53 (likely) pathogenic variants were detected in 2 (4%) out of 52 women diagnosed before age of 30 unselected for family history and in 3 (7%) out of 42 women diagnosed in their 30s with two or more first- or second-degree relatives with breast or ovarian cancer [40]. In a cohort of 100 Polish females with breast cancer diagnosed before the age of 30 years and positive family history of cancer, prevalence of TP53 pathogenic variant was 4% [48].

To note that the identification of a pathogenic variant can be influenced by the method used to detect the variant, thus absolute frequencies of TP53 germline carriers should be interpreted with caution.

The introduction of next-generation sequencing technique, the broader diagnostic criteria and more inclusive testing criteria will lead to a considerably higher prevalence of germline TP53 pathogenic variants detection and the identification of less penetrant Li-Fraumeni

Table 2

Studies exploring TP53 germline pathogenic variant prevalence among selected patients with breast cancer.

Author	Year	Selection criteria	No. of pts tested	BRCA1/2 status	TP53 (likely) pathogenic variant prevalence (%)
Evans DGR et al [35]	2002	Probands with sarcoma and BC (BC in proband or in a first degree relative) in family not fulfilling LFS	21	Negative	4.8% (1/21)
Walsh T et al [36]	2006	Probands from families with 4 or more cases of BC or ovarian cancer	300	12% BRCA1/2 mutated	1% (3/300)
Laloo F et al [37]	2006	BC ≤ 30 years	100	18% BRCA1/2 mutated	4% (4/100)
Manoukian S et al [38]	2007	Unrelated individuals from families with one case of sarcoma and at least one case of BC	23	Negative	13% (3/23)
Ginsburg OM et al [39]	2009	BC < 30 years	95	Negative	0% (0/95)
Gonzalez KD et al [30]	2009	BC between 30 and 49 years	14	Negative	7.1% (1/14)
Mouchawar Jet et al [40]	2010	(a) women diagnosed with BC before the age of 30 years irrespective of family history (b) women diagnosed with BC between 30 and 39 years with two or more first- or second-degree relatives with BC or ovarian cancer	(a) 52 (b) 42	Negative Negative	(a) 4% (2/52) (b) 7% (3/42)
Lee DSC et al [41]	2012	BC < 37 years	83	Negative	4.8% (4/83)
McCuaig JM et al [42]	2012	BC < 30 years	28	Negative	21.4% (6/28)
Rath MG et al [43]	2013	HER2-positive BC, <51 years	213	Negative	1.4% (3/213)
Carraro DM et al [44]	2013	BC < 35 years	43	Negative	2.3% (1/43)
Bougeard G et al [26]	2015	BC < 31 years	NR	NR	6% (NR)
Eccles DM et al [45]	2016	HER2-positive BC, <31 years	71	Negative	8.5% (5/71)
Hahn EC et al [46]	2018	Women with BC diagnosed before 46 years and without Chompret criteria for LFS or LFL	239	Negative	2.5% (6/239)
Bakhuizen JJ et al [33]	2019	BC < 30 years	364	19/364 BRCA1/2 mutated	2.2% (8/364)
Gallardo-Alvarado LN et al [47]	2019	BC < 45 years	78	Negative	6.4% (5/78)
Rogoża-Janiszewska E et al [48]	2020	BC ≤ 30 years	100	Negative	4% (4/100)
Siraj AK et al [49]	2021	BC ≤ 40 years	464	57/464 BRCA1/2 mutated	1.5% (7/464)
Waks AG et al [50]	2022	BC ≤ 35 years	92	13/92 BRCA1/2 mutated	1.1% (1/92)

Abbreviations: BC, breast cancer; FH, familial history; LFS, Li-Fraumeni syndrome; LFL, Li-Fraumeni-Like syndrome; NR, not reported.

syndrome [19,37]. In fact, multigene panel studies gave the possibility to broaden the phenotypic spectrum of Li-Fraumeni syndrome identifying *TP53* germline pathogenic variants in individuals who do not fulfill established clinical criteria for Li-Fraumeni syndrome testing [12,54,55].

### Breast cancer subtypes arising in *TP53* carriers

Patients harboring *TP53* pathogenic variants may develop distinct breast cancer subtypes. Some previous reports suggested that patients harboring germline *TP53* pathogenic variants are more likely to develop HER2-positive breast cancers (Table 3).

In particular, a multicenter international case-control analysis of the BRIDGES study including 42,680 patients and 46,387 controls aimed to characterize tumors associated with different breast cancer susceptibility genes [34]. Among the 42,680 patients included, 51 harbored a *TP53* pathogenic variant. *TP53* carriers were found to have a greater chance to develop HER2-positive breast cancers (46% of cases) [34]. Moreover, *TP53* carriers were more likely to have mixed lobular and ductal tumors than ductal carcinoma (OR 7.01, 95% CI 3.04–16.17) [34]. In a Brazilian cohort of 91 *TP53* female carriers, breast cancer was the first malignancy diagnosed in 90% of the women, of whom 78% had an early-onset breast cancer (i.e. age  $\leq$  45 years) [64]. Moreover, bilateral breast cancer was observed in 29% of the patients. Overall, 41% of the tumors were HER2-positive, and 33% were positive for both hormone receptor and HER2 [64].

Many other studies with <50 patients provided similar results with a prevalence of HER2 positivity ranging between 34 and 83% (Table 3) [33,56–63], clearly higher than expected in an unselected breast cancer population (15–20%) [65,66].

### Breast cancer prognosis

Several studies evaluated survival outcomes of patients with breast

**Table 3**  
Tumor subtypes among *TP53* carriers.

Author	Year	<i>TP53</i> carriers with BC N	HER2 positive tumors N	Other findings
Wilson JRF et al [56]	2010	12*	10* (83%)	–
Melhem-Bertrandt A et al [57]	2012	30	20 (67%)	–
Masciari S et al [58]	2012	32*	20 (63%)	–
Bakhuizen JJ et al [33]	2019	8	5 (63%)	–
Packwood K et al [59]	2019	36	20 (56%)	–
Le A et al [60]	2020	38*	22 (58%)	–
Alyami H et al [61]	2021	21*	10 (53%)	2 cases of malignant phyllodes tumor
Kuba MG et al [62]	2021	17	9 (53%)	2 cases of HER2 negative BC by IHC (1 + ) but positive by FISH.
Rippinger N et al [63]	2021	32	11 (34%)	10 cases (31.3%) of luminal B-like BC
Breast Cancer Association Consortium, Mavaddat N et al [34]	2022	51	NR (46%)	OR for HER2 + BC 7.14 (95%CI 3.34–15.28)
Sandoval RL et al [64]	2022	87	32 (41%)	43 cases (55%) of luminal-like BC

Abbreviations: HER2, human epidermal growth factor receptor 2; OR, odds ratio; IHC, immunohistochemistry; FISH, Fluorescence In Situ Hybridization; BC, breast cancer.

\* invasive breast cancers.

cancer according to somatic *TP53* pathogenic variants [67–70]. However, few data are available regarding clinical outcomes of patients with breast cancer according to germline *TP53* mutation status. In a cohort of 10,053 unselected Chinese patients with early-stage breast cancer, the 50 patients with a germline *TP53* pathogenic variant had significantly worse relapse-free survival (adjusted HR = 2.24; 95%CI 1.15–4.33;  $p = 0.02$ ), distant relapse-free survival (adjusted HR = 2.73; 95%CI 1.41–5.30;  $p = 0.003$ ) and overall survival (adjusted HR = 4.60; 95%CI, 2.26–9.41;  $p < 0.001$ ) as compared to patients with early stage breast cancer and wild type *TP53* germline status [8]. A second study, including the first cohort of 10,053 unselected Chinese patients with breast cancer and a second cohort of 1820 patients with breast cancer selected by age at diagnosis or family history of any cancer, demonstrated that the rate of ipsilateral breast tumor recurrence after breast conserving surgery was significantly higher in *TP53* carriers than in non-carriers (21.1% vs 3.8%) [71]. Moreover, the 10-year risk of contralateral breast cancer in *TP53* carriers was significantly higher than that in non-carriers (17.9% vs 3.6%; HR 7.0 95% CI 3.3–14.9;  $p < 0.001$ ) [71].

A study conducted by Hyder and colleagues in England aimed to determine the risk of contralateral breast cancer in *BRCA1* (N = 218), *BRCA2* (N = 132), and *TP53* (N = 47) carriers with very early-onset (<36 years) breast cancer [72]. Results indicate that the risk of contralateral breast cancer was significantly higher in *TP53* carriers compared to *BRCA1* and *BRCA2* carriers. The 10 and 20-year cumulative risk of contralateral breast cancer was 53% (95%CI 30–81) and 82% (95%CI 50–99) for *TP53* carriers as compared to 32% (95% CI 24–43) and 57% (95% CI 45–69) in *BRCA1* carriers and 21% (95% CI 13.0–32.1) and 45% (95% CI 31.4–61.9) for *BRCA2* carriers [72]. The difference in 10-year cumulative risk of contralateral breast cancer in *TP53* carriers among these two studies (i.e., 17.9% in the Chinese and 53% in the English study) could be attributable to the different populations, being unselected for the first one and highly selected for the second one.

To our knowledge, no data are available regarding survival outcomes of metastatic breast cancer patients according to germline *TP53* mutational status.

### Anticancer treatments

Special considerations regarding breast cancer treatment in *TP53* carriers are required.

As suggested by different studies, the risk of secondary radiation-induced malignancies reaches up to more than 30% among patients with *TP53* pathogenic variants treated with adjuvant radiotherapy. Among 16 Brazilian patients with breast cancer and germline *TP53* p. R337H pathogenic variant, 12 received adjuvant radiotherapy. After a median follow-up exceeding 50 months, 2 (16.7%) patients developed a radiotherapy-induced sarcoma [73]. In a group of 18 patients with a *TP53* pathogenic variant treated with radiation in a curative setting, after a median follow-up of 12.5 years, 2 (11.1%) patients developed a radiation-induced malignancy: one patient developed thyroid cancer, and the other developed sarcoma in the radiation field [60]. In a French cohort of 8 Li-Fraumeni patients with breast cancer, 6 received radiotherapy and 2 of them (33.3%) developed a secondary malignancy in the radiation field after a median follow-up of 6 years [74]. The secondary malignancies documented were an angiosarcoma and a fibrosarcoma [74]. Moreover, one patient developed papillary thyroid carcinoma inside the radiation field [74]. Other smaller case-series showed similar results [61,75–77].

Due to the risk of radiation-induced secondary malignancies after radiotherapy, a careful decision-making process with regard to risk-benefit ratios on the use of radiotherapy in patients with breast cancer harboring a germline *TP53* pathogenic variant is warranted. Current guidelines recommend that decisions about adjuvant radiotherapy should be considered with a multidisciplinary team and patient, with careful weighing of the risks and benefits, especially for patients

who need adjuvant radiotherapy after mastectomy [78].

To our knowledge, no evidence is available on the safety of radiation-guided imaging, such as bone scintigraphy, computed tomography scans and positron emission tomography scans, in patients with *TP53* pathogenic variant.

Regarding surgical management, several considerations should be made. Current guidelines recommend that radiation therapy should be avoided whenever possible due to the risk of radiation-induced secondary malignancies and that mastectomy rather than lumpectomy is preferable [27,78–80]. Moreover, as observed in *BRCA* carriers who have a significantly increased risk of further loco-regional disease but no increased risk of dying when treated with breast conserving surgery as compared to mastectomy, we might assume that similarly, mastectomy could also play a role in reducing the role of locoregional recurrences in *TP53* carriers [81]. However, no robust data are available in this population.

No information on the prognostic impact of the timing of risk-reducing mastectomy on life expectancy is available among *TP53* carriers. A study performed in *BRCA* carriers seem to indicate that the benefit of risk-reducing mastectomy is higher if mastectomy is performed at the age of 25 years but the benefit declines rapidly with increasing age at surgery [82]. Thus, due to the higher risk of contralateral breast cancer in *TP53* carriers compared to *BRCA1* and *BRCA2* carriers, current guidelines recommend discussing contralateral risk-reducing mastectomy [78]. However, the other cancer risks associated with *TP53* pathogenic variants should be taken into account during the surgical counselling [72].

Regarding the use of chemotherapy, Kasper and colleagues suggested that radiotherapy and genotoxic chemotherapies could increase the risk of new tumor development in a Li-Fraumeni syndrome mouse model. In particular, *TP53* mutant mice exposed to genotoxic agent (i.e. etoposide) had an increased risk of tumor development, whereas the exposure to non-genotoxic mitotic spindle agents (i.e. docetaxel) had no impact [83]. In humans, the demonstration of the potential contribution of chemotherapy to the development of subsequent primary tumors among *TP53* carriers derives from patients treated for childhood cancers [84]. Based on these findings, the European Reference Network GENTURIS recommends that priority should be given to surgical or ablative treatments, avoiding radiotherapy and preferring the use of non-genotoxic chemotherapies in the treatment of *TP53*-associated neoplasms [27]. Focusing on breast cancer treatment, despite HER2-positive tumors is the most frequent subtype among patients with *TP53* pathogenic variants, no data on treatment response to different chemotherapeutic and targeted therapy agents are available. A small study showed that *TP53* carriers treated with carboplatin-containing neoadjuvant chemotherapy reached a higher rate of pathological complete response as compared to patients treated with standard anthracycline-based or taxane-based chemotherapy regimens [8]. Recently, poly ADP ribose polymerase inhibitors (PARPi) have been studied in patients with a pathogenic variant in homologous recombination genes other than *BRCA*. However, *TP53* is not involved in the homologous recombination path, thus germline *TP53* carriers were excluded from both the TBCRC-048 and the Talazoparib Beyond *BRCA* trial [85,86].

## Survivorship

Guidelines recommend that *TP53* carriers should follow a dedicated cancer surveillance protocol [27,87,88]. Guidelines and recommendations for second primary cancer surveillance among adult female *TP53* carriers are summarized in Table 4.

Current guidelines agree to recommend annual breast magnetic resonance imaging (MRI) (from age 20) for breast cancer surveillance, and to discuss with patients the possibility to undergo risk-reducing mastectomy [27,78,80,89–91,88,87,92]. On the contrary, there is no consensus on the use of mammography, only routinely recommended by the NCCN guidelines and by the TORONTO protocol, [80,89] or in case

**Table 4**

Guidelines and recommendations for surveillance in adult female *TP53* carriers.

	<b>Breast cancer surveillance</b>	<b>Other cancers surveillance</b>
<b>TORONTO PROTOCOL [89]</b>	<ul style="list-style-type: none"> <li>- Clinical breast examination, every 6 months from age 20–25 or 5–10 years before the earliest case of breast cancer in the family.</li> <li>- Annual mammography and breast MRI from age 20 to 75 or 5–10 years before the earliest case of breast cancer in the family- Breast US with mammography (as indicated by breast density)</li> <li>- Consider RRM</li> </ul>	<ul style="list-style-type: none"> <li>- Complete clinical examination (including neurologic exam) and blood test every 3–4 months</li> <li><b>Brain tumor</b></li> <li>- Annual brain MRI</li> <li><b>Soft tissue and bone sarcoma</b></li> <li>- Annual WBMRI</li> <li><b>GI tumors</b></li> <li>- Colonoscopy every 2 years from age 25 or 10 years before the earliest known colorectal cancer in the family</li> <li><b>Melanoma</b></li> <li>- Annual dermatological examination</li> </ul>
<b>Modified TORONTO protocol - American guidelines [90]</b>	<ul style="list-style-type: none"> <li>- Clinical breast examination every 6 months from age 20</li> <li>- Annual breast MRI from age 20 to 75</li> <li>- Consider RRM</li> </ul>	<ul style="list-style-type: none"> <li>- Complete clinical examination every 6 months</li> <li><b>Brain tumor</b></li> <li>- Annual brain MRI (only first MRI with gadolinium enhancement)</li> <li><b>Soft tissue and bone sarcoma</b></li> <li>- Annual WBMRI</li> <li>Alternated to:</li> <li>- Annual US of abdomen and pelvis</li> <li><b>GI tumors</b></li> <li>- Upper endoscopy and colonoscopy every 2–5 years from age 25</li> <li><b>Melanoma</b></li> <li>- Annual dermatological examination</li> </ul>
<b>ESMO guidelines [78]</b>	<ul style="list-style-type: none"> <li>- Clinical breast examination every 6–12 months from age 20–25</li> <li>- Annual breast MRI from age 20 to 75. If MRI is not available, mammography may be considered.</li> <li>- Consider RRM</li> </ul>	<ul style="list-style-type: none"> <li>- Consider 6-monthly complete blood count</li> <li><b>Brain tumor and sarcoma</b></li> <li>- Consider annual WBMRI</li> <li>- Annual neurological examination</li> <li><b>GI tumors</b></li> <li>- Colonoscopy every 5 years from the age of 25 or as clinically indicated</li> <li><b>Melanoma</b></li> <li>- Annual dermatological examination</li> </ul>
<b>ESO-ESMO (BCY5) guidelines [91]</b>	<ul style="list-style-type: none"> <li>- Annual breast MRI and mammography with or without ultrasound</li> </ul>	<ul style="list-style-type: none"> <li>- Annual brain MRI</li> <li>- Annual WBMRI (without Gadolinium enhancement)</li> </ul>
<b>NCCN guidelines [80]</b>	<ul style="list-style-type: none"> <li>- Clinical breast examination, every 6–12 months from age 20</li> <li>- Annual breast MRI from age 20 to 75</li> <li>- Mammography considering tomosynthesis from age 30</li> <li>- Consider RRM</li> </ul>	<ul style="list-style-type: none"> <li>- Clinical exam including neurologic examination every 6–12 months</li> <li><b>Brain Tumor</b></li> <li>- Annual brain MRI</li> <li><b>Sarcoma</b></li> <li>- Annual WBMRI</li> <li><b>GI tumors</b></li> <li>- Colonoscopy and upper endoscopy every 2–5 years from age 25 or 5 years before the earliest known colon or gastric cancer in the family</li> </ul>

(continued on next page)

Table 4 (continued)

	Breast cancer surveillance	Other cancers surveillance
<b>The European Reference Network GENTURIS guidelines [27]</b>	- Annual breast MRI from age 20 to 65 - Consider RRM	<b>Melanoma</b> - Annual dermatological examination from the age of 18 <b>Brain Tumor</b> - Annual brain MRI until 50 years alternated to WBMRI (only the first with gadolinium enhancement) <b>Sarcoma</b> - Annual WBMRI (without gadolinium enhancement) <b>GI tumors</b> - Colonoscopy every 5 years from age 18 (Only if the carrier received abdominal radiotherapy for a previous cancer or if there is a family history of colorectal tumors suggestive of an increased genetic risk)
<b>UKCGG Consensus Group guidelines [88]</b>	- Annual breast MRI from age 20–70	- Routine clinical examination not recommended <b>Brain tumor</b> - Annual brain MRI (only first MRI with gadolinium enhancement) <b>Soft tissue and bone sarcoma</b> - Annual WBMRI (without gadolinium enhancement) <b>GI tumors</b> - Colonoscopy only indicated when family history of colorectal cancer or polyposis is present - Gastric endoscopy not indicated <b>Melanoma</b> - Annual dermatology review
<b>Kumamoto et al 2021 [87]</b>	- Breast exam twice a year from the age of 20 - Breast MRI every year from 20 to 75 years - Consider RRM	- Clinical examination every 6 months <b>Brain tumor</b> - Annual brain MRI (only first with gadolinium enhancement) <b>Soft tissue and bone sarcoma</b> - Annual WBMRI alternated to: - Annual US of abdomen and pelvis <b>GI tumors</b> - Upper endoscopy and colonoscopy every 2–5 years from age of 25 <b>Melanoma</b> - Annual dermatological examination
<b>Australian Recommendations [92]</b>	- Clinical breast examination every 6 months from age 20 - Annual breast MRI from age 20 - Consider RRM	<b>Brain tumor</b> - Annual brain MRI (only first with gadolinium enhancement) <b>Soft tissue and bone sarcoma</b>

Table 4 (continued)

	Breast cancer surveillance	Other cancers surveillance
		- Annual WBMRI (only first with gadolinium enhancement) <b>GI tumors</b> - Upper endoscopy and colonoscopy every 2–5 years from age 20–25 or younger dependent on family history <b>Melanoma</b> - Annual dermatological examination from age 18

Abbreviations: MRI, magnetic resonance imaging; US, ultrasound; RRM, risk reducing mastectomy; WBMRI, whole-body magnetic resonance imaging; GI, gastrointestinal.

the MRI could not be performed also taking into consideration that microcalcification are not optimally detected by MRI.

Considering the high risk of developing other tumors correlated with the presence of a germline *TP53* pathogenic variant, especially brain malignancies, soft tissue and bone sarcoma, melanoma, and the increased rate of gastrointestinal cancer, all guidelines agree to recommend annual whole-body MRI (generally from the age of 20) and annual brain MRI. Overall, there is agreement among guidelines that MRI should be preferred for secondary prevention over radiation-guided imaging. Conversely, there is no consensus whether or not to offer endoscopy surveillance of the upper and lower gastrointestinal tract: most guidelines suggest to tailor the indication and timing according to the family history. Many trials are currently ongoing with the aim of determine diagnostic efficacy of different surveillance imaging techniques and protocols among patients with *TP53* pathogenic variants (NCT03176836, NCT01464086, NCT02950987).

In summary, according to guidelines, surveillance for breast cancer should be based on annual breast MRI starting at the age of 20 and risk-reducing surgery should be discussed with the patients (Fig. 1). For brain tumors and sarcoma, annual whole-body MRI should be performed since birth while gastrointestinal and melanoma secondary prevention should be considered in adulthood (Fig. 2).

Regular follow up of patients with breast cancer should be scheduled based on current guidelines, considering not only the type of tumor, its biology and the treatment received, but also minimizing the diagnostic radiation in order to reduce the risk of radiation-induced secondary malignancies in these patients. Contrast-free diffusion-weighted whole-body MRI has proved to be effective for staging and follow-up in patients with breast cancer [89,93–96].

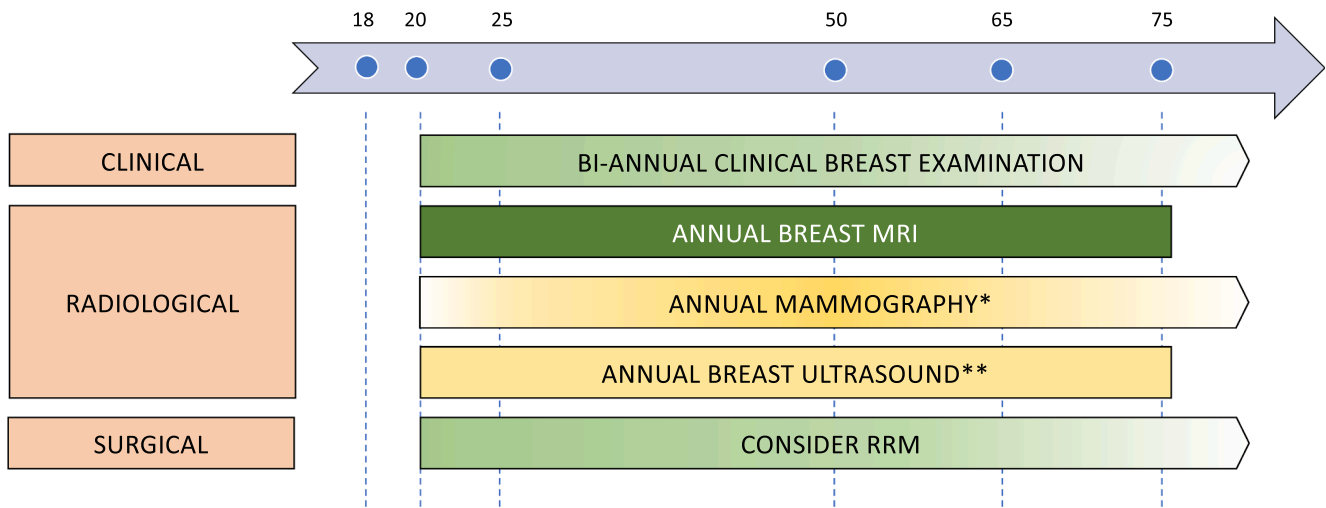
Finally, although limited evidence exist on the topic, all *TP53* carriers should be made aware of their risk of malignancy and the possible symptoms as well as encouraged to make positive lifestyle choices (e.g., not smoking, limit alcohol and red meat consumption, high fruits and vegetables intake, physical exercise, sun protection). An analysis of lifestyle factors and health behavior among *TP53* carriers suggested that women with a *TP53* carriers have healthier diet and smoked less compared to their relatives although no difference was observed in physical activity [97].

Other components of survivorship care in *TP53* carriers should be acknowledged. Survivorship trajectory of cancer patients is made not only by surveillance of recurrence and second primary malignancies but also by dealing with physical effects of cancer and chronic medical conditions, psychological effects and its social, work and financial implications [98].

#### Spectrum of *TP53* alterations and testing diagnostic perspective

In case a *TP53* pathogenic variant with minor allele frequency is

### Surveillance for breast cancer in germline *TP53* female carriers



**Fig. 1.** Surveillance for breast cancer in germline *TP53* female carriers.

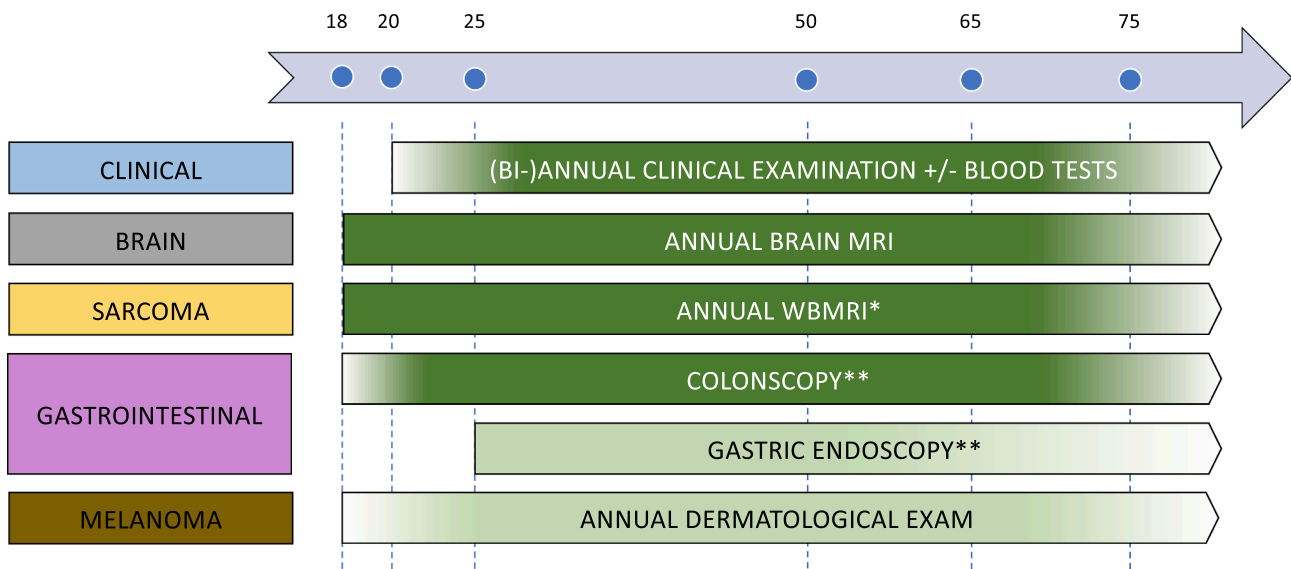
Dark green indicates high agreement, light green indicates medium agreement and yellow indicates very low agreement between guidelines  
 Filled arrows indicate agreement on the timing of examinations recommended between guidelines  
 Shaded arrows indicate discordance on the timing of examinations recommended between guidelines

\*To be considered in case the MRI could not be performed. Recommended only by NCCN guidelines and by the TORONTO protocol. Attention should be paid to radiation-induced malignancies.

\*\*as indicated by breast density

Footnote: no universal recommendation for mammography and breast ultrasound

### Surveillance for cancers other than breast in *TP53* carriers



**Fig. 2.** Surveillance for cancers other than breast in *TP53* carriers.

Dark green indicates high agreement, light green indicates medium agreement

Filled arrows indicate agreement on the timing of examinations recommended between guidelines

Shaded arrows indicate discordance on the timing of examinations recommended between guidelines

\* Annual WBMRI can be alternated to annual US of abdomen and pelvis (one radiological evaluation performed every 6 months)

\*\* every 2–5 years. Recommended if the carrier received abdominal radiotherapy or if there is a family history of upper GI and/or colorectal tumors

found, mosaicism and clonal hematopoiesis should be considered. Pathogenic variants are assumed to be of germline origin when the allele frequency is approximately 50%; however, low variant allele frequencies (i.e., < 25–35%) might be found in a genetic report. In this case, minor allele frequency pathogenic variant is the result of a

mutational event happened at a post-zygotic stage thus only tissues derived from the mutated cell will carry the pathogenic variant [99]. If the mutation is restricted to the hematopoietic compartment, it is called clonal hematopoiesis. Large cohort studies have demonstrated that the prevalence of clonal hematopoiesis increases with age and that clonal

hematopoiesis can be found in a significant portion of the healthy population [100–103]. Clonal hematopoiesis has most frequently been reported with *TP53* gene compared to other breast cancer susceptibility gene [99]. Thus, in case of detection of minor allele frequency *TP53* pathogenic variant the possibility of mosaicism should be ruled out as in this case different therapeutic and genetic counselling needs are implicated [99].

Identification of a *TP53* pathogenic variant does not always translate into the diagnosis of Li-Fraumeni syndrome. The different pathogenic variants can have different penetrance and thus different phenotypes. A pathogenic variant with reduced penetrance will possibly lead to an older age of occurrence of cancers of the Li-Fraumeni syndrome spectrum. For example, the founder mutation p.R181C in the *TP53* gene was found among 9 out of 453 Palestinian young women with breast cancer. None of the families that harbored the *TP53* p.R181C likely pathogenic variant fulfilled the clinical criteria for Li-Fraumeni syndrome [104]. Similarly, the penetrance of the p.R337H *TP53* pathogenic variant seem to be incomplete. In Southern Brazil, the population prevalence of *TP53* p.R337H pathogenic variant is 0.3%. In the Brazilian population, this variant seems to be associated with adrenocortical tumors in children but not with other cancers typical of the Li-Fraumeni syndrome [105–107].

Understanding the factors that lead to phenotypic differences among *TP53* carriers is important to tailor the surveillance program and counselling. The classification of the Li-Fraumeni spectrum suggested by Kratz and colleagues seem to be a valid approach to classify the different phenotypic spectrums of *TP53* variants [108]. Authors classified germline *TP53* variants of 3034 persons into: phenotypic Li-Fraumeni syndrome (i.e., absence of a pathogenic/likely pathogenic *TP53* variant in person meeting clinical Li-Fraumeni syndrome criteria), Li-Fraumeni syndrome (i.e., presence of a pathogenic/likely pathogenic *TP53* variant in person meeting Li-Fraumeni syndrome testing criteria), attenuated Li-Fraumeni syndrome (i.e., presence of a pathogenic/likely pathogenic *TP53* variant in a person with cancer who does not meet Li-Fraumeni syndrome testing criteria), incidental Li-Fraumeni syndrome (i.e., presence of a pathogenic/likely pathogenic *TP53* variant in a person without a history of cancer). Results showed that patients who met Li-Fraumeni syndrome genetic testing criteria have more frequently early adrenal, brain, connective tissue, or bone tumors. While carriers who did not meet Li-Fraumeni syndrome genetic testing criteria had more breast and other cancers (45% of them occurring after age 45 years) [108].

Identification of germline *TP53* pathogenic variants in a breast cancer individual triggers cascade genetic testing of relatives (including children) for early diagnosis through increased surveillance and prevention. As the information regarding the identification of a pathogenic variant in the family relies in proband (proband-mediated procedure), it is uncertain whether all eligible relatives access testing. To our knowledge, no results on the uptake of *TP53* testing among at-risk family members are available. Moreover, testing of asymptomatic children at risk of Li Fraumeni syndrome remained controversial for a long time, due to the lack of proven medical benefit of screening, concern about informed consent and potential stigmatization and discrimination towards the minor [109]. However, due to emerging screening protocols showing potential efficacy, testing of at-risk children is becoming more widespread in those institutions where access to whole-body MRI is available [89,94]. Nevertheless, future research should also focus on the long-term clinical and psychosocial impacts of *TP53* genetic testing and early detection of such pathogenic variants in minors.

Finally, among young carriers of a pathogenic variant in breast cancer susceptibility genes, further burden is given by family planning with the 50% risk of transmission of the pathogenic variant to the offspring. Thus, current guidelines recommend that *TP53* carriers should be offered preimplantation genetic testing (in the case of in vitro fertilization) or prenatal diagnosis (in case of natural conception) [110,111]. However, barriers to the uptake of these techniques are similar to the ones faced by *BRCA* carriers and include the lack of

availability and high cost of the procedure, ethical regulations and burden of additional psychological distress [110]. To our knowledge, no information is available regarding awareness, acceptance, and uptake of preimplantation genetic testing and prenatal testing among *TP53* carriers.

## Conclusions

In patients with breast cancer, the prevalence of patients with germline pathogenic variants in *TP53* ranges from <0.5% in unselected patients with breast cancer to around 5–10% in highly selected patients with breast cancer such as those with very young age at diagnosis or with strong family history. Regarding locoregional treatment, current guidelines recommend that radiotherapy should be avoided and mastectomy should be preferred to lumpectomy [27,78,79]. Moreover, risk-reducing contralateral mastectomy should be discussed, and annual breast MRI screening is recommended as secondary prevention [27,78,79]. Whole-body MRI should be used for secondary cancer surveillance. No information is available regarding potential differences in treatment efficacy and indications among *TP53* carriers. Considering their potential worse breast cancer prognosis and risk of developing secondary malignancies, special attention should be paid to signs or symptoms suggesting the occurrence of these events.

The identification of a *TP53* pathogenic variant is not a straightforward to the diagnosis of Li-Fraumeni syndrome as different penetrance and phenotypes are present. No information on the uptake of cascade testing to at-risk family individuals is available and limited evidence exist on the implication of genetic testing in minors. Current guidelines recommend that preimplantation genetic testing and prenatal testing should be offered to patients willing to conceive [110,111]. Finally, the identification of a minor allele frequency of pathogenic variant needs further evaluations to rule out the possibility of mosaicism that can affect both cascade testing and preimplantation and prenatal testing.

Considering the limited data available to counsel patients with breast cancer and germline *TP53* pathogenic variants, the low level of evidence on some of the topic presented, the relatively rarity of this condition, and the interpretation of *TP53* found in the blood for other reason (e.g. clonal hematopoiesis and mosaicism), collaborative research efforts are strongly encouraged in order to provide more solid answers to improve and better tailor the care of this special patient population.

## CRediT authorship contribution statement

**Eva Blondeaux:** Conceptualization, Writing – original draft, Writing – review & editing, Funding acquisition. **Luca Arecco:** Writing – review & editing, Visualization. **Kevin Punie:** Writing – review & editing, Visualization, Supervision. **Rossella Graffeo:** Writing – review & editing, Visualization, Supervision. **Angela Toss:** Writing – review & editing, Visualization, Supervision. **Carmine De Angelis:** Writing – review & editing, Visualization, Supervision. **Lucia Trevisan:** Writing – review & editing, Visualization. **Giulia Buzzatti:** Writing – review & editing, Visualization. **Sabine C. Linn:** Writing – review & editing, Visualization, Supervision. **Peter Dubsy:** Writing – review & editing, Visualization, Supervision. **Mara Cruellas:** Writing – review & editing, Visualization. **Ann H. Partridge:** Writing – review & editing, Visualization, Supervision. **Judith Balmaña:** Writing – review & editing, Visualization, Supervision. **Shani Paluch-Shimon:** Writing – review & editing, Visualization, Supervision. **Matteo Lambertini:** Conceptualization, Writing – original draft, Writing – review & editing, Visualization, Supervision.

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