Review article

Recognizing menopause in women with amenorrhea induced by cytotoxic chemotherapy for endocrine-responsive early breast cancer

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Abstract

Cytotoxic anticancer treatment may induce amenorrhea or menopause to a variable extent. These side-effects may not only impair or impede fertility, but also cause sexual dysfunction, bone loss and menopausal symptoms, with a strikingly negative effect on quality of life in many women. Aromatase inhibitors are a recommended adjuvant endocrine treatment option in postmenopausal patients affected by early breast cancer, but are contraindicated in premenopausal women and in those with residual ovarian function. Women over 40 years of age with chemotherapy-induced amenorrhea and routine hormonal levels consistent with menopause may receive an aromatase inhibitor as adjuvant endocrine treatment. For these women, the tools available to identify menopause do not appear to be completely reliable.

In this review, the attention is focused on the pathophysiology of ovarian toxicity induced by cytotoxic agents, and on potentially useful methods to diagnose chemotherapy-induced menopause in patients treated with adjuvant chemotherapy for early endocrine-responsive breast cancer. Moreover, practical approaches are proposed to distinguish between true menopausal women, who would benefit from aromatase inhibitors, from those with transient or persistent chemotherapy-induced amenorrhea.

**Key words:** breast cancer, chemotherapy-induced amenorrhea, chemotherapy-induced menopause, aromatase inhibitors.
Introduction

Breast cancer is the most common invasive malignancy in women of reproductive-age (Jemal et al. 2010). At diagnosis, approximately 30% of patients are premenopausal and 10% are 35-45 years old (Bines et al. 1996). Adjuvant endocrine therapy (ET) improves survival in patients with endocrine-responsive early breast cancer (EREBC) (Goldhirsch et al. 2011). For patients who are premenopausal, Tamoxifen ± ovarian function suppression (OFS) are considered standard options. For postmenopausal women, aromatase inhibitors (AI) are recommended as up-front treatment or sequentially after Tamoxifen, since these reduce the risk of recurrence in EREBC (Burstein et al. 2010). These drugs, however, are contraindicated in premenopausal women and in those presenting residual ovarian function (Burstein et al. 2010).

Adjuvant chemotherapy (CT) prolongs survival in women with early breast cancer (EBC), even in the case of endocrine-responsive disease, particularly if patients are <50 years of age (EBCTCG, 2005). Therefore, premenopausal patients with EREBC may sequentially receive adjuvant CT and ET (NCCN - Breast Cancer Guidelines 2011; Goldhirsch et al. 2011).

As a consequence of CT, a percentage of women, who are pre-/perimenopausal at the time of diagnosis, develop transient amenorrhea (chemotherapy-induced amenorrhea, CIA) or menopause (chemotherapy-induced menopause, CIM). While these side-effects predict better clinical outcomes (Walshe et al. 2006; Swain et al. 2010), they raise a number of concerns regarding residual fertility, sexual dysfunction, bone loss and menopausal symptoms, with a marked, negative impact on quality of life (Schover 2008).

Also, the choice of the most suitable adjuvant ET for women affected by EREBC and CIA may be challenging, and a correct diagnosis of menopause is crucial. In clinical practice, physicians may ascertain if a woman with CIA is menopausal by only using a non-validated pool of clinical data, including age, menstrual history, vasomotory symptoms (Table 1), and the likelihood of gonadal toxicity from chemotherapy (Table 2), together with hormonal evaluations. However,
information obtained from the assessment of these parameters may be misleading. In a recent survey, 45 patients with a median age of 47 years (range: 39-52), affected by EREBC with CIA and hormonal levels consistent with menopause, received AI therapy. At a median of 12 months (range 4-59), 27% of these women regained ovarian function, and one was pregnant. Median age at restart of ovarian function was 44 years (range: 40-50) (Smith et al. 2006).

In this report, the pathophysiology of primary ovarian insufficiency (POI) induced by chemotherapy and the role of predictive factors of CIA and CIM in women affected by EBC are reviewed.

Chemotherapy-induced ovarian insufficiency

Chemotherapy-induced ovarian insufficiency (CT-POI) results from an acceleration of the natural ovarian aging process due to damage to steroid-producing cells (granulosa and theca cells) and apoptotic death of a fraction of primordial follicles, mainly impairing follicular development (Figure 1) (Bines et al. 1996; De Vos et al. 2010; Meirow et al. 2010). The sensitivity of the ovaries to cytotoxic drugs varies considerably (Table 2) (Sonmezer & Oktay 2006), alkylating agents being the most commonly associated with permanent and irreversible gonadal damage (Chapman 1982). For some drugs, such as cyclophosphamide, a direct correlation has been demonstrated between dose intensity and CT-POI (Sonmezer & Oktay 2006).

The risk of CT-POI has been correlated with type of chemotherapy, higher cumulative doses, and older age, being age >40 years the strongest predictor both of CIA and CIM (Stearns et al. 2006; Jeruss & Woodruff 2009; De Vos et al. 2010). In addition, CT-regimens administered during the follicular phase of the menstrual cycle may have a greater toxic effect on ovaries (Bines et al. 1996; Di Cosimo et al. 2004; Walshe et al. 2006). Inherited factors have been proposed in playing a key role in the onset of menopause and emerging data suggest that specific genes may influence the risk of CIA/CIM (Stearns et al. 2006; Su et al. 2010a). In addition, breast cancer per
se may increase the risk of POI, whilst in the absence of systemic treatment (Mertens et al. 2001; Partridge et al. 2007b).

The extent and type of damage affect the degrees of subsequent ovarian dysfunction. Whether exposure to CT induces complete follicular depletion or very few follicles remain viable, periods may cease definitively and menopause will occur (Schover 2008; Partridge et al. 2007). If more follicles survive, women may develop amenorrhea or periods become irregular (oligomenorrhea), and menopausal symptoms arise. Despite many patients >40 years of age develop CIA, this type of ovarian failure may be temporary in a considerable number of women (Petrek et al. 2006; Sukumvanich et al. 2010). The percentage of women with CIA/oligomenorrhea that will later develop CIM, is not yet known. Menstrual cycles and/or fertility may recover months to years after withdrawal of chemotherapy. Menses are more likely to return in younger women, in those exposed to less gonadotoxic regimens, and in those with a higher basal number of follicles (Walshe et al. 2006; Schover 2008). In fact, the remaining follicles may regrow in 3-6 months from the primordial pool and gonadotropin levels may return to normal once chemotherapy is withdrawn, especially in very young women (Sonmezer & Oktay 2006). Women with temporary CIA present an increased risk of premature ovarian failure compared to those who continue to menstruate throughout treatment (Ganz et al. 2003). Short or irregular menstrual cycles also indicate a decrease in ovarian reserve (OR) (Oktay et al. 2006).

Very few studies evaluated specifically the rate of CIM in patients with EBC (Padmanabhan et al. 1986; Goodwin et al. 1999). The occurrence of CIM is reported to be in the range of 22-61% in women <40 years, and 61-97% in those >40 years (Del Mastro et al. 1997). Higher cumulative doses of alkylating agents in older premenopausal patients and an arbitrary 12-month period of CIA are considered predictive of CIM (Partridge et al. 2007a; Tham et al. 2007; Han et al. 2009).
Rates of CIA in premenopausal women receiving a polyCT-regimen for EBC may range from 49 to 100% in women >40 years, and from 21 to 71% in younger women (Goldhirsch et al. 1990; Bines et al. 1999; Goodwin et al. 1999; Basser et al. 2006; Del Mastro et al. 2011). Transient and prolonged amenorrhea were more frequent with CMF and CEF/CAF-type regimens, compared to AC (Bines et al. 1999), presumably due to a higher cumulative dose of cyclophosphamide received. Addition of taxanes has shown to increase the risk of CIA, particularly in the first year, in many (Tham et al. 2007; Han et al. 2009; Martin et al. 2005; Swain et al. 2009; Najafi et al. 2011) but not all trials (Davis AL et al. 2005; Fornier et al. 2005; Berliere et al. 2008; Lee et al. 2009; Abusief et al. 2010; Perez-Fidalgo et al. 2010; Zhou et al. 2010). However, the comparison of rates of CIA across different studies is limited by considerable differences in treatments used, median age of patients, prevalence of endocrine-responsive disease, follow-up duration, and variability in the definition of CIA (from 3 months to >1 year absence of menses).

Tamoxifen, following a CT-regimen, led to a significant increase in the rate and/or duration of CIA (Boccardo et al. 1990; Jordan et al. 1991; Goodwin et al. 1999; Colleoni et al. 2006; Swain et al. 2009; Jung et al. 2010; Ganz et al. 2011) and resulted in a slight, but statistically significant increase in the risk of CIM (Bines et al. 1999). However, how Tamoxifen influences CIA/CIM remains unclear. It has been suggested that the drug increases plasma estradiol levels and interferes with the hypothalamic-ovarian feedback loop that regulates estrogen synthesis (Rose et al. 1980; Rossi et al. 2009; Partridge et al. 2010).

Evaluating ovarian reserve in cancer patients

Ovarian reserve (OR) refers to the number and quality of follicles that, at any given age, are available to produce a dominant follicle late in the follicular phase of the menstrual cycle. In the fertility setting and assisted reproduction, in order to ascertain the OR, a number of procedures are used (Table 3) (Lambalk et al. 2009). These include ultrasound assessment of the antral follicle
count (AFC) and the ovarian volume (OV), as well as blood tests to establish the levels of follicle-stimulating hormone (FSH), estradiol, inhibin-B and anti-Müllerian hormone (AMH). AMH and AFC provide the most reliable assessment of the reproductive lifespan of the ovaries, estimation of fertility status, and risk of premature ovarian failure. Menstrual cycle irregularity, vasomotor symptoms, very high basal FSH and undetectable inhibin-B levels have been shown to be the only short-term predictors of menopause (within 2 years) (Lambalk et al. 2009). Low/undetectable levels of AMH, low AFC, a poor response to in vitro follicle stimulation and rise in the early follicular phase of FSH, indicate a limited OR and earlier menopause in later life, but do not predict imminent menopause (Lambalk et al. 2009).

In patients exposed to anticancer treatments, the above-mentioned tests are routinely used to assess residual OR and to predict outcome in assisted reproduction (Oktay et al. 2006, Lutchman Singh et al. 2007; Partridge et al. 2010). To this end, AMH is the most promising marker of OR (Schover 2008). Compared with FSH and inhibin-B, AMH was the most sensitive predictor for OR in women treated with chemotherapy for Hodgkin’s lymphoma, in young women who had received chemotherapy/radiotherapy for childhood cancer (Bath et al. 2003: van Beek et al. 2007; Lie Fong et al. 2009), and in premenopausal patients affected by EREBC receiving adjuvant CT/ET (Anderson & Cameron 2011).

Recognizing menopause in women affected by EBC and CIA

Certain clinical features (age, menstrual history and menopausal symptoms) are generally indicative of menopausal status, which may be confirmed by the presence of serum levels of FSH and estradiol within the menopausal range. These parameters, however, are not completely reliable to confirm menopause. Furthermore, the definition of menopause is not consistent across studies
that have assessed ovarian function following chemotherapy (Clemons & Simmons 2007). In most of these reports, menses cessation was the only surrogate marker of menopause, and the duration of the follow-up period was limited. National Cancer Comprehensive Network (NCCN) guidelines defined some criteria for diagnosing menopause in breast cancer patients (Table 1) (NCCN - Breast Cancer Guidelines 2011). Moreover, it was emphasized that for premenopausal women starting adjuvant ET, CIA is not a reliable indicator of menopausal status, as ovarian function may still be preserved or resume despite chemotherapy-induced anovulation/amenorrhea. Serial measurements of FSH/estradiol are recommended in patients with CIA, if treatment with AI is foreseen (NCCN - Breast Cancer Guidelines 2011).

Aromatase inhibitors are a standard treatment option for postmenopausal women with EREBC (Goldhirsch et al. 2011; Burstein et al. 2010). It has been reported that pre-/perimenopausal women at the time of diagnosis who became amenorrheic following adjuvant chemotherapy, may have received an AI as monotherapy, if they had shown FSH/estradiol levels within menopausal range (Smith et al. 2006; Burstein et al. 2006). The inappropriate use of AI in premenopausal women induces a temporary inhibition of estrogen production, leading to a feedback increase in gonadotropin levels, which, in turn, stimulate follicular growth, aromatase production and restoration of pre-CT estradiol levels (de Ziegler et al. 2005). These changes in hormonal levels would be expected to reduce or abolish the efficacy of the anticancer treatment received, and to expose to further unjustified side-effects, including pain from ovarian hyperstimulation and increased risk of unplanned pregnancy (Smith et al. 2006). Therefore, AI as single agents are contraindicated in premenopausal women, and confirmation of the menopausal status is mandatory before starting these drugs (Ortmann et al. 2011).

Elevated FSH and reduced levels of estradiol generally confirm the clinical diagnosis of menopause. However, biochemical tests present a number of limits. The transition towards menopause is highly variable, as it is a dynamic continuum, and a diagnostic cutoff of these
biomarkers would be difficult to define. Therefore, testing for FSH/estradiol only at a single point in time is not sufficient to confirm menopause. In this respect, repeated measurement of these biomarkers, at more than one time point, would be more reliable. However, the number of time-points to be collected and the duration of the collection intervals are arbitrary. In addition, some technical aspects may negatively affect reliability of biochemical tests. Current plasma estradiol radioimmunoassay is not sufficiently sensitive to detect the low postmenopause estradiol levels (Wang et al. 2005). Tandem mass spectrometry, a validated method dosing steroids in the picogram/millilitre range, is not widely available in non-research settings (Smith et al. 2006; Sundaram et al. 2003). Furthermore, Tamoxifen has been reported to increase circulating estrogens and to decrease FSH levels (Rossi et al. 2009). Aromatase inhibitors have been shown to profoundly decrease estrogens and to increase FSH levels in postmenopausal patients (Rossi et al. 2009). Increased levels of estradiol induced by Tamoxifen may be related to cross-reactivity of Tamoxifen and its metabolites in the estradiol assay (Rossi et al. 2009). Likewise, Exemestane, a steroidal aromatase inhibitor, may interfere with serum estradiol measurement (Johannessen et al. 1997). Therefore, in this clinical setting, amenorrhea and FSH/estradiol levels remain inaccurate surrogate markers of menopause (Amir et al. 2009).

Interestingly, in a few studies on a limited cohort of patients who received adjuvant CT for EREBC, pre-chemotherapy AMH (Anderson et al. 2006), or AMH and inhibin-B (Anders et al. 2008, Su et al. 2010b) were significantly lower in women who experienced CIA, resulting predictive of CIA. These results, however, have not been confirmed in another retrospective study (Yu et al. 2010). Also, the influence of Tamoxifen on AMH and inhibin-B has been studied, but conflicting results have been reported (Anderson et al. 2006; Partridge et al. 2010; Su et al. 2010b).

Unfortunately, due to some limitations in these studies, it is not possible to define the role of these new markers of OR as predictive factors of CIM in clinical practice. In fact, none of these
studies has been specifically designed to test AMH/inhibin-B since predictive factors of CIM, duration of follow-up and cohorts of patients are limited, the age distribution among the cohorts appears inhomogeneous, as well as the treatment received and sample collection time.

Very recently, in a prospective study, with a 5-year median follow-up, basal serum AMH was reported to be strongly predictive of long-term ovarian function in a cohort of 42 patients undergoing CT (± ET) for EBC. In particular, AMH remained the only significant predictive factor of late OR in a multivariate analysis including age and FSH (Anderson & Cameron 2011).

At present, AFC, AMH and inhibin-B are reliable predictive factors of fertility even in cancer patients. Moreover, AMH appears to be the most promising tool to improve the assessment of CIM (Schover 2008; Anderson & Cameron 2011).

**Practical approaches**

In premenopausal women presenting amenorrhea following adjuvant CT for EBC, the diagnosis of menopause still remains difficult.

The likelihood of resuming ovarian function decreases as a woman approaches the mean age of natural menopause (51 years) and when more ovarian toxic agents are included in CT-regimens. However, the individual risk of CIM cannot be predicted. To this end, a pre-chemotherapy evaluation of OR may offer another predictive element (Oktay et al. 2006), to be compared later with a post-chemotherapy OR assessment.

The choice of adjuvant ET may be guided by age only in a specific group of patients (Figure 2). Women ≤40 years with CIA should not receive an AI as the only adjuvant ET. If in these patients estrogen depletion is the desired endocrine strategy, this should include OFS (oophorectomy or chemical ovarian suppression with a gonadotropin-releasing hormone agonist) in

Tamoxifen ± OFS should be considered the standard of care even in women 40-50 years of age, who were pre-/perimenopausal at the time of starting adjuvant chemotherapy for EREBC. In these patients, and even in those older than 50 years, if an AI is considered to be a better option, the most accurate definition of the true menopausal status is mandatory. To this aim, there is some new evidence that AMH may reveal the residual activity of ovarian function in women with CIA (Anderson & Cameron 2011). In our opinion, the use of AMH, in conjunction with an endocrinology consult if needed, may support and strengthen the information obtainable from high quality assessment of estradiol and FSH.

Accordingly, women between 40-50 years of age who have developed CIA should preferably be evaluated by a laboratory where a high-quality estradiol assay is available, in order to obtain the most accurate monitoring of serial estradiol together with gonadotropin levels. Women who have levels within the premenopausal range (i.e., FSH ≤40UI/L and estradiol ≥10 pmol/L), should receive Tamoxifen alone, or Tamoxifen together with OFS. Another option is to participate in a clinical trial evaluating the combination of an AI with OFS. If hormone levels indicate the presence of a postmenopausal status (i.e, FSH >40UI/L and estradiol <10 pmol/L), AMH assessment may be useful in order to ascertain residual ovarian function (Anderson & Cameron 2011). If AMH levels are below the lower limits of normal range, AI may be cautiously started. In addition, despite the known limitations, serial hormone monitoring should be performed (with a reasonable timing of 4 months between two consecutive measurements) to achieve an ongoing confirmation of menopausal status (Figure 2). If levels remain in postmenopausal range, AI can be continued. Conversely, Tamoxifen (± OFS) is the appropriate ET.
The same approach should be used in premenopausal women >40 years with CIA who may start AI after 2-3 years of treatment with Tamoxifen.

Likewise, in women who develop amenorrhea during Tamoxifen treatment, irrespective of previous CT, and who are considered candidates for switching to an AI, it is advisable to perform serial high-quality evaluations of estradiol together with FSH and AMH. Only in the case of confirmed menopausal findings, can the shift be safely made.

Women over 50 years of age at the time of CT and with CIA lasting ≥6 months, may receive AI if the hormone assessment has provided enough certainty of menopause. However, if a continuous rise in estradiol levels is documented, Tamoxifen should replace AI.

It should be emphasized that amenorrhea alone is always a poor surrogate for ovarian function, and CIA may be transient and reversible, especially in younger women. Therefore, all pre-/perimenopausal women with CIA, particularly if they are receiving an AI, should be instructed to inform their clinician if vaginal bleeding occurs or hot flashes suddenly stop (Smith et al. 2006). Furthermore, sexually active women require counseling regarding the need to maintain birth control, because they may still ovulate and become pregnant, even when they are not menstruating. Finally, despite the fact that resumption of ovarian function with an AI is anecdotic, even while women are receiving a gonadotropin-releasing hormone agonist, a barrier contraception method should be recommended and practiced during the monitoring period or, alternatively, ovarian surgical ablation may be proposed (Smith et al. 2006).

Conclusions

The risk of premature iatrogenic menopause should be taken into consideration when assisting young women with their anticancer treatment and family planning decisions, both at diagnosis and during follow-up. Evaluation of residual ovarian function following adjuvant CT may
be challenging and the availability of better predictors providing more reliable assessments of OR is of particular relevance in patients with EREBC, as AI lead to improvements in survival of those who are postmenopausal. However, in these patients, tamoxifen should be considered the standard of care until menopause can be confirmed, even in women between ages 40-50, unless OFS is being induced. AMH, inhibin-B, FSH, estradiol, AFC and OV are currently used to estimate the OR in women with POI and CT-POI. The basal assessment of OR may identify the true reproduction potential of a woman before starting a cytotoxic regimen, and thus allow timely planning of appropriate fertility preservation procedures (Oktay et al. 2006; Lee et al. 2006). Moreover, the post-treatment evaluation of OR, compared with basal assessment, may be useful to evaluate residual OR, and indirectly offer the clinician the opportunity to estimate the onset of menopause in women with CIA. However, this is a stimulating hypothesis that would require confirmation through appropriately designed clinical studies. Prospective trials on a large number of patients, aimed at correlating the available OR parameters with the exact time of the last menstrual period, would then define their role in predicting the menopausal status of women with EREBC and CIA, and, therefore, provide reliable information that would be helpful in the selection of the most suitable ET for these patients. Meanwhile, rational and careful use of the best predictors of OR, in particular AMH, may be useful in prescribing the most appropriate ET for these patients. To this aim, a close collaboration between endocrinologists and oncologists may help in properly implementing the above diagnostic tools in daily clinical practice.

**Declaration of interest**

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**References**


Initial follicle recruitment is as a continuous process, whereas cyclic recruitment is driven by a rise in FSH serum levels at the end of a previous menstrual cycle. AMH is secreted by pre-antral and antral follicles and appeared to play an inhibiting role in initial recruitment of primary follicles from the resting primordial follicle pool and in the selection of the dominant follicle, by reducing the sensitivity of antral follicles for FSH. Inhibin-B may have paracrine functions positively influencing folliculogenesis (Hilier 1991; Findlay et al. 2000; Visser et al. 2006; Broekmans et al. 2008).
Figure 2. Practical approaches suggested if AI are considered as ET in women with EREBC and CIA or amenorrhea under TAM

- **≤40 years** CIA/amenorrhea under TAM
- **40-50 years** CIA
- **40-50 years** CIA and 2-3 years TAM (candidate to AI)
- **40-50 years** Amenorrhea under TAM
- **>50 years** CIA

If the use of AI is preferred ET or considered a component of ET

Measure FSH + E2 to assess menopausal status

- FSH ≤ 40 Ul/L
  - E2 ≥ 10 pg/ml
- FSH > 40 Ul/L
  - E2 < 10 pg/ml

Measure AMH to assess ovarian reserve

- AMH within normal range
- AMH < normal range

TAM ± OFS (AI + OFS trial)

AI: aromatase inhibitor; AMH: anti-Müllerian hormone; CIA: chemotherapy induced amenorrhea; E2: estradiol; EREBC: endocrine-responsive early breast cancer; ET: endocrine therapy; FSH: follicle-stimulating hormone; OFS: ovarian function suppression; TAM: tamoxifen

254x190mm (96 x 96 DPI)
Table 1. Definitions of ovarian insufficiency, amenorrhea, menopause

<table>
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<th>Definition</th>
<th>Description</th>
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<td><strong>In primary ovarian insufficiency (POI)</strong></td>
<td>The cause of ovarian dysfunction is inherent in the ovary. In most cases, an unknown mechanism leads to premature exhaustion of the resting pool of primordial follicles, but POI might also result from genetic defects, autoimmunity, surgery, radiotherapy or cytotoxic chemotherapy. POI is defined as amenorrhea for at least 3 months, and two recordings of serum concentrations of follicle-stimulating hormone (FSH) &gt;40 IU/L and low estradiol levels (&lt; 10 pg/ml) at least one month apart, in a woman aged less than 40 years (De Vos et al. 2010). The disorder usually leads to sterility.</td>
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<td><strong>The term amenorrhea</strong></td>
<td>Indicates the absence of menstrual cycles, either on a permanent, intermittent or temporary basis and may be classified as primary or secondary. In primary amenorrhea, menstrual periods have never appeared (by age 16), karyotype being abnormal in about 50% of cases. Secondary amenorrhea, with the exception of hysterectomy and uterine disorders, is defined as the lack of menses for more than 3 cycles or for 6 months in women who previously had menses. It may be due to pregnancy or caused by infections, uncontrolled diabetes mellitus, malnutrition, hypothalamic or thyroid dysfunction, hyperprolactinemia and polycystic ovary syndrome. Secondary amenorrhea together with increased levels of FSH often indicates ovarian insufficiency. However, there are no established gonadotropin cutoff values suggesting the onset of ovarian insufficiency, probably because the decline in ovarian function is intermittent and sometimes erratic (De Vos et al. 2010).</td>
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<td><strong>Menopause</strong></td>
<td>Defines the permanent cessation of menses resulting from the loss of ovarian follicle activity and marks the end of the natural reproductive life. Menopause is the physiological end-stage of ovarian ageing, which corresponds to a continuous process of insufficiency. Natural menopause can only be retrospectively established after 12 consecutive months of spontaneous amenorrhea. The age of natural menopause shows a normal distribution with a mean at approximately 51 years, range 40-60 years ((De Vos et al. 2010). In postmenopause, FSH levels are markedly increased, estradiol levels are low, whereas inhibin-B and anti-Müllerian hormone (AMH) are very low or undetectable (Knauff et al. 2009). A variety of definitions of menopause has been used in breast cancer clinical trials (Clemons &amp; Simmons 2007). According to the National Cancer Comprehensive Network (NCCN), criteria for determining menopause may alternatively include: bilateral oophorectomy; age ≥ 60 years; age &lt;60 years with amenorrhea for ≥12 months in the absence of chemotherapy, Tamoxifen, Toremifen, or ovarian suppression with FSH and estradiol in the postmenopausal range. If taking Tamoxifen or Toremifen, and age &lt;60 years, FSH and plasma estradiol levels should be within the postmenopausal range (NCCN - Breast Cancer Guidelines 2011).</td>
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| **Menopausal transition**                                                | Typically begins several years before the natural menopause, in the mid-40s, preceding the final menses by 2-8 years, with a mean duration of 4 years. In this period, the levels of hormones produced by the ageing ovaries fluctuate considerably, leading to abnormal menstrual patterns (irregularity in the length of the periods, the time between periods, and the level of flow), hot flashes, night sweats, mood changes, vaginal dryness, fluctuations in libido, forgetfulness, trouble sleeping, fatigue and weight gain. The endocrine changes underlying menopausal transition are predominantly the consequence of a marked decrease in ovarian follicle numbers. Estradiol levels fall considerably, whereas estrone levels remain almost unchanged, reflecting peripheral aromatization of adrenal and ovarian androgens. FSH levels increase more than those of the luteinizing hormone, presumably because of the loss of inhibins, as well as estrogen feedback. Other significant changes include a decrease in inhibin-B in the early phase of the menstrual cycle.
and in AMH levels.

**Perimenopause** starts with menopausal transition, lasting throughout the 12 months of amenorrhea.
Table 2. Estimated risk of permanent amenorrhea resulting from single agent chemotherapy and combination regimens used as adjuvant treatment for early breast cancer (modified from Lee et al. 2006).

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<th>Single drug</th>
<th>Adjuvant regimens</th>
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<td><strong>High risk (&gt;80%)</strong></td>
<td>Cyclophosphamide, Ifosfamide, Chlorambucil, Melphalan, Busulfan, Nitrogen Mustard, Procarbazine, Thiotepa</td>
<td>• CMF, FEC, FAC x 6 cycles in women aged ≥40 years</td>
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<td><strong>Intermediate risk</strong></td>
<td>Cisplatin, Carboplatin, Adriamycin, Taxanes</td>
<td>• CMF, FEC, FAC x 6 cycles in women aged 30-39 years</td>
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<td></td>
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<td>• AC, EC x 4 in women aged ≥40 years</td>
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<td></td>
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<td>• Taxane-containing combinations</td>
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<td><strong>Low risk (&lt;20%)</strong></td>
<td>Bleomycin, Dactinomycin, Vincristine, Vinblastine, Methotrexate, Mercaptopurine, 5-Fluorouracil</td>
<td>• CMF, FEC, FAC x 6 cycles in women aged &lt;30 years</td>
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<tr>
<td>or no risk</td>
<td></td>
<td>• AC, EC x 4 in women aged &lt;40 years</td>
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<tr>
<td><strong>To be determined</strong></td>
<td>Trastuzumab, Lapatinib</td>
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Table 3. Tools available to estimate ovarian reserve and menopause

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<th>Antral follicle count (AFC)</th>
<th>The most common ultrasound tests evaluating ovarian reserve (OR) are AFC, ovarian volume (OV) and stromal blood flow. However, only AFC and OV are reliable indicators of OR and potential predictors of menopausal age. However, OV assessment may not be precise and the inter-cycle variation of OV is more pronounced than that of AFC (Jayaprakasan et al. 2008). Although the results are conflicting, AFC is currently the most reliable ultrasound parameter predicting age at menopause (Lambalk et al. 2009).</th>
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<td>Follicle stimulating hormone (FSH)</td>
<td>FSH is responsible for follicular recruitment and growth as well as for androgen conversion to estrogen during folliculogenesis (Figure 1). Ovarian granulosa cells are the target of FSH. Elevated levels of FSH are the hormonal hallmark of reproductive aging. The STages of Reproductive Aging Workshop (STRAW) proposed FSH as the best predictive marker of menopause, but did not establish the precise cutoff values defining menopausal status (Soules et al. 2001). The early follicular phase FSH values gradually start to increase approximately 10 years before menopause, possibly simultaneous with the beginning of reduction in fertility (van Rooij et al. 2005; Sowers et al. 2008a). Low FSH levels (&lt;20 IU/L), assessed on day 3 of the cycle, indicate a good likelihood of achieving pregnancy and are inconsistent with perimenopause. FSH values ≥30 IU/L indicate poor likelihood of pregnancy while values ≥40 IU/L are indicative of late menopausal transition (van Montfrans et al. 2000). FSH levels are influenced by age and body size, independently of menstrual status. Furthermore, differences in results between assays evaluating serum FSH may have a confounding effect.</td>
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<td>Estradiol</td>
<td>A recent longitudinal follow-up study showed a continuous decline in sex steroids with advancing age (Sowers et al. 2008b). Average estradiol levels showed an increase in late menopausal transition, before a rapid decline shortly before menopause occurred (20 pg/mL) (Gracia et al. 2005).</td>
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<tr>
<td>Luteinizing hormone (LH)</td>
<td>LH levels increase with age as a result of increased pituitary sensitivity to GnRH, independently of estradiol levels (de Koning et al. 2000). During menopausal transition, LH rises slowly, reaching moderately elevated levels in postmenopause. FSH levels increase more than those of LH, presumably because of the loss of inhibin-B, as well as estrogen feedback.</td>
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<tr>
<td>Inhibins and activins</td>
<td>These hormones are members of the transforming growth factor (TGF)-β superfamily. Both inhibin-A and -B directly suppress pituitary FSH secretion, while activins selectively stimulate FSH secretion (Hillier 1991; Findlay et al. 2000). Inhibin-B may also have paracrine functions influencing folliculogenesis in the ovary (Figure 1) (Hillier 1991; Findlay et al. 2000). Little evidence has so far been obtained supporting a role for activins in FSH regulation during menopausal transition (Lambalk et al. 2009). Inhibin-A, secreted primarily by the mature follicle and corpus luteum, suppresses FSH secretion (Roberts et al. 1993). In some cross-sectional studies, inhibin-A levels appeared lower in older women, but at a later stage of menopausal transition (Lambalk et al. 2009). Inhibin-B is a product of the smaller non-dominant antral follicles, and, as such, reflects the ovarian follicle pool (Hall et al. 1999). Serum inhibin-B levels decrease to very low or undetectable levels about 4 years prior to the last menstrual period (Sowers et al. 2008a). In longitudinal studies, inhibin-B correlates with age only during a relatively short time before menopausal transition (van Rooij et al. 2005). Inhibin-B is probably a better indicator of ovarian</td>
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</table>
activity than of OR, due to its direct link with growing follicles, and is influenced by fluctuating ovarian function of late ovarian ageing and throughout the menstrual cycle. Inhibin-B seems not to be affected by the concomitant use of Tamoxifen (Su et al. 2010b).

**Anti-Müllerian hormone (AMH).** AMH, also known as Müllerian inhibiting substance, is another member of the TGF-β superfamily. AMH is produced by the Sertoli cells of the testis in the male and by ovarian granulosa cells of pre-antral and small antral follicles in the adult female, the number of which is related to the size of the primordial follicle pool (Broekmans et al. 2008). AMH modulates primordial follicle recruitment and inhibits cyclic follicle recruitment for folliculogenesis, mainly by inhibiting the action of FSH on follicle growth and selection (Themmen 2005; Broekmans et al. 2008). In the female, serum AMH is undetectable until the onset of puberty. AMH is considered to reflect the non-FSH dependent follicular growth (La Marca et al. 2007). As a follicle matures, AMH production disappears allowing the follicle to complete the development process during the FSH-dependent stages of growth (Visser et al. 2006). AMH secretion is independent of other hormones and is expressed at a constant level, irrespective of the day of the menstrual cycle (Cook et al. 2000). AMH levels show a progressive and linear decline until menopause, this being attributed to a decreasing number of primordial pool follicles (van Rooij et al. 2005; van Disseldorp et al. 2008). Healthy perimenopausal women showed a linear decline in AMH profiles to values below detection 5 years before the final menstrual period, whereas mean serum estradiol levels were maintained until approximately 2 years before the final menstrual period (Sowers et al. 2008b).

AMH is more strongly related to AFC than other biomarkers, thus reflecting the quantity of follicles and the quality of oocytes (Visser et al. 2006). Therefore, AMH may be used as a direct measure of OR and is considered the best single predictor of poor response to assisted reproductive techniques (La Marca et al. 2009). When women with a normal reproduction activity were examined, during an average time of 4 years, which included AFC and various hormonal markers, serum AMH, followed by AFC, showed the most consistent correlation to the age-related decline in reproductive capacity (van Rooij et al. 2004). Specific nomograms are available to individually calculate, using age and AMH, the age range in which menopause will subsequently occur both for normoovulatory women and reproductive likelihood of infertility patients (Broer et al. 2001; Nelson et al. 2011).

**Menstrual cycle changes.** Shortening of menstrual cycle duration, multiple follicle growth and anovulation are key features of reproductive ageing (Van Voorhis et al. 2008). However, these changes occur relatively late, and are not reliable predictors of menopause. At present, the occurrence of vasomotor symptoms is held to predict the final menstrual period within approximately 2 years (Lambalk et al. 2009).