Biomagnetic activity in the female breast at various physiological states

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Summary

Purpose: To investigate the biomagnetic activity produced physiologically by the various normally occurring states of the female breast: puberty, reproductive age, pregnancy, lactation and menopause.

Method: The mammary glands of 90 healthy women were examined using a Superconducting Quantum Interference Device (SQUID).

Results: Biomagnetic activity was low at puberty (105.46±3.77 fT/√Hz) and the menopause (111.66±25.06 fT/√Hz), but was high during the reproductive years (142.13±20.70 fT/√Hz), particularly in the hyperplastic states of late pregnancy (221.86±12.14 fT/√Hz) and lactation (252.73±54.77 fT/√Hz). The results were statistically significant ($p<0.0001$ ANOVA test).

Conclusion: Our observations indicate the importance of SQUID in understanding the biomagnetic activity of the female breast at the various physiological states of life.

Introduction

The female breast responds to hormonal stimuli throughout life and, as a result, it displays a spectrum of normal appearances which correspond to the physiological states of puberty, reproductive age, pregnancy/lactation and menopause [1-3]. These states have been studied extensively by histological means and correlated with the accompanied endocrinological events [4, 5]. There is, however, little information regarding the magnetic activity produced by the differing physiological states of the breast, a physical phenomenon which can be recorded by SQUID.

The biomagnetometer SQUID is a non-invasive research tool capable of measuring the exceedingly weak magnetic signals generated spontaneously by living tissues, as a consequence of the continuous ionic movement across the plasma membranes: the greater the functional activity of the tissue, the greater the ionic movement across the cell membranes and the greater the emitted signal [6-9].

Biomagnetometry has been used successfully in recording brain [10, 11] and heart [12] activity for many years and, more recently, in recording signals emitted from benign and malignant breast [13] and ovarian [14] lesions, and the umbilical [15] and uterine arteries [16] of normal and preeclamptic women.

This study was designed to explore the potential value of biomagnetometer SQUID in assessing the magnetic activity produced by the normal female breast during its functionally different states. The male breast being a rudimentary structure, relatively insensitive to hormonal stimulation, was not included in this investigation.

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Subjects and Methods

We studied 90 randomly selected healthy female volunteers of various age and of different functional states of life, 15 in each case. The women's age ranged from: 14 to 17 years in puberty (mean 15.53±1.06); 25 to 44 years in reproductive era (mean 36.73±7.15); 21 to 35 years in early and mid pregnancy (mean 27.86±6.05); 19 to 27 years in late pregnancy (mean 23.06±2.84); 23 to 30 years in lactation (mean 25.53±3.68); and 50 to 67 years in menopause (mean 58.13±5.38). Prior to biomagnetic measurements physical and mammographic examination of both breasts failed to reveal any palpable mass or other mammary disturbances. The women of the reproductive era were all in the proliferative phase of the menstrual cycle. The duration of menopause was defined by the date of the last menstrual period. The Hospital Ethics Committee approved the study and informed consent was obtained from all participating women prior to the procedure.

The method used for recording magnetic activity has been described previously [13]. In brief, we used a single channel SQUID with a sensitivity of 95 pTesla/Volt at 1000 Hz (DC SQUID model 601 with second order gradiometer, Biomagnetic Technologies Inc.). The gradiometer operates at a low liquid helium temperature of 4°K on the basis of the Josephson effect of superconductivity [17]. In order to minimize interference from stray electromagnetic radiation, recordings were taken in an electrically shielded room of low magnetic noise, 400 meters away from the hospital. During the procedure the patient was lying supine on a wooden bed, free of any metallic objects. None of the women were reluctant to participate and none subsequently withdrew from the study. Recordings were taken from the upper/outer quadrant of the right breast, i.e., the area with the largest proportion of lobular units [18], at a distance of 1 cm from the areola. For each point 32 recordings of 1-second duration each were taken with the SQUID detector placed 3 mm above the recording position. This allows the maximum magnetic flux to pass through the coil with little deviation from the vertical direction. The duration of the recordings was adequate to cancel out all random events, leaving the persistent ones undisturbed. Only measurements in the frequency range between 2-7 Hz were considered. By convention, the maximum

Table 1. — *Biomagnetic activity in the female breast during the various physiological states of life.*

Physiological states	Biomagnetic activity ($fT/\sqrt{Hz}$)
Puberty	105.46±3.77
Reproductive years	142.13±20.70
Early and mid pregnancy	141.46±8.63
Late pregnancy	221.86±12.14
Lactation	252.73±54.77
Menopause	111.66±25.06

value was used when assessing the breast lesions. Data conversion of the analog signals into digital recordings was accomplished by means of an AD converter operating with sampling frequency 256 Hz on line with a personal computer. The average spectral densities for the 32 1-second recordings were obtained after applying Fourier statistical analysis. In all cases the signals were related to measurements of background magnetic activity (environmental magnetic noise).

Results

The results are shown in Table 1. At puberty the magnetic activity produced by the normal breast tissue was on average (105.46±3.77 $fT/\sqrt{Hz}$) in the frequency range 2-7 Hz. These values were considerably increased during the reproductive years with the normal «cycling» breast reaching a mean measurement of magnetic activity (142.13±20.70 $fT/\sqrt{Hz}$) in the same frequency range. In early and mid pregnancy the mean values were equal (141.46±8.63 $fT/\sqrt{Hz}$) to those of the normal breast of the reproductive era, but they were increased considerably at term (221.86±12.14 $fT/\sqrt{Hz}$), reaching a peak during lactation (252.73±54.77 $fT/\sqrt{Hz}$). The magnetic activity was low at menopause (111.66±25.06 $fT/\sqrt{Hz}$), with the exception of three cases, which showed values above 145 $fT/\sqrt{Hz}$.

The ANOVA statistical analysis was used to compare the mean values of biomagnetic activity in the six physiological states of life. There was a highly significant difference between the groups ($p<0.0001$).

Figure 1A shows a representative biomagnetic signal of a normal pubertal breast, with low amplitudes and rhythmicity. The Fast Fourier Transform (FFT) algorithm of magnetomammography (MMG) data is illustrated in Figure 1B; it shows a maximum value of 100 $fT/\sqrt{Hz}$ at the frequency of 2 Hz.

Figure 2A indicates a representative recording of a lactating breast, with high amplitudes and rhytmicity. As illustrated in Figure 2B the algorithm shows a maximum value of 222 $fT/\sqrt{Hz}$ at the frequency of 5 Hz.

Discussion

This study sheds light on a new aspect of breast physiology, the biomagnetic activity produced by the mammary gland during the normally occurring states of puberty, reproductive era, pregnancy/lactation and meno-

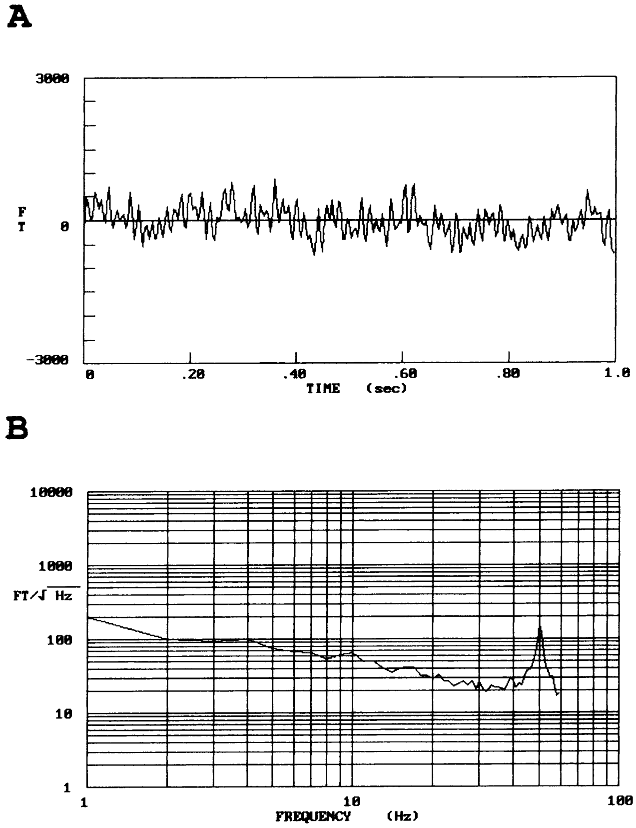

Figure 1. — Biomagnetic activity in the female breast at puberty. A) Representative wave-form recordings of the magnetic field emitted with low amplitudes in the frequency range 2-7 Hz. B) The corresponding spectral densities from the same woman: the spectral amplitudes are 100 $fT/\sqrt{HZ}$ in the frequency of 2 Hz.

pause. Breast, like any other living tissue, generates alternating magnetic fields as a result of the continuous ionic micro-currents across the plasma membranes. Their magnitude depends on the functional state of the tissue. The more intense the breast dynamics the higher the magnetic fields produced. The biomagnetometer SQUID can measure this weak activity, which is about 10^{-8} of the earth's magnetic field.

The low magnetic fileds recorded at puberty (105.46±3.77 $fT/\sqrt{Hz}$) correspond to an immature mammary gland, consisting of a few branched ducts without any true acini, but with multiple solid epithelial buds, which are potential acini [20]. This state is under the influence of oestrogens. A slight enlargement of the breasts seen at the premenarcheal stage is entirely due to the deposition of fat and an increase in acellular collagenous fibrous tissue and not to active epithelial tissue with intense cellular activity, high vascular density and high-energy production.

The equally low magnetic fields (111.66±25.06 $fT/\sqrt{Hz}$) noted in women of advanced age conforms with the histological picture of an involuted mammary gland, showing marked atrophy of the functioning unit of the breast, the terminal duct lobular mit (TDLU) [19, 21].

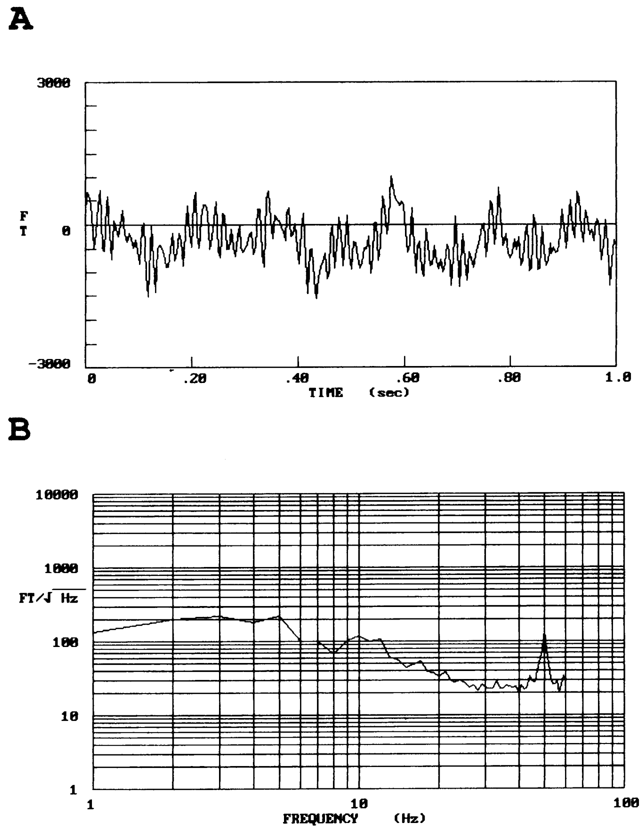

Figure 2. — Biomagnetic activity in the female breast during lactation. A) Representative wave-form recordings of the magnetic filed emitted with high amplitudes in the frequency range 2-7 Hz. B) The corresponding spectral densities from the same patient: the spectral amplitudes are 222 fT/√Hz in the frequency of 5 Hz.

Indeed, following the decline of ovarian fuction, the postmenopausal breast consists largely of fibrous tissue and fat containing only a few residual acini and large ducts.

On the other hand, the high magnetic activity recorded during childbearing age (142.13±20.70 fT/√Hz) corresponds to a well developed mammary gland in the female, undergoing cyclical changes in response to ovarian hormones, in a manner comparable with that of the normal menstrual cycle [4, 5]. The metamorphosis of the underdeveloped immature gland of puberty to the mature gland of reproductive years, with definitive functional units (TDLU), is achieved under the coordinated action of many hormones, including estrogens and progesterone.

In early and mid pregnancy, the magnetic activity of the mammary tissue retains the high activity recorded in the normally cycling breast (141.46±8.63 fT/√Hz), but towards the end of gestation and, particularly during lactation, the magnetic fields reach maximum values. At this stage, the breasts attain their greatest development and their full differentiation, with both the intralobular and interlobular stroma being completely obliterated by the actively secreting acini [22]. There is a greater volume of circulating blood [23]. The biomagnetic activity is at a peak (252.73±54.77 fT/√Hz). These changes are due to the synergic action of estrogen, progesterone, prolactin, growth hormone and oxytocin.

Our results show that the magnitude of the biomagnetic activity in the breast is dependent on the cell volume and the stromal vascularity of this tissue and are, therefore, in complete accord with the age-dependent changes of breast parenchyma reported by Prechtel [23] and Hutson [18]. According to these investigators, the breast epithelial volume reaches a maximum between 23 and 38 years of age, followed by a gradual decline in volume thereafter. Thus, retention of more than a few residual foci of TDLU in postmenopausal age reflects an increased functional activity of the breast and production of higher than the expected magnetic values. This was indeed the case in three of the 15 postmenopausal women studied (values above 145 fT/√Hz) raising the question of an increased risk of subsequent development of breast cancer [13, 24].

In conclusion, our data, although preliminary, contribute to a better understanding of the biomagnetic activity physiologically produced by the breast. Additional studies are certainly required to establish objective values of mammary biomagnetic activity in health and disease.

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