Contribution and Performance of Mobile Units in an Organized Mammography Screening Program

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ABSTRACT

BACKGROUND: The aims of this study were to evaluate the contribution of mobile mammography units to participation rate and to compare their performance to fixed screening centres within the organized mammography screening program of Quebec, Canada.

METHODS: The study is based on all screening mammograms carried out in women aged 50-69 who participated in the Québec program from 2002 to 2010. Performance was measured by screening sensitivity, false-positive rate (1-specificity), positive likelihood ratio as well as abnormal call rate, detection rate, interval cancer rate, positive predictive value, and tumour characteristics. Poisson regression models with robust variance estimation were used to take into account the multi-level structure of the data. All models were adjusted for characteristics related to women.

RESULTS: During the 2002-2010 period, 2,292,592 screening mammograms were performed, of which 42,279 (1.8%) were in mobile units. In regions serviced exclusively by mobile units, the participation rate reached an average of 63.4% during the 2006-2010 period compared to 54.7% for the entire study population. Estimated sensitivity was similar to that of fixed sites (rate ratio = 0.98 [0.84-1.15]) while the false-positive rate was lower (rate ratio = 0.76 [0.57-1.02]) although this difference was of marginal statistical significance ($p=0.07$).

CONCLUSIONS: In this program, mobile mammography units allowed regions lacking a fixed centre to attain participation rates slightly higher than those in the rest of Quebec, without loss of sensitivity and with some gain in the false-positive rate.

KEY WORDS: Breast neoplasms; mass screening; mammography; mobile health units; mobile mammography

La traduction du résumé se trouve à la fin de l'article.

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Breast cancer screening enables early detection of breast cancer which leads to a reduction in mortality.^{1,2} The Quebec breast cancer screening program began in 1998 and offers women aged 50-69 a biennial screening mammography.³ Since 2002, three mammography mobile units were progressively added to the program. The program relies on two motorized units and a portable unit transported by plane or boat that extends screening services to regions not accessible by land. In the present study, we use the term "mobile units" to refer to both (motorized and portable) types of mammography units. The purpose of these units is to provide services to regions not covered by fixed centres. In addition, they can provide temporary relief to fixed centres that have insufficient resources to ensure timely breast screening.

Mobile units have been added to screening programs in various countries to increase geographical accessibility to breast cancer screening.⁴ Studies have shown that mobile units are effective at improving the participation rate,⁵⁻⁷ that mobile units can decrease barriers to screening for hard-to-reach populations⁸ and that educational interventions associated with mobile unit visits can increase adherence.⁹ However, mobile units have different operating practices when compared to stationary (fixed) centres in terms of personnel, work conditions and environment. Moreover, screening in mobile units may require ongoing calibration of instruments, and where analogue units are used, films cannot be developed onsite. These differences could have an impact on screening outcomes but there are few studies comparing the performance of

mobile units to fixed sites.^{10,11} These studies focussed primarily on comparing costs and other elements (price, access, quality assurance). In some studies, screening results for mobile units were reported but were not compared to fixed centres.^{8,12-14}

The aims of this study were to evaluate the contribution of mobile mammography units to participation rate, and to compare screening performance between mobile units and fixed centres in the organized mammography screening program of Quebec, Canada.

METHODS

Population and data

All eligible women residing in the province, aged 50-69 years, are invited to participate in the Quebec breast cancer screening program. Each participant is asked to sign a written consent form to allow the collection of personal characteristics and screening information. Over the study period, 98% of participants provided written consent.

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Table 1. Definition of Performance Indicators

Screening mammogram	Assessment	Cancer		
		+	-	Total
		a	b	N ₁
+	-	c ₁	d	N ₀
-	-	c ₂	d	N ₀
Total		M ₁	M ₀	T

Indicators	Formula	Definitions
Sensitivity	a / M_1	Proportion of true-positives among all cancers diagnosed in the 24 months following screening
False-positive rate	b / M_0	Proportion of false-positives among mammograms without a cancer diagnosed in the 24 months following screening
Positive likelihood ratio	a / M_1 b / M_0	Sensitivity/false-positive rate
Abnormal call rate	N_1 / T	Proportion of all women screened who are referred for follow-up investigation
Cancer detection rate	a / T	Number of true-positives for 1000 screening mammograms
Interval cancer rate	$(c_1 + c_2) / (T \times t^*)$	Number of false-negatives for 10,000 person-years of follow-up
Positive predictive value	a / N_1	Proportion of true positives among positive screening mammograms

* t = average follow-up in person-years.

Data pertaining to characteristics of participants, region of residence, screening mammograms and screening centres are recorded in the program's information system. Characteristics of radiologists were retrieved either from the information system or from the Quebec College of Physicians.¹⁵ Using a validated approach, breast cancers were identified from various sources such as the program's information system, the Quebec physician claims database and the hospitalizations and one-day surgeries data registry.¹⁶ The sensitivity of this approach to identify breast cancer cases was 98.9% and the specificity was 99.7%. Cancer information was available for all women who had a screening mammogram up to 2006. Data confidentiality is maintained through an anonymizing process.

Definition of performance indicators

Participation rate was defined as the proportion of the target population who participated at least once in the program within a two-year period. It is calculated by dividing the number of women aged 50-69 years who have undergone at least one screening mammography in the program within a two-year period by the mean number of women of similar age in the population during the same period.

Screening mammograms were classified as abnormal if a follow-up investigation was requested; otherwise it was classified as normal. A cancer was considered "screen-detected" if a ductal carcinoma in situ (DCIS) or an invasive carcinoma was diagnosed within 6 months following an abnormal screen. Screen-detected cancers were considered true-positives at screening. If a cancer (DCIS or invasive) was diagnosed in the 24 months following a normal screen, or if cancer was diagnosed in the 6-24 months interval following an abnormal screen, then such cancers were considered interval cancers (false-negatives). Screening was considered true-negative if cancer was not diagnosed in the 24 months following a normal screen. If a follow-up investigation was requested following an abnormal screen but cancer was not diagnosed in the following 24 months, then the screen was considered false-positive.

Table 1 presents the definition of all performance indicators used in our analysis. Sensitivity was defined as the proportion of true-positives among all cancers diagnosed in the 24 months following screening (true-positives/(true-positives + false-negatives)). Detection rate was defined as the number of true-positives per 1,000

screening mammograms. Interval cancer rate was calculated as the number of false-negatives (interval cancers) for 10,000 person-years of follow-up. Person-years were calculated by summing the follow-up time of each woman screened, excluding the first six months of follow-up after an abnormal screen since all cancers diagnosed during this period are considered screen-detected and thus, women are not "at risk" of interval cancer. A small proportion (6.5%) of women has an annual screening; since follow-up is less than 2 years at the time of the early screen in these women, sensitivity may be slightly overestimated.

False-positive rate (1-specificity) was defined as the proportion of abnormal screens among screens without a cancer diagnosis in the following 24 months (false-positives/(false-positives + true-negatives)). Abnormal call rate was defined as the proportion of all women screened who are referred for follow-up investigation.

Positive likelihood ratio was equal to sensitivity/false-positive rate. Positive predictive value was defined as the proportion of true positives among all abnormal screens. Additional indicators were calculated for screen-detected cancers (true-positives) such as the proportion of in situ cancers among all true-positives, the proportion of invasive cancers less than 1 cm among all invasive true-positives, and the proportion of invasive cancers without nodal invasion among all invasive true-positives.

Analysis

The participation rate was calculated for 2002-2010 and included all screening examinations performed in the program during that period (2,292,592 screens done on 891,699 women). However, the analysis of screening performance was limited to 2002-2006 because data on cancer diagnosis were only available for screening occurring up to December 2006 (cancer follow-up information is available up to December 2008). A total of 1,017,360 screening mammograms were analyzed after excluding 45,828 (4.1%) for presence of symptoms, 29,923 (2.7%) for breast implants, 2,443 (0.2%) for prior mastectomy, 479 (<0.1%) for having a mammogram in the previous 11 months (likely diagnostic mammograms mislabelled as screening), and 18,196 (1.6%) for missing key variables.

For the population of a given region, the contribution of mobile mammography units to the participation rate corresponds to the

Figure 1. Contribution of mobile units to the participation rate for regions serviced exclusively by fixed centres, fixed centres and mobile units, and mobile units during 2002-2010

proportion of all screening examinations carried out in mobile units. This percentage can be interpreted as the percentage of the total participation rate in the region that is attributable to mobile units: (total participation rate – participation rate of fixed centres)/total participation rate. The participation rate of fixed centres corresponds to an estimate of the participation rate that is achieved in this population in the absence of mobile units. However, it must be noted that even in regions without fixed centres, this rate is not zero because some women do travel outside their region to have a mammogram.

To compare performance indicators of mobile units and fixed centres, we used multivariate Poisson regression with robust standard errors to estimate adjusted rate ratios.¹⁷ Poisson regression was chosen since log-binomial models would not converge even after using the COPY method.¹⁷

To respect the multi-level structure of the data and to account for a potential correlation between mammograms interpreted by the same radiologist, models were constructed with generalized estimating equations (GEE) with an independent working correlation matrix.¹⁷ Adjusting for correlation between repeated examinations for the same woman has been shown previously to have little to no effect.^{18,19} A model was constructed for each performance indicator. Models were adjusted for age, parity, family history of breast cancer, breast density, body mass index (BMI), previous breast aspiration or biopsy, use of hormone-replacement therapy (HRT) and screening round (initial mammogram in the program without a previous mammogram; initial mammogram in the program with a previous mammogram; subsequent mammogram in the program with ≤ 18 months, 19-30 months and >30 months delay from the previous mammogram). Radiologist characteristics were considered intermediate variables and were not included in the main models.

However, complementary analyses were performed by adjusting simultaneously for characteristics related to women and for radiologist characteristics (sex, year of radiology certification, and annual interpretive volume) to examine the effect of adjusting for radiologists' characteristics on estimates. Statistical analyses were conducted with SAS version 9.2 (SAS Institute, Inc., Cary, NC).

RESULTS

Contribution of mobile mammography units to the participation rate

Among the 2,292,592 screening mammograms performed in the program in 2002-2010, 42,279 (1.8%) were performed in a mobile unit. Most of these (87.5%) were done in regions also serviced by fixed centres and 5,118 (12.5%) were done in regions not serviced by fixed centres. The annual number of mammograms performed in mobile units increased from 2,152 in 2002 to 7,714 in 2009 (it decreased in 2010 due to the conversion of two units to digital technology).

The contribution of mobile units to the participation rate varies with the type of services offered to each region (fixed centres, mobile units or both) (Figure 1). The overall participation rate in regions serviced only by mobile units was 44.3% in 2002-2005 and 63.4% in 2006-2010, surpassing the provincial rate in 2006-2010 (46.9% and 54.7% in 2002-2005 and 2006-2010, respectively). In these regions, in 2002-2005, the participation rate in fixed centres (mammograms done in a fixed centre available in another region) was 7.7%; therefore, the contribution from mobile units was $(44.3 - 7.7)/44.3 = 82.7\%$. Similarly, in 2006-2010, mobile units accounted for 90.6% of the overall participation rate. In regions serviced by both types of services, mobile units accounted for 3.5% of the par-

Table 2. Demographic and Clinical Characteristics by Type of Service Utilized, 2002-2006

Characteristics	Fixed Centres		Mobile Units	
	N Mammograms 1,000,706	% 100.0	N Mammograms 16,654	% 100.0
Women				
Screening round				
Initial without prior mammogram	66,808	6.7	1887	11.3
Initial with prior mammogram	220,159	22.0	5198	31.2
Subsequent*	713,739	71.3	9569	57.5
Age, years, mean ($\pm$ SD)	58.0,(5.5)		57.9,(5.5)	
BMI, kg/m ² , mean ($\pm$ SD)	26.6,(5.2)		27.7,(5.8)	
Family history of breast cancer	161,863	16.2	2364	14.2
Breast density $\geq$ 50%	341,338	34.1	5196	31.2
Number of children (at least 1 child)	835,582	83.5	14,952	89.8
Previous breast aspiration or biopsy	107,564	10.8	1965	11.8
Hormonal treatment (current)	354,462	35.4	5694	34.2
Radiologists				
Male radiologists	739,318	73.9	15,060	90.4
Year of radiology permit				
<1970	138,773	13.9	0	0.0
1970-1979	339,323	33.9	9166	55.0
1980-1989	212,650	21.2	5422	32.6
1990-1999	251,803	25.2	1721	10.3
$\geq$ 2000	58,157	5.8	345	2.1
Annual radiologist volume				
<250	75,703	7.6	713	4.3
250-499	122,630	12.2	828	5.0
500-749	125,569	12.5	913	5.5
750-999	133,989	13.4	512	3.0
1000-1249	125,893	12.6	185	1.1
1250-1499	72,863	7.3	481	2.9
$\geq$ 1500	344,059	34.4	13,022	78.2

SD = standard deviation; BMI = body mass index.

* Subsequent category groups women with a subsequent mammogram with a delay <18 months, 18-30 months, and $\geq$ 30 months following a previous mammogram.

participation rate in 2002-2005 and 5.0% in 2006-2010. Comparing these regions individually, the contribution to the participation rate ranged from 0.9 to 31.0% in 2006-2010.

Performance of mobile mammography units

Analysis of screening performance in 2002-2006 was based on 1,000,706 mammograms performed in fixed centres on 580,420 women and interpreted by 321 radiologists, and 16,654 mammograms performed in mobile units on 13,193 women and read by 21 radiologists. Radiologists who interpreted mammograms in mobile units also interpreted mammograms in fixed centres.

Demographic and clinical characteristics are presented in Table 2. Women who had their mammogram in mobile units had a lower risk of breast cancer. Except for a higher BMI, they less frequently had a family history of breast cancer, lower breast density, more children, and less HRT usage. In addition, there were more initial screens among these women than among those participating in fixed centres. Compared to radiologists working in fixed units, radiologists reading mammograms from mobile units were more often male, with greater seniority and a higher annual screening volume.

Mobile units had similar sensitivity when compared to fixed centres (rate ratio = 0.98 [0.84-1.15]) and a lower false-positive rate, but these differences were of marginal statistical significance (rate ratio = 0.76 [0.57-1.02], ($p=0.07$)) (Table 3). Since sensitivity remained unchanged while the false-positive rate decreased, it follows that the positive likelihood ratio was higher for mobile units (1.28 [0.97-1.70]; $p=0.08$). However, despite the similar sensitivity, mobile units have a slightly lower detection rate (rate ratio = 0.80 [0.58-1.10]) and interval cancer rate (rate ratio = 0.86 [0.66-1.11]).

Characteristics of cancers detected in mobile units were comparable to those detected in fixed centres (Table 4) but the proportion of cancers without nodal invasion was somewhat higher in mobile

units when compared to fixed centres, 82.4% versus 74.5% (rate ratio = 1.11 [0.96-1.28]).

Complementary analyses

Adjustment for radiologist characteristics attenuated some of the observed differences between mobile units and fixed centres. The false-positive rate ratio increased from 0.76 [0.57-1.02] to 0.87 [0.75-1.02] and the positive likelihood ratio decreased from 1.28 [0.97-1.70] to 1.12 [0.93-1.35] (results not shown). Thus, accounting for radiologist characteristics explained, at least in part, the slight reduction in false-positive rate observed in mobile units compared to fixed centres.

DISCUSSION

Effectiveness, efficiency and equity are key considerations for policy-making in health services.²⁰ This study provided data on effectiveness and equity. In regions without fixed centres, mobile units facilitated access to screening and bolstered the participation rate by more than 80%. They helped women achieve participation rates comparable to or higher than those of regions serviced by fixed centres. In regions with fixed centres, mobile units also improved equity of access by alleviating temporary problems with fixed centre availability (equipment failure or long waiting lists) and thus contributed to the reduction of waiting lists and delays.

The improvement in equity was observed without loss of effectiveness. Sensitivity for mobile units was comparable to fixed centres while the false-positive rate was slightly improved. After adjustment for radiologists' characteristics, differences noted in the false-positive rate between mobile units and fixed centres decreased. Thus, radiologists' characteristics such as greater seniority and greater annual screening volume appear to explain, at least in part, the lower false-positive rate observed in mobile units.

Table 3. Comparison of Sensitivity, False-positive Rate, Positive Likelihood Ratio, Abnormal Call Rate, Cancer Detection Rate, Interval Cancer Rate and Positive Predictive Value Between Mobile Units and Fixed Centres, 2002-2006

Indicator	Numerator	Denominator	Crude Rate	Adjusted Rate*	Adjusted Rate Ratio (95% CI)*	
Sensitivity, %						
Fixed centres	5166	7353	70.3	71.1	1.00	
Mobile units	72	103	69.9	69.7	0.98	[0.84-1.15]
P-value					0.82	
False-positive rate, %						
Fixed centres	89,678	993,353	9.0	8.2	1.00	
Mobile units	1274	16,551	7.7	6.3	0.76	[0.57-1.02]
P-value					0.07	
Positive likelihood ratio						
Fixed centres	0.703	0.090	7.8	8.7	1.00	
Mobile units	0.699	0.077	9.1	11.1	1.28	[0.97-1.70]
P-value					0.08	
Abnormal call rate, %						
Fixed centres	95,440	1,000,706	9.5	8.7	1.00	
Mobile units	1354	16,654	8.1	6.7	0.77	[0.58-1.02]
P-value					0.07	
Cancer detection rate, /1000						
Fixed centres	5166	1,000,706	5.2	4.7	1.00	
Mobile units	72	16,654	4.3	3.8	0.80	[0.58-1.10]
P-value					0.18	
Interval cancer rate, /10,000 PY						
Fixed centres	2187	1,906,164	11.5	9.7	1.00	
Mobile units	31	32,217	9.6	8.3	0.86	[0.66-1.11]
P-value					0.24	
Positive predictive value, %						
Fixed centres	5166	95,440	5.4	5.4	1.00	
Mobile units	72	1354	5.3	5.7	1.05	[0.78-1.43]
P-value					0.73	

CI: confidence interval; PY: person-years.

* Adjusted for screening status, age, family history of breast cancer, BMI, breast density, number of children, prior breast aspiration or biopsy, and HRT use.

Table 4. Comparison of Percent In situ Cancers, Invasive Cancers Less Than 1 cm and Invasive Cancers Without Nodal Invasion Between Mobile Units and Fixed Centres, 2002-2006

Indicator	Numerator	Denominator	Crude Rate	Adjusted Rate*	Adjusted Rate Ratio (95% CI)*	
In situ cancers, %						
Fixed centres	1160	4798	24.2	23.5	1.00	
Mobile units	18	68	26.5	27.4	1.17	[0.75-1.81]
P-value					0.49	
Invasive cancers less than 1 cm, %						
Fixed centres	1422	3638	39.1	38.5	1.00	
Mobile units	17	50	34.0	35.8	0.93	[0.72-1.20]
P-value					0.58	
Invasive cancers without nodal invasion, %						
Fixed centres	2716	3638	74.7	74.5	1.00	
Mobile units	40	50	80.0	82.5	1.11	[0.96-1.28]
P-value					0.17	

CI: confidence interval.

* Adjusted for screening status, age, family history of breast cancer, BMI, breast density, number of children, prior breast aspiration or biopsy, and HRT use.

In regions lacking fixed centres, the proportion of native women is greater than that in regions with fixed centres. This might explain why women seen in mobile centres have higher BMI, lower breast density, and higher number of children than women seen in fixed centres. In a Canadian cohort study involving 141,290 First Nations women, the incidence of breast cancer was much lower in these women than in the rest of the population (RR = 0.54).²¹ Given equal sensitivity, a group of women with a low incidence rate would tend to have lower detection and interval cancer rates than a group with higher incidence. Thus, differences in ethnicity could explain, at least in part, the lower detection rate and interval cancer rate observed in mobile units compared to fixed centres.

Performing screening mammograms in mobile units presents several challenges. Film developing in analogue units is deferred, the quality of the image (positioning, artefact, compression and contrast) cannot be verified onsite, film quality must be maintained during transportation, and units may require frequent calibration. In addition, work conditions for technologists differ from fixed cen-

tres, i.e., high number of screenings in a short period of time, longer working hours and extended periods away from home. To address these challenges, the film-developing process in mobile units follows a rigorous protocol and mammogram quality is systematically verified by the accreditation process. Mobile units in Quebec are now converted to digital units, which should permit real-time treatment of mammograms, including repeating the mammogram, if necessary. Moreover, technologists who do the mammograms and the radiologists who read them are chosen from among those with greater experience in mammography. This study shows that, despite the challenges, the performance of mobile units is equivalent to or slightly better than the performance of fixed centres.

Regarding efficiency, the costs per mammogram performed in mobile units in the Quebec screening program were not studied here but they are likely to be higher than those of fixed centres. For instance, in regions serviced only by mobile units, women are transported to the mobile unit by plane or boat to receive a screening mammogram, and are also transported and lodged if referred

for assessment. In addition, the units have to be hauled across the province to reach remote destinations, and medical personnel need to be transported to the unit and work longer hours. Indeed, a study published in 2009 reported higher annual costs for analogue mobile units compared to fixed sites.¹⁰ Although digital units can potentially reduce costs due to reduction in expenses for film processing, the authors reported that the annual operating costs for digital mobile units were greater than for fixed centres.¹⁰ Some studies have shown that mobile units could be more cost efficient if they targeted hard-to-reach populations and maintained high mammography volumes.²²⁻²⁴

Strengths of this study include the fact that it is one of the first to compare the performance of mobile units to fixed centres. Previous articles had reported only on the increase in participation rate attributed to mobile units.⁵⁻⁷ Concerning the other performance indicators, data have been reported in a few articles but the results were limited to mobile units and were not compared to fixed centres.^{8,12-14} This population-based study utilized routine follow-up data collected for women participating in the same screening program. Comparisons between mobile units and fixed centres were conducted for several key performance indicators while taking into account a broad range of potential confounding factors. This study also has some limitations. First, the low number of cancers detected in mobile units limits the statistical power for the analysis of sensitivity. Second, it was not possible to differentiate native from non-native women and this could explain in part the differences observed in the detection rate and interval cancer rate. However, it should have little or no effect on findings for sensitivity and false-positive rate because these indicators are not affected by underlying incidence differences and we were able to adjust for key confounding factors such as age, BMI, breast density and HRT use.

In conclusion, while mobile mammography units may be more costly than stationary centres, in this program, they play a major role in ensuring access to breast cancer screening and guarantee adequate participation rates in regions deprived of a fixed centre. Mobile units also provide an important supporting function in regions where a fixed centre's resources are temporarily insufficient. Moreover, despite the operational differences between fixed and mobile services, screening sensitivity in mobile units is comparable to that of fixed centres with a slight improvement in the false-positive rate.

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RÉSUMÉ

CONTEXTE : Les objectifs de cette étude sont d'évaluer la contribution des unités mobiles en mammographie du Programme québécois de dépistage du cancer du sein sur le taux de participation du programme ainsi que de comparer leur performance à celle des centres fixes.

MÉTHODES : L'étude est basée sur toutes les mammographies de dépistage réalisées chez des femmes de 50 à 69 ans pour la période 2002 à 2010. La performance des unités mobiles est évaluée à partir de la sensibilité, du taux de faux positif (1-spécificité), du ratio de vraisemblance, du taux de référence pour anomalie, du taux de détection, du taux de cancer d'intervalle, de la valeur prédictive positive et des caractéristiques des cancers. Un modèle de régression de Poisson avec estimation robuste de la variance a été utilisé afin de prendre en compte la structure multiniveaux des données. Les modèles sont ajustés pour les caractéristiques des femmes.

RÉSULTATS : Pour la période 2002 à 2010, 2 292 592 mammographies de dépistage ont été réalisées, dont 42 279 (1,8 %) en unités mobiles. Dans les régions desservies uniquement par les unités mobiles, le taux de

participation atteint une moyenne de 63,4 % pour la période 2006 à 2010 comparativement à 54,7 % pour l'ensemble de la cohorte à l'étude. La sensibilité était similaire à celle des centres fixes (rapport de risque = 0,98 [0,84-1,15]) tandis que le taux de faux positif était plus faible (rapport de risque = 0,76 [0,57-1,02]), quoique presque statistiquement significatif ($p=0,07$).

CONCLUSIONS : Dans ce programme, les unités mobiles de mammographie permettent aux régions dépourvues de centres fixes d'atteindre un taux de participation légèrement plus élevé que dans le reste du Québec, et ce avec une sensibilité équivalente et un certain gain dans le taux de faux positifs.

MOTS CLÉS : cancer du sein; dépistage systématique; mammographie; unités mobiles