Correlation of diagnostic breast imaging data and pathology : application to diagnosis and treatment

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Chapter 2

Displacement of breast tissue and needle deviations during stereotactic procedures

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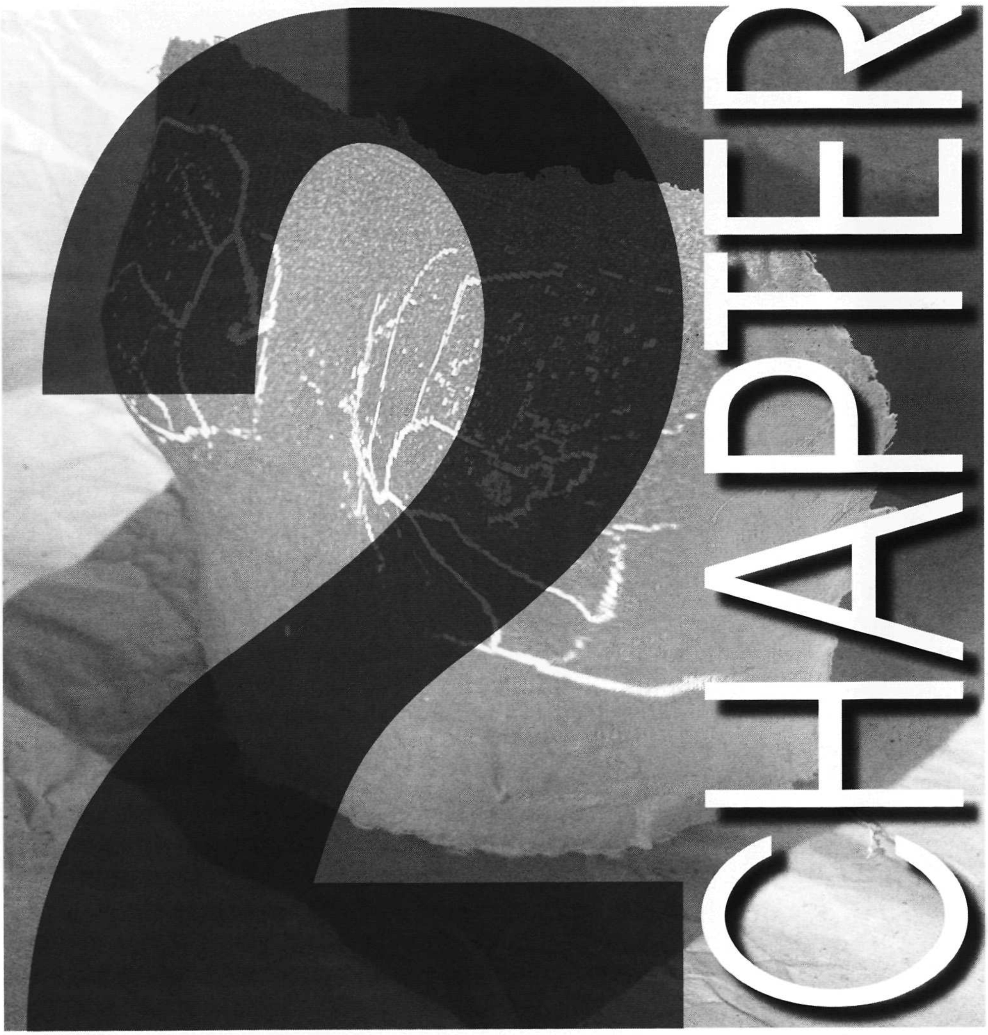

Abstract

Rationale and objectives: The aim of this study was to quantify the displacement of breast tissue and the inaccuracy of needle positioning for biopsy (14 gauge) and localization (19.5 gauge) needles.
Methods: For displacement of breast tissue, differences between the coordinates of identifiable microcalcifications in the images before (baseline) and after needle positioning were analyzed (n = 52). For accuracy of needle positioning, differences between the coordinates of the needle tip and the target were analyzed in breast tissue (n = 97) and in air (n = 246).
Results: Average target displacement was 2.1 mm for biopsy needles (95% prediction interval [PI] 0.6 - 7.8) and 1.0 mm (95% PI 0.3 - 3.9) for localization needles. Mean inaccuracy of needle positioning in breast tissue was 1.1 mm (95% PI 0.4 - 3.0) and 1.8 mm (95% PI 0.7 - 4.6) for biopsy and localization needles, respectively.
Conclusion: Tissue and needle displacements cause a total positioning error of 2.4 mm in stereotactic core biopsy, which will limit the attainable diagnostic accuracy.

2.1 Introduction

Many studies have addressed the issue of the diagnostic accuracy of radiological stereotactic core biopsy of non-palpable breast lesions [10-14, 75-80]. These studies have shown that the diagnostic accuracy of core biopsy is almost as reliable as that of tissue obtained during surgical excisional biopsy [11, 12, 81]. In some cases, however, a correct diagnosis is not obtained. In lesions showing microcalcifications only, this situation occurs more frequently: 8 to 9% in cases of microcalcifications only versus 1 to 2% in densities [13, 15, 78, 79]. In these cases no diagnostic material was obtained, which means that the lesion was missed. There are several possible explanations for these failures.
First, breast tissue and / or the lesion itself may shift during positioning of the needle. The stereotactic breast core biopsy system guides the core needle to a position in the breast with the same coordinates as the selected target. If the lesion is pushed away by the needle, the coordinates of the lesion change, so the needle will not arrive at the correct place. Dowlatshahi et al. [82] stated that lesions in fatty parts of the breast move when the needle tip pushes against them, even though the breast is immobilized. Secondly, there can be an error in the positioning of the needle. The needle may be deviated by the breast tissue, and the instrument itself may be in error. This instrument error has been determined in at least one other study and it was shown to be < 2 mm [83]. Furthermore, breast tissue and / or the lesion may move during firing of the biopsy gun. Finally, operator errors may occur during the stereotactic procedure [75-78, 84, 85].
To determine the influence of these errors on the diagnostic accuracy of stereotactic biopsy procedures, the occurrence of these errors must be quantified. The accuracy of stereotactic procedures is important not only for biopsy and localization procedures but also for modern techniques, such as robotic systems for biopsy and therapy in magnetic resonance imaging [86] and stereotactic-guided laser therapy systems [87].

In this study, we have quantified displacement of the target by registering tissue movement using microcalcifications in the breast as internal markers. We have also quantified the inaccuracy in positioning of the needle in both breast tissue and air (instrument error).

2.2 Patients and methods

Patients and lesions

Images of patients who underwent stereotactic core biopsy or stereotactic localization between April 23, 1998 and April 20, 2000 were used. Data of 84 patients with a non-palpable lesion of the breast and a technically correct procedure were used in this study. Sixty-one patients (73%) underwent core biopsy, 10 patients (12%) underwent guide-wire localization and 13 patients (15%) underwent both core biopsy and localization. Most of the stereotactic core biopsy patients (n = 52) were participants in a nation-wide study on the value of the stereotactic breast biopsy technique (core biopsy after radiological localization [COBRA] study).
Seventy-seven percent (n = 65) of the lesions on the mammograms showed microcalcifications only, 14% (n = 12) showed a density and microcalcifications combined, 5% (n = 4) showed a density only, and 4% (n = 3) showed a stellate lesion. Lesions showing microcalcifications only will be referred to as nonsolid lesions (77%, 65 patients); the other lesions will be referred to as solid lesions (23%, 19 patients). The mean length of the lesions, as measured on the mammograms, was 17 mm (range 3 - 70 mm); the mean width was 11 mm (range 3 - 50 mm). The histological diagnosis was a benign lesion in 36% (n = 30), ductal carcinoma in situ in 36% (n = 30), and invasive carcinoma in 29% (n = 24). Ninety-eight percent of the patients underwent a confirmation surgical biopsy, and 2% had clinical and mammographic follow-up (range 6 - 14 months). The diagnostic accuracy of the core biopsy procedure was 97% for nonsolid lesions and 100% for solid lesions.

Methods

The stereotactic procedures were performed with a StereoGuide (Lorad; Trex Medical Corp., Danbury, CT). The core biopsy procedure has been extensively described elsewhere [13, 76, 77]. In brief, a digital set of stereotactic baseline images (+15° and -15° views) is obtained. The coordinates of six targets are calculated. After local anesthesia is induced, a small incision is made. The needle is inserted through the incision and positioned 5 mm proximal to the lesion. Stereotactic prefire images are acquired to confirm the position of the needle compared with that of the target. Then the biopsy gun is fired. In cases where a solid lesion is present, stereotactic postfire images are obtained. For the localization procedure, the same protocol is used, but only one target is selected for placement of a guide wire, and this wire is placed in the center of the lesion. For the biopsy procedure 14-gauge needles, 13 cm long (Bard, Magnum; C.R. Bard Inc., Covington, GA) are used with an automated biopsy gun with a 22-mm stroke (Bard, Magnum Biopsy Instrument; C.R. Bard Inc.). For the localization procedure, 19.5-gauge localization needles with x-shaped guide wires are used (X-Reidy breast lesion needles; Cook, Bjaeverskov, Denmark). For this study, we used the baseline and prefire images. The postfire images of the solid lesions contained insufficient calcifications to apply our method of calculation.

Coordinates and three-dimensional displacement

All shifts were measured as separate x, y and z components. The y value is in the direction of gravitational force, the z value is the penetration depth and x is horizontal and perpendicular to the y-z plane. Overall or total displacement distances were calculated from these components by using equation 1 (see Appendix [2.5, page 31]).
Usually, total distance values have a log-normal distribution, so the geometric mean must be calculated to determine the average value.

Marker displacement

To examine the movement of tissue during positioning of a needle in the breast, we searched for identifiable microcalcifications in the tissue surrounding a lesion to use as markers. A microcalcification was identifiable when it was seen and recognized on both the baseline and prefire images. The coordinates of these internal markers were determined on the baseline images and again after positioning the needle 5 mm proximal to the lesion (prefire images). The coordinates on both images were compared to ascertain the movement of the markers, and therefore, of the breast tissue. On the images of 52 procedures an identifiable marker could be found. Eighty-three percent of the lesions were nonsolid (n = 43) and 17% (n = 9) were solid. For each marker, the total distance between the marker and the target (DMT) was calculated using equation 1. Influences of distance to the target, different needles (biopsy or localization needle), and lesion type (solid or nonsolid) on tissue displacement were studied.

Accuracy of needle positioning (in breast tissue and in air)

Ninety-seven procedures (74 biopsy procedures and 23 localization procedures in 84 patients) were available for determination of the accuracy of needle positioning in breast tissue. In the baseline images the coordinates of the target were determined. In the set of stereotactic prefire images the coordinates of the needle tip were determined, and the z coordinate was corrected by 5 mm because the needle is placed 5 mm proximal to the target on the prefire image. Influences of needle type, lesion type, and coordinates of the target on the accuracy of the needle placement were studied. Additional measurements were performed to determine the accuracy of needle positioning in air. Several targets in air were chosen, the needle was moved to the selected targets, and stereotactic images were obtained. Differences in coordinates between the selected target and the needle tip were calculated.

Statistics

The statistical methods used were Student's t-test and multivariate linear regression analysis with backward regression by use of SPSS software (SPSS Inc., Chicago, IL). A significance level of 5% was used. Details of the linear regression analyses are given in the Appendix (2.5, page 31). Reliability of the mean is given as the confidence interval (CI). Variability around the mean is given as the standard deviation (SD) or as the prediction interval (PI).

2.3 Results

Marker displacement

Displacement of the marker in the z direction and the total displacement are shown as a function of the distance between marker and target in figures 2.1 and 2.2. Displacement in the z direction and total displacement were statistically significantly dependent on the distance between marker and target and the type of needle (see Appendix [2.5, page 31]). By extrapolating the data to a distance of zero between marker and target, we were able to predict the displacement of the target for different types of needles (summarized in table 2.1).

Accuracy of needle positioning (in breast tissue and in air)

In breast tissue, systematic errors in all three directions were found (t-test; see table 2.2). The deviations in the x and y directions were larger than those in the z direction. Figure 2.3 is a representation of the front view of the breast biopsy window with inaccuracies in the x and y directions. Inaccuracy in the y direction increased with depth of the target in the breast and was larger for the localization needle (see Appendix [2.5, page 31]). Typically, at a depth of 30 mm, the needle is 0.5 mm lower than the target for the biopsy needle and 0.8 mm for the localization needle. Combining x, y and z deviations by using equation 1, and taking the geometric mean, we found an average error of 1.1 mm (95% CI 1.0 - 1.2; 95% PI 0.4 - 3.0) for biopsy needles and 1.8 mm (95% CI 1.4 - 2.2; 95% PI 0.7 - 4.6) for localization needles.

In air, some very small but statistically significant systematic inaccuracies in needle positioning were found (table 2.3). Deviations in the x and y direction are illustrated in figure 2.3. The mean total inaccuracy or instrument error was 0.4 mm (95% CI 0.4 - 0.5; 95% PI 0.2 - 0.7).

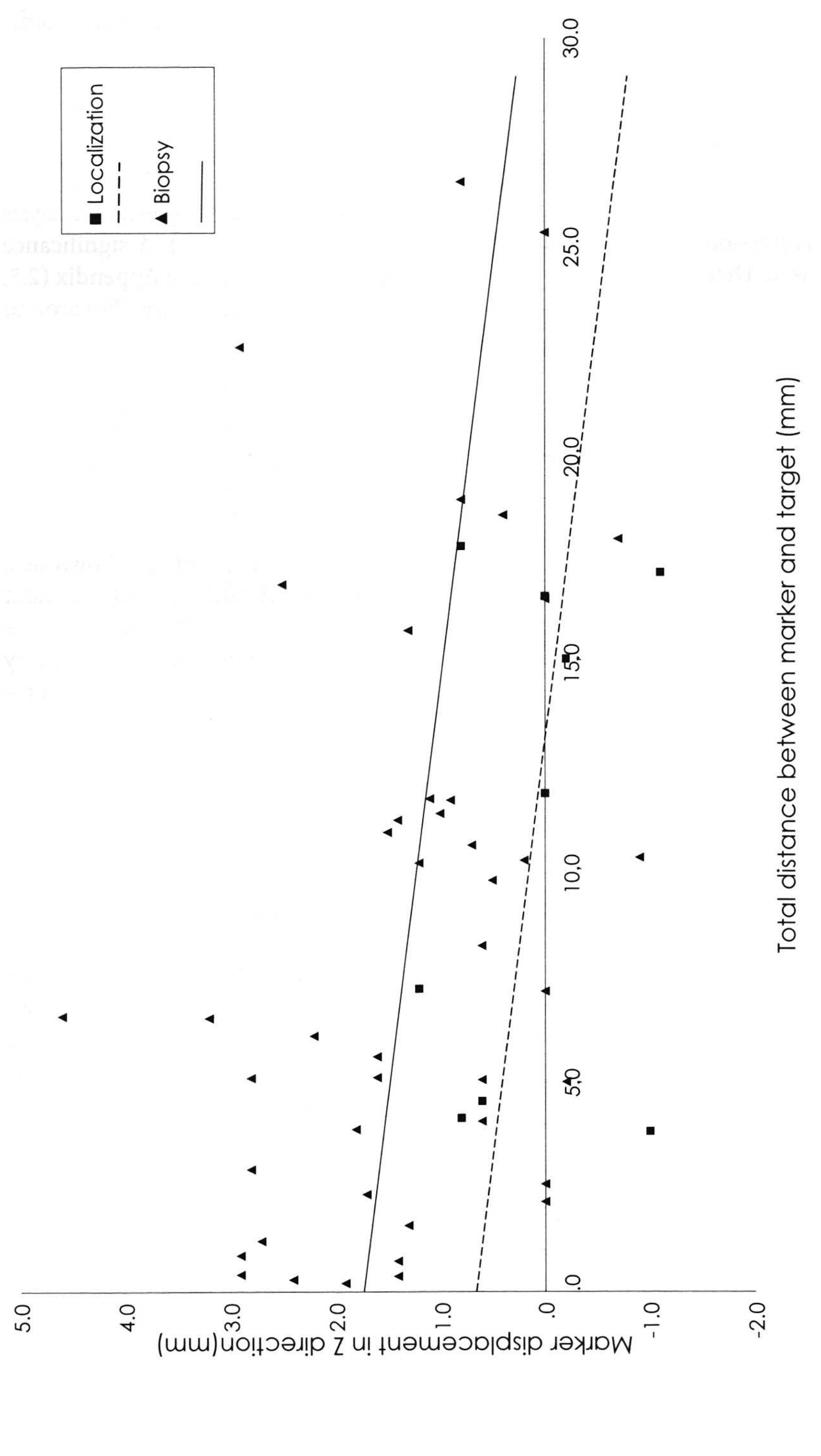

Figure 2.1. Marker displacement in the z direction (depth) as a function of total distance between marker and target (in mm). The target is situated at a total distance between marker and target of 0. The lines are obtained by linear regression (see Appendix [2.5, page 31]). Data are shown for biopsy needles (▲ and solid line) and for localization needles (■ and dotted line).

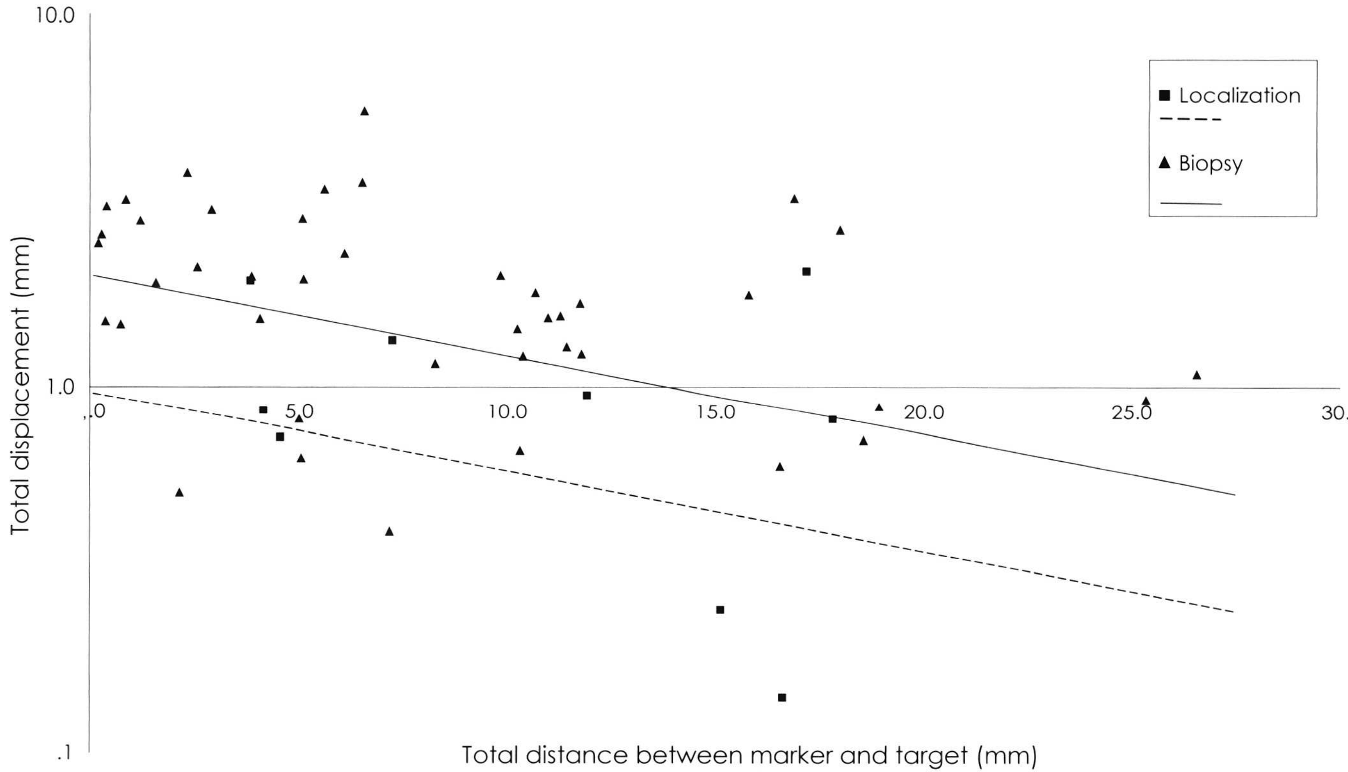

Figure 2.2. Total displacement of breast tissue. Total marker displacement is lognormal distributed, so a log transformation is applied. Shown is total marker displacement (in mm) on a log scale as a function of total distance between marker and target (in mm). The target is situated at total distance between marker and target of 0. The lines are obtained by linear regression (see Appendix [2.5, page 31]). Data are shown for biopsy needles (▲ and solid line) and for localization needles (■ and dotted line).

	Biopsy needle (14 gauge)			Localization needle (19.5 gauge)		
isplacement (mm)	ean	l	l	ean	l	l
z direction	1	1 2 to 2 2	-0 to 0	0	-0 3 to 1	-1 to 3 1
otal	2 1	1 to 2	0 to	1 0	0 to 1	0 3 to 3

Table 2.1. Predicted displacement of the target for different needle types. 95% CI indicates 95% confidence interval for the mean; 95% PI: 95% prediction interval.

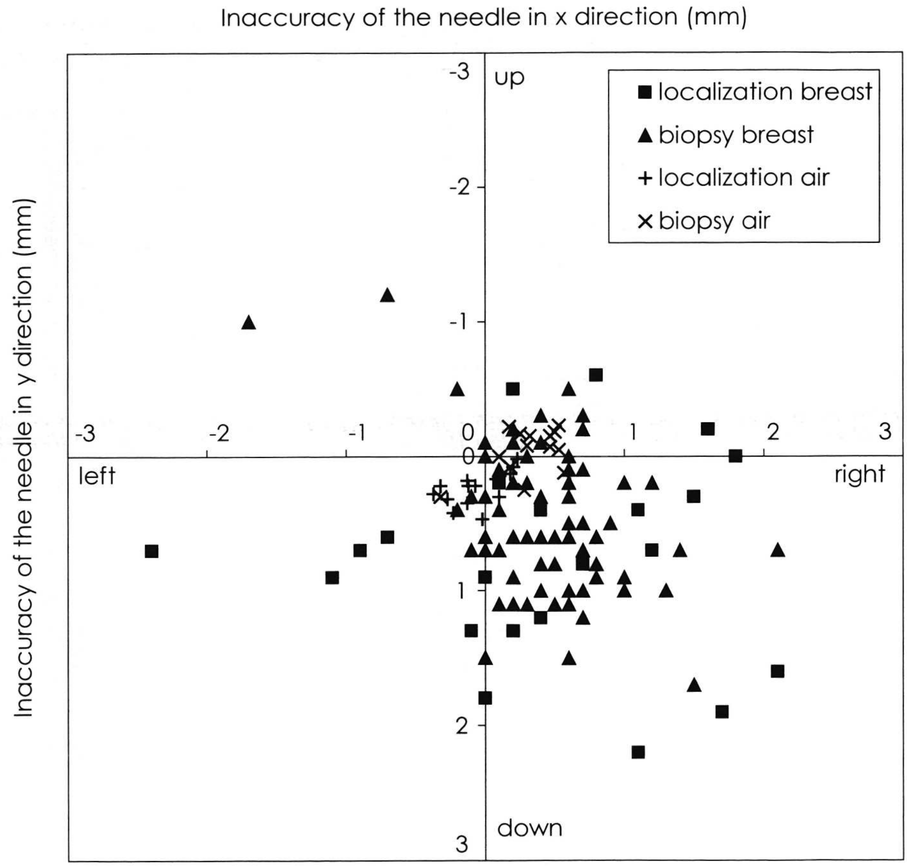

Figure 2.3. Inaccuracy of needle positioning in breast tissue and in air. Shown is a representation of the front view of the biopsy window, with the target situated at (0,0). The inaccuracy in positioning of the needle tip in x and y direction is shown for biopsy needles (▲ in breast tissue, x in air) and localization needles (■ in breast tissue, + in air). Note: deviation of the needle to the right and down, which is larger in breast tissue than in air.

	Biopsy needle (14 gauge)					Localization needle (19.5 gauge)					Difference**
Inaccuracy (mm)	Mean	95% CI	SD	p ≤	Direction*	Mean	95% CI	SD	p ≤	Direction*	p ≤
x	0.45	0.34 to 0.57	0.51	0.0001	Right	0.42	-0.04 to 0.88	1.07	NS	Right	NS
y	0.45	0.32 to 0.57	0.54	0.0001	Down	0.78	0.46 to 1.10	0.74	0.0001	Down	0.02
z	0.34	0.15 to 0.54	0.86	0.001	Behind	-0.17	-0.87 to 0.52	1.62	NS	In front	NS

Table 2.2. Inaccuracy in positioning of the needle tip in breast tissue.
** Relative to the target.*
*** Difference between biopsy needle and localization needle.*
95% CI indicates 95% confidence interval for the mean; SD = standard deviation; NS = not significant.

	Biopsy needle (14 gauge)					Localization needle (19.5 gauge)					Difference**
Inaccuracy (mm)	Mean	95%CI	SD	p ≤	Direction*	Mean	95%CI	SD	p ≤	Direction*	p ≤
x	0.31	0.17 to 0.45	0.24	0.0001	Right	-0.06	-0.17 to 0.05	0.20	NS	Left	0.0001
y	-0.04	-0.14 to 0.06	0.17	NS	Up	0.24	0.17 to 0.31	0.12	0.0001	Down	0.0001

Table 2.3. Inaccuracy in positioning of the needle tip in air.
** Relative to the target.*
*** Difference between biopsy needle and localization needle.*
95% CI indicates 95% confidence interval for the mean; SD = standard deviation; NS = not significant.

2.4 Discussion

Using microcalcifications as internal markers, we were able to show that, on average, a target displacement of 2.1 mm for biopsy needles and 1.0 mm for localization needles will occur during positioning of the needle in the breast (table 2.1). This means that the calculated coordinates of the target will not be the true target coordinates after needle positioning. In other studies, it was reported that solid lesions, like fibroadenomas, sometimes move when the needle tip pushes against them [75, 77, 82, 85]. In this study, we could not show a difference in displacement of solid and nonsolid lesions. Our calculations were, however, performed only on solid lesions containing microcalcifications and we had a limited number (n = 9) of this type of lesions. We were not able to perform these calculations in breasts with densities only because we needed an identifiable microcalcification as a marker for displacement.

In addition to the tissue displacement, we found an inaccuracy of needle placement in breast tissue, with needle deviations predominantly in the *x* and *y* directions (both perpendicular to the needle), and a mean total inaccuracy of 1.1 mm for biopsy needles and of 1.8 mm for localization needles. The mean total instrument error (0.4 mm) is smaller than the instrument error of 1 to 2 mm reported in the literature [75, 78, 85]. The inaccuracy of the needle in the *x* direction was a systematic shift to the right, which occurred in breast tissue to a larger extent than in air. Possibly this inaccuracy is caused by traction of the border of the incision on the needle. In this study, all three radiologists were right-handed. Moreover, the radiologist who typically made the smallest incisions had the widest distribution of needle deviations, although the differences in results between the radiologists were not statistically significant. The inaccuracy in the *y* direction was also larger in breast tissue than in air and can partly be explained by the depth of the target and the beveled shape of the needle tip. A guide supports the needle from the biopsy gun to the compression paddle. The deeper that the needle is inserted into the breast, the larger is that part of the needle that is not supported by the needle guide and is therefore more strongly influenced by breast tissue. Hence, the deviations are larger. This influence of breast tissue on needle placement is stronger with thin needles, such as localization needles. Their beveled shape is often implicated as a possible source of error [88]. Indeed, for localization needles, we observed a systematic deviation in the expected direction.

The third factor that can influence the diagnostic accuracy of the stereotactic biopsy procedure is displacement of the lesion during firing of the biopsy gun. To our knowledge no quantitative data are available for this type of error. Because the speed at which the biopsy needle is 'fired' is high relative to breast tissue, this lesion movement has been generally assumed to be very small [75].

Operator errors (such as improper calibration of the stereotactic device or inaccurate determination of the coordinates of the target) cannot be evaluated or quantified from the postfire images but can in principle be avoided by careful performance of the procedure by well-trained personnel.

By combining tissue displacement error and needle inaccuracy, the total error made during a stereotactic breast procedure can be calculated. The direction of the displacement of breast tissue is predominantly in depth, and the direction of needle inaccuracy is mainly in the *x* and y direction. Both deviations are perpendicular to each other. Therefore, by taking the square root of the sum of the squares of tissue displacement and needle inaccuracy, total displacement distance during stereotactic breast biopsy can be calculated. By not considering inaccuracies in displacement as a result of firing the gun and operator errors, the total error is 2.4 mm in biopsy procedures and 2.1 mm in localization procedures (see table 2.4). The deviations of target and needle will influence the diagnostic accuracy of stereotactic breast biopsy, in particular in lesions consisting of microcalcifications only. Microcalcifications associated with breast cancer are very small, only 150 to 200 µm [89], so only a slight deviation in needle or target may cause failure in targeting a microcalcification. We experienced a failure rate of 3%, which is in accordance with the literature [13, 15, 78, 79]. Liberman et al. [13] emphasized the need for a higher degree of precision to target microcalcifications. In their study, they found a diagnostic yield of the first sample in 84% of the masses and in 47% of the lesions that consisted of microcalcifications only. They

Mean errors (mm)	Biopsy needle (14 gauge)	Localization needle (19.5 gauge)
Displacement of breast tissue	2.1	1.0
Inaccuracy of the needle	1.1	1.8
Mean total error	2.4	2.1

Table 2.4. Magnitude of mean errors during biopsy and localization procedures.

recommended that for optimal results, multiple samples should be taken and that in cases of microcalcifications, a specimen radiograph should be acquired to ensure that microcalcifications have been sampled [13]. In this study, the effects of two types of needles on target displacement and needle inaccuracy were analyzed. Our results are applicable only to the same type of needles. When other needle types are used, other tissue displacements and needle inaccuracies may be found. We found target displacement to be larger for thicker needles and needle inaccuracy to be larger for thinner needles (see table 2.4).

We expect that for needles thicker than 14 gauge, target displacement will be the dominating error and will probably be > 2.1 mm that we found. Likewise, for needles thinner than 19.5 gauge, the needle deviation error will dominate and will likely be > 1.8 mm.

By using a thicker needle (such as the 11-gauge needle in a vacuum-assisted device), more tissue is removed [90], which will probably increase diagnostic accuracy [91-95]. The vacuum-assisted device is increasingly being used in the United States. In Europe, however, the acceptance of the method is considerably less, with a large number of hospitals still relying on core biopsy devices.

Reducing occurring errors will lead to a higher diagnostic accuracy, especially in small lesions. It is not possible to reduce tissue shift. To reduce the inaccuracy of needle positioning, the shortest path to the target should be selected to limit the influence of the surrounding breast tissue on the needle, and the incisions should probably not be made too small. With caution, it would be possible to compensate for the systematic error in the y direction, which is probably caused by the beveled shape of the needle.

Tissue and needle displacements cause a total average positioning error of 2.4 mm when a 14 gauge biopsy needle is used, which will limit the attainable diagnostic accuracy of stereotactic core biopsy. We have shown that the unavoidable error will be about 2 mm, which is large compared to the size of a microcalcification (0.2 mm). Therefore, it is very important to avoid any additional errors by operator mistakes.

2.5 Appendix

In stereotactic breast biopsy procedures, both the target and the needle are displaced due to needle-tissue interaction.
Cartesian coordinates of microcalcifications and needles before and after needle insertion (but before firing) were determined, as illustrated in figure 2.4 for two dimensions. The components of displacements in three dimensions were computed as follows:

Microcalcifications:

$$D_x = Mx_{post} - Mx_{pre}$$
$$D_y = My_{post} - My_{pre}$$
$$D_z = Mz_{post} - Mz_{pre}$$

Needle:

$$D_x = Nx_{post} - Tx_{pre}$$
$$D_y = Ny_{post} - Ty_{pre}$$
$$D_z = Nz_{post} + 5 - Tz_{pre}$$

The *z* coordinate is corrected by 5 mm because the needle is 5 mm proximal to the target before firing.

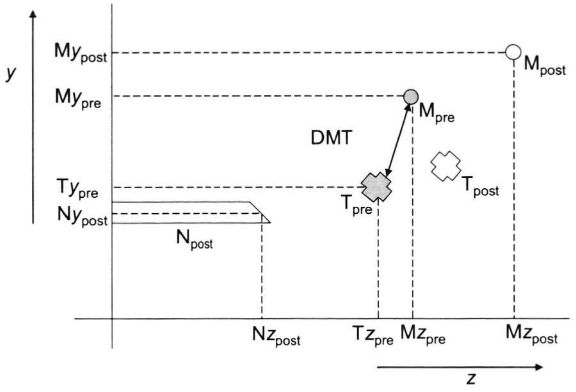

Figure 2.4. Schematic representation for calculation of displacements (two-dimensional side view). T indicates target at coordinates (ty,tz); N: needle at coordinates (ny,nz); M: microcalcification at coordinates (my,mz); pre: before needle insertion; post: after needle insertion; DMT: distance between M_{pre} and T_{pre}.

Total displacement distance is defined as:

Total distance $= \sqrt{(D^{x2} + D^{y2} + D^{z2})}$ [1]

Components of displacements in the x, y and z directions and the total distance of displacement of microcalcifications and needle were analyzed by using backward multivariate linear regression. Markers were defined as microcalcifications in the breast tissue surrounding the target.

Because total displacements were log-normally distributed, logarithmic transformation was applied. For marker (i.e., microcalcification) displacement, factors were needle type, lesion type, and marker-to-target distance (DMT); for needle inaccuracy, factors were needle type, lesion type and target coordinates. A linear relation between marker displacement and marker-to-target distance can be assumed close to the target but of course is unjustified at sites far from the target. The majority of our markers were close to the needle. The resulting regression equations with significant factors are:

Marker displacement in z direction (mm) = A + (B*needle) + (C*DMT) [2]

Log (total marker displacement) (mm) = A + (B*needle) + (C*DMT) [3]

Inaccuracy of the needle in y direction (mm) = A + (B*needle) + (C* depth of the target) [4]

where needle indicates needle type (localization = 0 and biopsy = 1) and DMT indicates total distance between marker and target (in mm).

Table 2.5 lists the constants A, B and C for all three equations.

Acknowledgments

We gratefully acknowledge Frank A. Pameijer for his assistance.

	Equation	A	95% CI of A	B	95% CI of B	p of B ≤	C	95% CI of C	p of C ≤
Marker displacement in *z*	[2]	0.66	-0.22 to 1.53	1.08	0.27 to 1.88	0.01	-0.049	-0.09 to -0.004	0.03
Logarithm of total marker displacement	[3]	0.03	-0.49 to 0.54	0.71	0.24 to 1.18	0.004	-0.028	-0.05 to -0.001	0.04
Inaccuracy in positioning of the needle tip in *y*	[4]	0.22	-0.25 to 0.69	-0.36	-0.63 to -0.08	0.01	0.020	0.005 to 0.04	0.008

Table 2.5. Linear regression analysis and constants A, B and C for equations 2 - 4.
95% CI indicates 95% confidence interval.