Prone-Supine Breast MRI Registration for Surgical Visualisation

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Abstract. The concept of multi-modal data fusion generally involves some facet of registration. However to truly distinguish the notion of "fusion" from conventional "registration" an understanding of representation and visualisation must be incorporated into the solution. This is a particularly critical issue in the case of breast data fusion as the representation of the breast changes considerably between different imaging techniques (for example the compressed shape in a mammogram compared with the prone shape of a typical breast MR image) and the conditions of the operating room. To address this, we introduce the idea of registering prone acquired MRI images to a supine acquisition to generate a visual representation that is meaningful to the surgeon.

1. Clinical Overview

One of the little-known facts about breast surgery is that minimal imaging data enters the operating room (OR). Clearly, imaging data is a critical part of the screening, diagnosis and extended management of breast disease. However in our experience of working with breast surgeons, imaging data is seldom used at the time of excision. There are a number of reasons for this:

1. A large proportion of breast pathology is palpable and therefore image-guidance is usually not necessary to localise the lesion in the OR.

2. The surgical removal of breast disease generally involves a limited range of options. A wide-local excision is the most breast-conservative approach but is only suitable for certain classes of malignancy. Larger-scale excision may be as localised as a breast quadrant (see Fig. 1) or as extensive as complete mastectomy.

3. The representation of the breast on the operating table is unlike that of most commonly used imaging modalities. A considerable "mental transformation" is required to map the location of a feature identified in imaging data to that of the supine (on the back) shape of the breast with better accuracy than a quadrant (having said this, we are constantly astounded by the spatial visualisation abilities of surgeons).

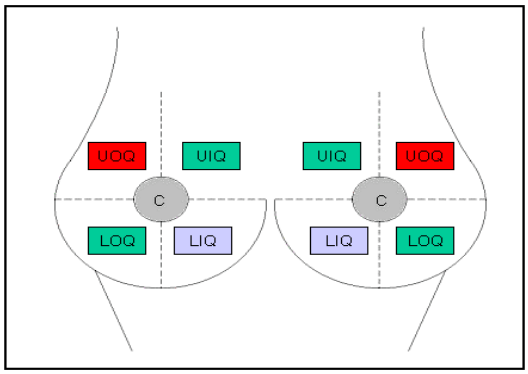


Figure 1. An illustration of how the breast is divided into quadrants (e.g. UOQ = upper/outer quadrant)

Although these considerations seem to reduce the complexity of decision making during surgery, there remains the difficult issue of excision margins (and hence localisation). Certain classes of pathology are difficult to localise, as the lesion may be impalpable. As many as 20% of patients have impalpable lesions and this number may increase as mammography screening and other imaging techniques (e.g. MRI, nuclear medicine) successfully detect breast disease at earlier stages of development. For the purposes of discussion, there are three main types of malignancy that confound the localisation issue due to their impalpable or poorly differentiated nature:

1. Early-stage ductal carcinoma in-situ (DCIS) as the size of the lesion may be only a few mm rather than a palpable "lump" and therefore difficult to detect. DCIS is difficult to diagnose with most imaging modalities (for example contrast-enhanced MRI) but may be indicated by microcalcifications in an X-ray mammogram.

2. Multifocal/multicentric disease where the pathology consists of several “lobules” of malignancy connected together in a poorly differentiated cluster.

3. Diffuse or fleshy lesions (typical of some kinds of carcinoma) which may be quite extensive but difficult to differentiate from normal tissue in a clinical assessment.

In addition, it may be useful to provide the surgeon with some idea of the extent to which chemotherapy has influenced the dimensions of a lesion. This is particularly true for cases where adjuvant chemotherapy has been prescribed for large (several cm), inoperable tumours to minimise adenosis (swelling) for improving the effectiveness of surgery. Lesions that intersect several quadrants of the breast but have been shrunk by chemotherapy may also require larger margins to account for residual pathology in surrounding tissue.

2. An “Atlas” of Breast Pathology

Our previous research in breast registration has involved developing techniques for temporal mammogram matching [1,2], MRI/X-ray mammography data fusion [3,4] and chemotherapy assessment with contrast-enhanced MRI [5,6]. We have demonstrated that it is possible to “fuse” features visible in X-ray mammography and MRI as well as quantify the effects of chemotherapy. The result is a breast “atlas” that is the combination of temporal and multi-modal pathological indicators. The geometrical reference frame we have used is the prone-acquired MRI scan. An example is shown in Figure 2 where a mammographically visible lesion is localised in an MRI volume.

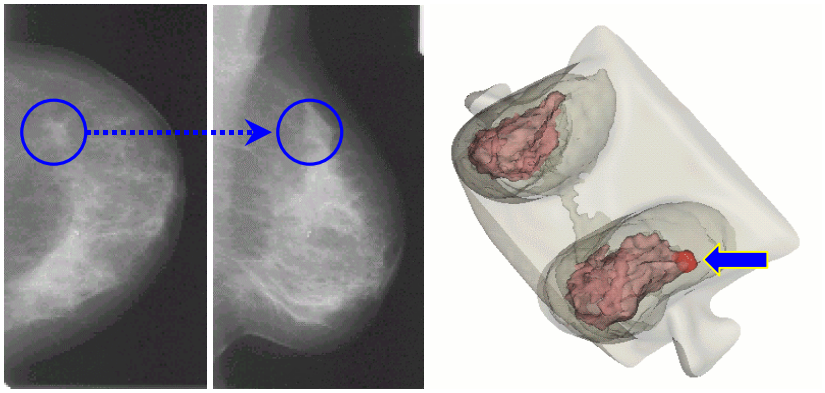


Figure 2. A sample “atlas” showing the results of X-ray mammography/MRI fusion using [4].

However the problem of presenting this cumulated information to the surgeon remains. Although visualisations like Figure 2 are useful to the surgeon as they illustrate the quadrant location of the lesion, it would be better if this model could be transformed to a breast shape consistent with the surgical positioning of the patient.

3. Prone-Supine Registration

Our approach to the issue of breast surgical visualisation has incorporated a radiological aspect, a registration component and a simple deformation model. In addition to a conventional prone-acquired contrast-enhanced MRI acquisition, we have taken a relatively low resolution scan of the patient lying supine using the MRI body coil to get an idea of the shape of the breasts as they would appear in the OR (Figure 3). This is not quite an exact shape because the patient’s arms rest behind the head as opposed to perpendicularly when in the OR, however we attempt to compensate slightly for this at a later stage in the process.

The registration process is simple and represents a preliminary approach to the problem:

1. Rotation of the body-coil acquired data set by 180^{o} to align the prone and the supine data.

2. Segmentation of the skin in both acquisitions using a simple threshold and iso-contour detection. A threshold-based segmentation is quite robust in the case of MRI as the signal background of T1-weighted images is easy to differentiate from tissue.

3. A global rigid/affine transformation is computed using a variation of the iterated closest point algorithm, ICP [7] on the skin data. This is mainly to align the thoracic component of the image.

4. The breast in each image is segmented using coronal re-slicing of the volume and a region growth algorithm. By growing each breast through successive slices and looking for the point at which the two largest regions

merge, the location of the sternum (and hence the chest wall) is approximated. The sternum is used to separate the left and right breast for registration.

5. Non-rigid registration driven by the skin surface, utilising a tensor B-spline mesh [8] to compute the deformation. We do not currently use any internal landmarks or features to drive the registration.

6. As mentioned previously, the shape of the breast in the supine-acquired MRI scan is slightly different to the OR shape due to the location of the patient's arms (the breasts are pulled more upright). To visually compensate for this, surface matching points are re-weighted towards the thorax and spline bending energy can be adjusted to implement a degree of "pstosis" (or sag).

The application of non-rigid registration based purely on a breast surface match is certainly an over-simplification of the problem. Ideally, one would include internal landmarks to properly control the deformation. However the difference in resolution between the two acquisitions and the gravitational compression of tissue in the supine position makes it difficult to compare the internal characteristics of the breast. Our justification for demonstrating this registration concept based on a surface match derives from our initial objective of localising the position of the supine-deformed lesion to *quadrant accuracy only*.

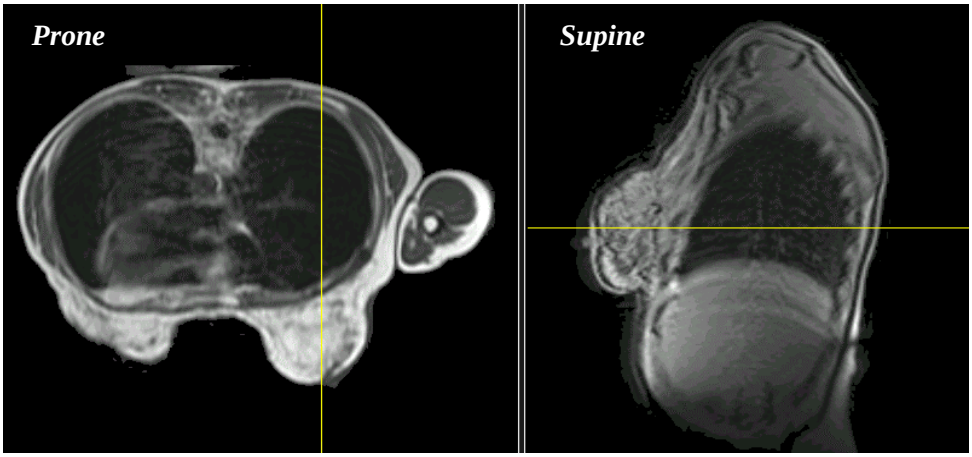


Figure 3. Slices from prone and supine MRI acquisitions at approximately the same location (supine is resliced in the saggital plan for clarity). Whilst the main structural characteristics of the breast appear similar, internal tissue registration is difficult due to the difference in resolution between the breast and body coil acquisition and the large compressive deformation.

4. Preliminary Results

We have performed an initial study on two patient cases with impalpable lesions. The purpose of this experiment was to convince clinicians that there might be value in acquiring the additional supine MRI scan for relevant cases (and hence build a database for future research). Figure 4 shows the results of a case with a highly localised (2-3mm) lesion that was detected during mammography screening and fused to the MRI volume using the technique described in [4]. This was quite a challenging case as the lesion was located quite deeply in the quadrant and may have resulted in inter-quadrant margins when excised. Although it is difficult to validate the lesion location against the excision specimen, the lesion remained quadrant-consistent after deformation and histology confirmed the presence of DCIS in approximately the indicated area.

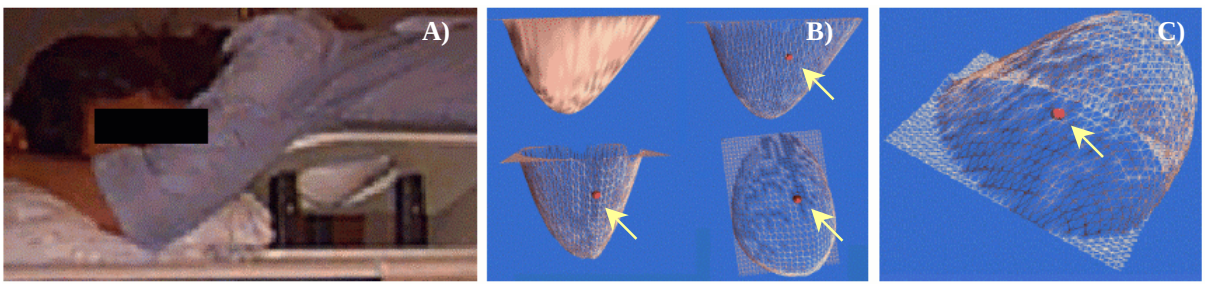


Figure 4. A) illustrates the prone position of the patient in the breast coil. B) several renderings of the lesion location in the prone shape. C) The supine deformation of the breast.

As mentioned earlier, there is a need to incorporate some kind of provision for the slight difference in pstosis between the supine MRI and OR breast shape. By re-weighting the matched surface points towards the thorax and changing the spline bending energy it is possible to introduce a small amount of additional pstosis and produce a visualisation more consistent with the surgical shape of the breast. This is illustrated in Figure 5, showing the motion of the lesion with respect to the simulated pstosis.

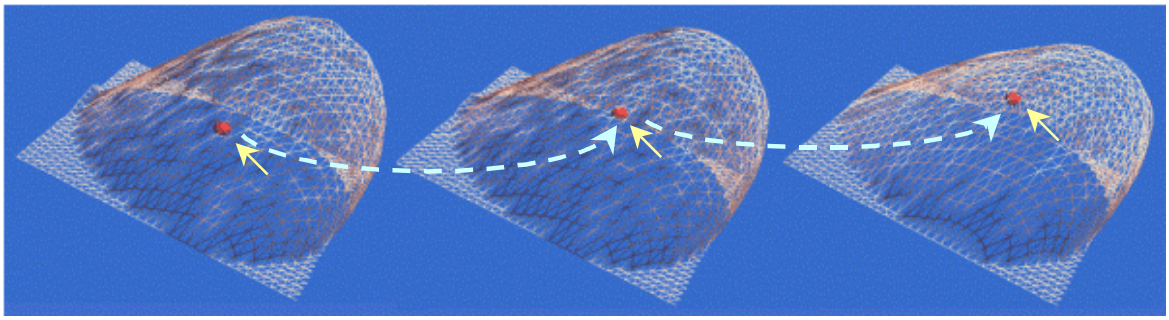


Figure 5. Adjustment of the spline bending energy characteristics to simulate pstosis.

5. Discussion and Conclusion

There is little doubt that the registration approach presented in this article is a considerable simplification over what would be necessary to implement a clinically usable tool. Part of our objective in this initial evaluation was to address the issue of data fusion visualisation in the surgical context and to improve the surgeon's visibility of the potential benefits of data fusion with respect to patients with impalpable tumours. We hypothesise that if the prone-supine registration/deformation framework were robustly quadrant conservative, this would already be useful to the surgeon.

In order to achieve this it is likely that a more sophisticated approach based on truly volumetric models with material constraints and control over the internal deformation would be required. The difficulty with such models is the extreme variability of tissue characteristics between patients and hence "calibration" problems are likely to arise. There is no doubt, however, that advancements in rotationally invariant non-linear FEM tissue models (for example [9,10]) could be used as the basis of such a scheme. We advocate, however, that free-form models (for example based on a gravitationally influenced breast rotation) are perhaps not the best solution and that by using a supine-acquired MRI in a registration context, a suitable model may be better constrained.

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