Ablation-induced tissue contraction measured by CT: Correlation with dehydration
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Background Information

New thermal ablative devices are typically designed using computer modeling, then evaluated using ex vivo and in vivo tissue models. Device performance is assessed by measuring the geometry of the ablation zone, which is then used as a guide to safety and to visualize treatment success. However, tissue contraction caused by prolonged exposure to high temperatures can cause these post-ablation geometries to deviate from the actual dimensions of tissue ablated. Comparisons of pre- and post-ablation dimensions are thus essential to determine the actual geometry of ablated tissue.[1] The methods used the previous study did not provide temporal data, nor did they allow direct observation of contraction – only comparisons of unlogged pre-post samples.

The objective of this study was to use computed tomography (CT) to monitor tissue contraction over time and analyze the correlation between tissue dehydration and contraction.

Materials and Methods

Ablation Setup
- Diode laser at 980 nm
- Microwave at 2.45 GHz

- Diameters of each marker-marker pair were measured automatically
- Central coordinates of each feature were extracted using 2D-otsu detection and thresholding
- 100 selected marker pairs (20-40 mm apart) were analyzed, 30 pairs were measured from CT images at each time point
- Diameter contraction from each pair = Change in diameter leading to a more uniform and dense ablation zone that previously existed

Results

Total Contraction
Diameter contraction occurred most rapidly at the beginning of the ablation, with less effective change over time (Figure 1). After two minutes of heating, the distance between marker pairs decreased by a mean of 20% of their original distance. This was approximately 65% of the total contraction. That is, 65% of the contraction occurred within the first 20 min post-ablation. The remaining 35% of contraction occurred from 20-100 min post-ablation. Most of the total contraction was noted between the central positions, with less total contraction at more peripheral positions. As expected, this result was consistent with previous studies, and can be explained by the fact that contraction slows down as distances increase away from the antenna.[1] However, the percent total contraction – the total contraction divided by the original distance – was greatest near the antenna (Figure 2).

Relative Contraction and Dehydration

Not surprisingly, the relative contraction between adjacent markers was increased over time and was most marked at positions near the antenna (Figures 4-5). In some samples, expansion was noted between some adjacent markers. This expansion appeared more consistent with gas formation and possible expansion due to gas transport from the high-temperature water vaporization zone at the center of the ablation (Figure 6). Relative contraction correlated positively to mass fraction of water loss (Figures 1-2, Figure 6). Where minor contraction occurred, the relative contraction was due to collapse of small vessels and features, creating a change in the tissue morphology that included shaped changes post-ablation (Figures 3,4). The mean contraction percent observed between each marker position over time indicates contraction of the ablated tissue. Contraction was most rapid in the first 2-3 min.

Discussion and Conclusions

We tracked the change in position of several markers using CT imaging to quantify the total and relative contraction of tissue around each marker caused by microwave thermal effects.

The significant findings of this study were:
- Contraction was most significant in the first two minutes of heating and near the antenna.
- Contraction correlated well to total water loss due to high temperatures in excess of 100 °C.
- Tissue dimensions measured post-ablation underestimated original dimensions by ~30%.
- CT numbers acquired during the ablation are substantially lower than pre-ablation.

Future work
- Automation of tracking devices tracking or eliminate or reduce the need for fiducial markers. Such techniques may also allow more accurate assessment of tissue contraction and assessment of contraction in human cases.
- In vivo testing and longer-term follow-up.
- Characterization of other devices (RF, MW, laser).
- Real-time correlation of intraprocedural CT features.

Possible implications for our findings include:
- Improved and deformable registration may be required for accurate pre-post-ablation assessment.
- Guidelines for human use created from device testing in ex vivo tissue should account for contraction.
- Devices should be compared head-to-head, rather than by reference to published data in an accurate tissue model.

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Christopher Brace is a shareholder and consultant for NeuWave Medical, Inc., and near the antenna. The mean contraction percent observed between each marker position over time indicates contraction of the ablated tissue. Contraction was most rapid in the first 2-3 min.

Figure 1: Distances between marker pairs. Marker pairs were normally spaced 10-40 mm apart and decreased with distance from the antenna.

Figure 2: Total contraction percent. The mean percent contraction obtained between each marker pair was calculated and decreased with distance from the antenna.

Figure 3: Total contraction over time. The mean total contraction from each marker position over time indicates contraction of the ablated tissue. Contraction was most rapid in the first 2-3 min.

Figure 4: Relative contraction. As suggested in the top image, changes in distance between adjacent markers, the relative contraction was most marked near the antenna.

Figure 5: Relative contraction percent. Even when normalized for the actual distances between adjacent markers, the relative contraction was most marked near the antenna.

Figure 6: Relative contraction versus dehydration. Relative contraction (left Y-axis) correlated well to dehydration (right Y-axis), with the greatest affect again noted near the antenna.