Observational Study

Adipose Tissue Impacts Radiofrequency Ablation Lesion Size: Results of an Ex Vivo Poultry Model

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Background: Radiofrequency ablation (RFA) is a common treatment in which radiofrequency (RF) is used to heat neural tissue and reduce pain. The impact of adipose content in tissue on the lesion size may impact efficacy, and to date, there is little, if any, data comparing its influence on RFA.

Objectives: We evaluated the influence of adipose tissue on RF lesion size.

Study Design: Controlled, ex vivo study.

Setting: Academic institution in a procedural setting.

Methods: RF lesions were created using 20-G 10-mm protruding electrode (PE) needles inserted into unbrined chicken breasts and thighs at 21°C. RF current was applied for 90 seconds at 80°C. Chicken breasts were used as the control group and chicken thighs were used as the high adipose variant. Four different groups were examined: 1- Standard 20 g RFA needle, 2- 20 g RFA PE needle, 3- Standard RFA needle with lidocaine 2% injectate, and 4- Standard RFA needle with iohexol 240 mg injectate. There were 12 lesions performed in each group; length, width, and depth were measured.

Results: The control group had significantly deeper lesions in all 4 cohorts. Lesions' lengths were smaller in the fat-rich group. The control and PE cohorts showed a significant difference in width between the 2 fat-rich and nonfatty groups.

Limitations: Radiofrequency ablation was performed at room temperature and not heated to physiological temperature. This was an ex vivo study, thus factors of human anatomy and physiology could not be evaluated.

Conclusions: Adipose tissue content was inversely related to lesion size in all samples. This factor should be considered when assessing methods of enhancing lesion size in human models.

Key words: Radiofrequency, ablation, lesion size, injection, adipose tissue, tissue modeling, interventional pain, education

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Radiofrequency ablation (RFA) is a minimally invasive technique that involves using high-frequency electrical current emitted through an insulated needle to deliver thermal energy to a neural target to disrupt conduction (1). Clinical evidence supports the benefits of RFA in spinal targets (1). Lesion size has been suggested to be a contributing factor to the success of RFA. Identifying variables that influence lesion size is critical to planning probe placement so that maximum desirable tissue damage occurs and undesired tissue damage is minimized (2). These variables include the magnitude of radiofrequency (RF) current, insulated needle size, relative placement of the needle in relation to the targeted nerve, use of protruding electrode (PE) RFA needles, and solutions injected prior to ablation (2). Literature has demonstrated variability in RF lesion size with different injectates, including variation in salinity of the solution (3). Further progress into understanding these variables was made with an ex vivo study of injectates used most frequently in clinical practice (e.g., lidocaine and contrast), utilizing RF settings as recommended by the American Society of Anesthesiologists' clinical practice guidelines. Statistically significant findings of increased lesion size with increased solution concentration were found (4).

One of the limitations of the latter study was the use of chicken breasts with little to no fat in this ex vivo model. These tissue samples, therefore, may not reflect the composition of human tissue, especially in areas with a high-fat distribution. This is particularly important given the documented positive correlation between atrial fibrillation chronicity after RFA and epicardial fat volume (5). Given the growing number of accepted anatomic locations for RFA treatment, it is increasingly critical that variables affecting high-fat density ablation sites are considered (6). The present investigation aims to further explore these injectate solutions commonly used in clinical practice with a higher fat ex vivo model. Chicken thigh, which has over 6 times the total fatty acid content of chicken breast (7), was substituted as the ex vivo model while maintaining the same injectates and RF settings. We hypothesized that fat would create an overall decreased lesion size compared to the chicken breast model.

Methods

This study did not use any patients or patient information and remained Institutional Review Board exempt.

In the current study for RFA burning medium, we used organic, nonbrined chicken thighs to imitate the properties of muscle with adipose tissue. Focal areas in each model were selected which had 2-3 mm of fat substrate overlying muscle to permit consistency in lesioning and interpretation. We performed RFA with PE needles in 4 different cohorts: 1- RFA with active tip needles in nonprotruding position without any medication injection, 2- RFA with active tip needles in PE position without any medication injection, 3- RFA with active tip needles in nonprotruding position post-lidocaine 2%, and 4- RFA with active tip needles in nonprotruding position post-iohexol 240 mg. Each group contained 12 lesions, for statistical precision, which were then measured in length, width, and depth (in mm). Length of the lesion was considered the lesion parallel to the needle position.

To create lesions, the following standardized method was used: PE needles were placed 3 mm below the surface of the chicken breast in parallel 1.5 cm apart so that adjacent lesions would not be superimposed on one another. PE 20-G 10-mm active tip needles in nonprotruding position were inserted (Fig. 1). If injectate was to be used, 0.1 cc of injectate was inserted into the thermal RFA needle and lesioning occurred for 90 seconds at 80°C. Needles were removed and lesions were subsequently measured.

Similar processes were repeated for the chicken thigh group and each subsequent injectate group until 12 lesions were achieved. In one group, 2 PE needles were placed in the protruding deployment to assess the size of lesions compared to nonprotruding lesions. In this group, no solution (medication) was used.

Statistical Analysis

Data analysis was performed using SPSS software (Version 27, IBM Corporation, Armonk, NY). Independent t test was used to measure the difference in size of lesions between each 2 groups. P value < 0.05 was considered statistically significant.

Results

Data analysis was performed in different steps. First, distribution of lesions' width, length, and depth post-RFA in adipose content tissue (here chicken thigh) and nonadipose content tissue (here chicken breast) was measured (Table 1).

Data analysis showed in adipose content tissue, lesions' width (Fig. 2) is significantly larger with no medications in single and PE dual needles (P value 0.03

and 0.01, respectively). There were no significant differences between lesions' width in post-lidocaine 2% and iohexol 240 lesions.

Comparing the length of lesions (Fig. 3) in the thigh group vs the chicken breast group showed significant differences in all 4 cohorts.

The depth of the lesions was compared as well in the present investigation (Fig. 4). In these groups, lesions in all 4 sets of cohorts were significantly deeper in nonfatty breast tissue than lesions of the fat-rich thigh group. In this regard, almost always the size of the lesions was significantly larger in nonadipose content tissue than adipose content tissue, except for width of the lesion when using lidocaine 2% and iohexol 240, which were not significantly different.

Discussion

RFA involves electrical current to create a predictable thermal lesion using an electrode that targets nociceptive pain pathways in the peripheral nervous system, commonly used for chronic back, neck, and large joint pain syndromes (8). Ionic agitation induced by RFA creates frictional heat that is transferred to tissue via heat conduction and causes tissue necrosis and other neural injury (9). RF needle electrode tip length, tip gauge, temperature, and duration play an important role in RF lesion size; preinjectate fluid has also been found to increase lesion size (10,11). Additionally, heat produced at the electrode is affected by various factors, including electrical current density, tissue resistance and impedance, thermal conductance, thermal capacity, blood supply, and others (12). One factor that may have clinical significance is the underreported effect of adipose tissue on the lesion size.

A standard ex vivo animal model used in various RFA studies is chicken breasts. The total fatty acid content in chicken breasts is lower than that of chicken thighs (7). Adipose tissue also has a lower thermal conductance compared to muscle (13). Pennes' bioheat model of heat transfer in perfused tissue suggests that heat transfer is dependent on the thermal conductivity of the tissue in question (14). Given the increased fatty acid content in chicken thighs and its lower thermal conductance, if other relevant RFA parameters are identical, it can be posited that RFA lesions in chicken thighs will be smaller compared to RFA lesions in chicken breasts. Our study sought to evaluate the RFA lesion size in chicken thighs. To our knowledge, this is the first study to examine the effect of adipose tissue on RFA lesion size.

Ortiz et al (4) documented the comparative effects of lidocaine 2%, iohexol, and solutions on lesion size. This study evaluated the effect of the same injectates

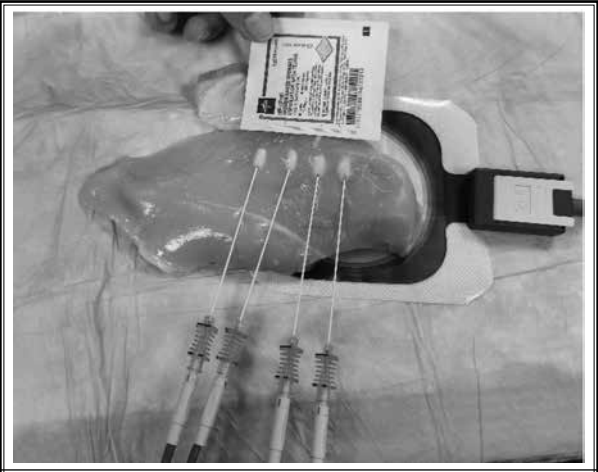

Fig. 1. *Position of the inserted needles.*

Table 1. *Comparison of lesions' size in chicken breast and thigh groups.*

	Width +/- SD** (mm)	*P* value	Length +/- SD (mm)	*P* value	Depth +/- SD (mm)	*P* value
Standard RFA Needle* w/ Adipose Interface (Thigh)	4.25 +/- 2.9	0.03	5.5 +/- 5	< 0.001	1.25 +/- 0.87	< 0.001
Standard RFA Needle w/o Adipose Interface (Breast)	6.33 +/- 0.65		12.75 +/- 0.86		5.16 +/- 1.11	
Standard Needle + Lidocaine 2% in Thigh	6 +/- 3.6	0.18	5.75 +/- 4	< 0.001	2.25 +/- 1	< 0.001
Standard Needle + Lidocaine 2% in Breast	7.5 +/- 0.79		14.08 +/- 0.9		5.5 +/- 0.9	
Dual Pronged Needle in Thigh	11 +/- 1.59	0.01	5.9 +/- 1.9	< 0.001	4.5 +/- 1.37	< 0.001
Dual Pronged Needle in Breast	9.58 +/- 0.66		15.25 +/- 2.13		6.33 +/- 0.65	
Standard Needle + Iohexol 240 in Thigh	7.16 +/- 3.97	0.34	6.83 +/- 3.88	< 0.001	2.87 +/- 1.31	< 0.001
Standard Needle + Iohexol 240 in Breast	6 +/- 1.04		14.25 +/- 0.86		5 +/- 0.73	

*Standard RFA needle = Single pronged needle.
**Standard deviation.

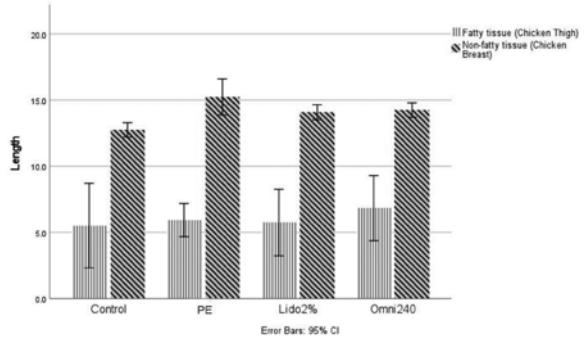

Fig. 2. *Distribution of lesions' width (mm) post-thermal RFA.*

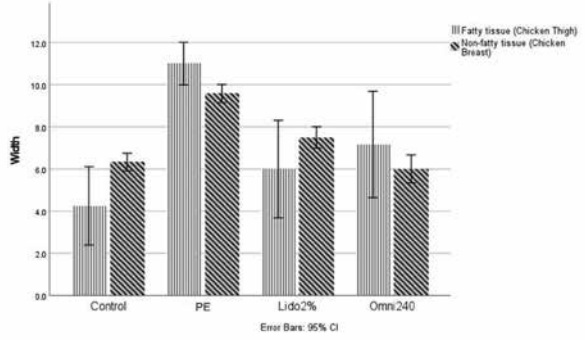

Fig. 3. *Distribution of lesions' length (mm) post-thermal RFA.*

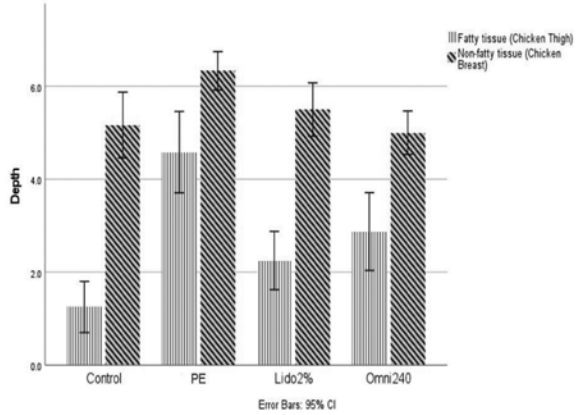

Fig. 4. *Distribution of lesions' depth (mm) post-thermal RFA.*

to opine on possible clinical significance as they are commonly used by interventional pain practitioners. We followed the same protocol as Ortiz et al (4) in adipose and the standard chicken breast model to evaluate the variability of these solutions in a relatively fatty model that more closely resembles human tissue in commonly ablated sites. In our study, nearly all groups demonstrated smaller lesions in the adipose compared to chicken breast groups. Lesion length and depth were significantly smaller in the adipose group; however, the PE cohort displayed the deepest lesions in adipose. The exceptions to the adipose limitation of size were PE and iohexol 240 increase in width. Power and resistance were not selected as observable outcomes in our study because of the potential variability it presents with data interpretation. We noticed that small changes in probe location caused modest fluctuations in resistance that did not translate into differential lesion changes. The authors controlled for uniformity of adipose obstruction by premeasuring all periadipose ablation points. Furthermore, we explain that the general decrease in lesion size is due to adipose's characteristic trait as a resistor or heat sink, which likely caused the smaller lesion sizes. Length of the ablation sizes was the most impacted by adipose and depth, decreasing ablation distance from the tissue by > 75% in all groups. Depth was the next most impressive change, demonstrating > 50% change in all groups tested; however, PE created a small, but more comparable lesion size to the nonadipose tissue. Iohexol 240 and PE created wider lesions in adipose presumably because the inhibition of depth and length penetration coupled with the generator's design for consistent power delivery in this larger diameter device delivered energy along a wider course. On the other hand, iohexol 240 may have decreased focal impedance causing a small change, though this was not statistically significant.

Regardless of the reason for the ablation size differential, it is important to understand the potential clinical interpretation of these results. We infer that the composition of tissue surrounding an RFA probe can potentially alter lesion shape and size. We posit here that local tissue with abundant adipose may be an important factor when selecting patients that would benefit from RFA (15). Fortin et al (16) demonstrated that increased fatty infiltration of the erector spinae and multifidus muscles at L5-S1 was predictive of continued, frequent, and persistent low back pain. These muscles are adjacent to the target area of the medial branch nerve RFA, and our study indicates that the presence of adipose tissue near the lesion site itself can affect lesion characteristics. When selecting patients that may benefit from RFA, characterization of fatty muscular infiltrates as seen on magnetic resonance

imaging, near the site of the planned lesion, may be a significant predictor of pain relief. It is unknown how prerequired sensory or motor testing is affected by local adipose; this may be important for future investigation. We believe that our findings should also be considered when evaluating patients for sacroiliac joint, genicular, hip, shoulder, and other RFA procedures where there is some contribution of adipose in the ablation area. Furthermore, there is cardiac and oncology literature (13,17) that supports differential lesioning dependent upon local tissue adipose characteristics. This is the first time this information has been reported in chronic pain. For the near term, it is difficult to say if this adipose impact will have any change in patient selection, but it is certain that these findings should influence future product development, and potentially lesioning methods in areas thought to have more fatty content.

Neuroablation is a valuable and viable option for those with joint-related pain syndromes. The implication of this research is to help clarify potential reasons for variable outcomes in some patient groups. The authors submit that understanding the local milieu of tissue can support or create ablation technique methods to improve clinical outcomes. For example, the placement of an RFA needle adjacent to bone has been reported to increase lesion size (18). In the setting of higher local adipose juxtapositioning of an RFA needle on bone may overcome the lesion limitations described here, though this needs validation. Our results suggest that PE needles may also be important in limiting adipose-related lesion inhibition. Similarly, studies, which reported poor RFA clinical outcomes, now can be further criticized by potential practitioner technique and patient habitus limitations, which can alter the course of clinical outcomes. If attention to technical detail and bony or adipose microanatomy of the RFA lesion site are not properly considered, suboptimal outcomes may occur. In other words, to have more reliable clinical outcomes, we may need to reinforce the importance of RFA techniques, which instruct adipose avoidance or bony approximation whenever possible. The clinical necessity of this recommendation should be considered in a prospective fashion in future research.

Limitations

The limitations of this study include using an ex vivo animal model and lower baseline tissue temperature compared to perfused tissue. Using an ex vivo animal model may introduce differences in tissue structure, and the lower baseline temperature can cause the RFA lesion size to be underestimated as it requires more energy to produce the lesion (19). We attempted to mitigate these limitations by using a standard method to produce and measure all RFA lesions; the same researcher performed all ablations and measurements were taken by 2 independent observers to avoid interoperator variability.

Increased adipose tissue and its effect on lesion size appear to be another factor to be considered in future studies. This could include examining RFA lesion size using the PE deployment in addition to injectates (lidocaine and iohexol, but also injectates with higher salinity have been shown to increase lesion size [10]). Increasing RFA lesion time from 90 seconds to 150 seconds also increases lesion volume (20). For future studies, we recommend a larger sample size and measuring adipose tissue to determine a more precise correlation between the amount of adipose tissue and lesion size, which can lead to better RFA parameters change. Other directions for future research include the evaluation of cooled RF and cryoablation to determine adipose-related lesion effects. However, the authors submit that altering needle placement and changing landmark-based approaches may be the most easily adopted approach to address the findings in this manuscript (20).

Conclusions

RFA size is appreciably decreased by adipose tissue in the microenvironment of RFA probes. It is important to consider how we understand and plan RFA procedures based on these inherent limitations. Future studies are warranted to improve the efficacy and safety of RFA in clinical practice.

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