

doi: 10.63360/ipmm.v1.e17

Preclinical and Experimental Laboratory Study

Quantifying the Temporal Resolution of Gas-Induced Ultrasound Changes Following Percutaneous Electrolysis in Tendon Tissue. A Cadaveric Study

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ABSTRACT

Objective: To quantitatively assess the temporal evolution of the electrolytic ultrasonographic effect induced by percutaneous electrolysis on cadaveric patellar tendons, and to compare the behavior of three different application protocols.

Methods: An in vitro experimental study was performed on three cadaveric patellar tendons. Three percutaneous electrolysis protocols were applied: Dose A (3 impulses x 3 seconds x 3 mA), Dose B (3 impulses x 3 seconds x 3 mA plus a three-needle bath at 1 mA up to 1,000 mJ), and Dose C (three-needle bath at 1 mA up to 14,000 mJ). The electrolytic effect was quantified using ultrasound image analysis at multiple time points: pre-treatment, immediately post-treatment, and at 0.5, 1, 2, 3, 4, 5, 10, 20, 30, 60, 360 (6h), 720 (12h), and 1,440 minutes (24h). Graphical inspection and curvilinear regression models were used to describe the temporal dynamics of each protocol.

Results: Dose A showed a stable, reproducible response, with a peak effect at 20 minutes (value: 5.60), followed by a gradual return to baseline at 360 minutes (6 hours). Dose B exhibited greater variability but returned to baseline by 360 minutes. Dose C revealed the greatest dispersion, with high peaks (8.50 at 20 minutes) and persistent negative values at 24 hours, without evidence of stabilization. Quadratic and cubic models provided the best fit for Dose A, while lower fitting was observed for Doses B and C.

Conclusions: The temporal pattern of the electrolytic effect varies notably depending on the protocol used. Quantitative ultrasound imaging provides an objective, non-invasive method for monitoring changes during percutaneous electrolysis therapy.

Keywords: Percutaneous electrolysis, dosing, quantitative ultrasound, galvanic current, tendinopathy.

1. Introduction

Therapeutic percutaneous electrolysis has become a reference technique in the treatment of various musculoskeletal disorders⁽¹⁾, particularly due to its ability to induce a controlled electrochemical response through the application of galvanic current via a dry needling procedure⁽²⁾. This process triggers a localized redox reaction that leads to molecular decomposition of the target tissue, resulting in the release of hydrogen, sodium, and other gaseous by-products, which are detectable via ultrasound imaging⁽²⁻⁷⁾.

In tendinopathies and soft tissue injuries, percutaneous electrolysis has demonstrated efficacy in modulating the inflammatory response, stimulating neocollagenesis, and promoting tissue repair⁽²⁻⁷⁾. However, the optimal definition of treatment parameters, especially current intensity, exposure time, and total delivered charge, remains an open question⁽²⁻⁹⁾. Current clinical protocols often rely on standardized configurations⁽¹⁰⁻¹²⁾, without considering how specific combinations of intensity and time dynamically affect the tissue response. Tendons are among the most frequently treated structures, particularly in chronic cases characterized by fibrotic and disorganized connective tissue^(6,13,14). While several studies have suggested that electrolysis can support tendon regeneration, the available clinical evidence remains limited and highly heterogeneous, especially regarding ultrasound changes and their correlation with long-term outcomes^(9,15).

Some modern devices incorporate dosing systems based on tissue resistance, allowing for more precise adjustment. However, none of these approaches currently considers the ultrasound response as an objective criterion for dosage control⁽²⁻⁹⁾. Given that electrolysis induces visible ultrasound changes^(7,16), primarily the appearance of microbubbles and tissue gasification, quantifying this effect could serve as a useful biomarker to guide real-time dosage strategies⁽²⁾. Moreover, excessive gas accumulation may saturate the ultrasound field, compromising procedural monitoring. It is therefore crucial to examine how the combination of parameters, particularly current intensity and duration, influences the magnitude and evolution of ultrasound changes. Establishing whether a threshold exists beyond which gas saturation impairs visibility could be essential for safe and effective treatment planning⁽²⁾. In clinical settings, this gas-induced echogenicity may become a quantifiable variable to assess the adequacy of the applied dosage.

Although the gasification effect produced by percutaneous electrolysis is readily observable in real-time ultrasound during clinical procedures, experienced practitioners often report that this echogenic response progressively fades over time, typically within hours after the intervention. Despite being a consistent clinical observation, to the authors' knowledge, no previous study has systematically evaluated the temporal resolution of these ultrasound-visible changes. Understanding the natural course of this echogenic washout is crucial, as it may reflect the tissue's

recovery dynamics and influence the timing of subsequent treatment sessions. Furthermore, characterizing this phenomenon could offer valuable insights into the optimal interval between applications, particularly in protocols involving multiple treatment sessions. Quantifying the washout time of the gas-induced ultrasound signal thus represents a novel and potentially impactful approach to refining dosage strategies and personalizing patient care.

In this context, the present study aims to quantitatively analyze the temporal evolution of ultrasound changes induced by percutaneous electrolysis in cadaveric patellar tendon tissue. A dedicated ultrasound analysis tool developed by our team, UZ eDose, was used to quantify the echogenic changes caused by gas formation objectively^(7,17). The study compares three clinical application protocols to identify dose-dependent patterns and assess the stability and duration of ultrasound-detected effects. This approach may support the development of more personalized and objective dosage models, grounded in the physiological response of the treated tissue.

2. Materials and Methods

2.1 Study Design

An in vitro experimental study was designed to analyze the temporal evolution of the electrolytic effect induced by percutaneous electrolysis on cadaveric tendon tissue. Three different electrolysis protocols (Doses A, B, and C) were applied to cadaveric patellar tendons. The galvanic effect was objectively quantified through ultrasound image analysis using a custom-developed tool, UZ eDose. This tool enables quantitative measurement of the degree of electrolysis—reflected as tissue gasification on ultrasound—by providing a score directly associated with the intensity of the galvanic effect. Ultrasound measurements were taken at multiple time points after electrolysis to track the effect's evolution and estimate the time required for the tissue to return to baseline. This study is part of a research project approved by the Local Ethics Committee of Universitat Internacional de Catalunya (CBAS-2023-11). All procedures followed good scientific practice guidelines for the handling of biological samples, ensuring data reliability and reproducibility.

2.2 Participants

Three human cadaveric patellar tendon samples were used. The samples were stored at -20°C and thawed at room temperature for 48 hours before experimentation. There were no marks indicating surgical procedures in the area.

2.3 Variables and Follow-up

Each tendon received one randomly assigned electrolysis protocol (Dose A, B, or C). Dose A consisted of a standard electrolysis application using 3 impulses of 3 seconds each at 3 mA (the 3x3x3 protocol). Dose B combined the standard 3x3x3 protocol with a subsequent bath using three needles, applying a continuous current of 1 mA until a total energy of 1,000 mJ was delivered. Dose C consisted exclusively of the three-needle bath protocol at 1 mA, applied until a cumulative energy of 14,000 mJ was reached, without the initial standard application.

For each intervention, the tendon was positioned to replicate standard clinical conditions, with a consistent 15° knee flexion angle across all samples. The procedure was performed under ultrasound guidance in a longitudinal view of the patellar tendon, using an in-plane approach, with needle insertion from distal to proximal. The galvanic current was applied by a specialist with over 10 years of experience in ultrasound-guided invasive techniques and specific expertise in percutaneous electrolysis. The needles used were 40 mm long and 0.30 mm in diameter (Agupunt®), and current was delivered using the Bipolar System, a device designed for controlled application of galvanic current.

Quantitative ultrasound assessments using UZ_eDose were performed at the following time points: pre-treatment (baseline, without electrolysis), and post-treatment at 0 minutes (baseline), 30 seconds, 1, 2, 3, 4, 5, 10, 20, 30 minutes, and 1, 6, 12, and 24 hours. Imaging was performed with a GE Vscan portable ultrasound device immediately after each application (Figure 1). Longitudinal in-plane images were acquired, selecting the best available frame that accurately captured the treated area. Ultrasound evaluation was performed by an expert with over 15 years of experience in musculoskeletal (MSK) ultrasound, ensuring consistent and reliable interpretation of the echogenic changes.

All images were quantified using UZ eDose, a specific function of the UZ_qTool software, which allows objective assessment of electrolysis-induced ultrasound effects in tendon tissue. The software extracts quantitative metrics from the ultrasound image, providing detailed information on changes in texture, echogenicity, and internal tendon structure following galvanic stimulation. Higher UZ eDose scores correspond to greater electrolysis effect, specifically indicating increased hydrogen release and tissue gasification. This quantification facilitates the identification of response patterns and potential dosing thresholds based on tissue reaction.

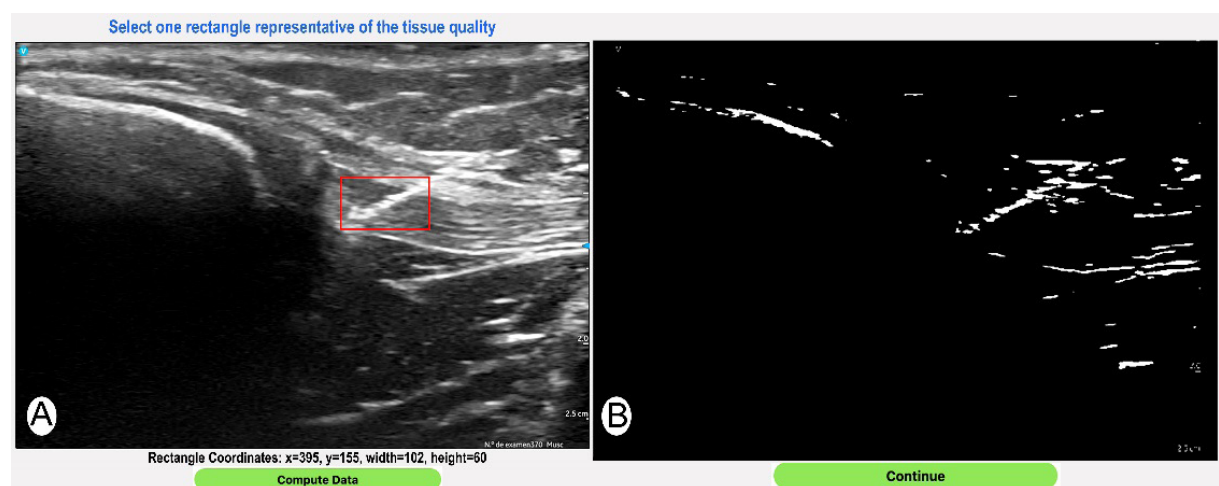


Figure 1. Gas analysis example with UZ eDose.

2.4 Risk of Bias

Only three cadaveric patellar tendon samples were used. This limits generalizability and increases susceptibility to bias from biological variability.

Subjectivity in Ultrasound Frame Selection: Although quantification is software-based, the operator selected the "best available frame" from the longitudinal ultrasound images. This intro-

duces subjectivity and potential for selection bias, especially if the evaluator was aware of the treatment condition.

Single Evaluator: Ultrasound analysis was conducted by a single expert without cross-validation by a second blinded rater. This limits reproducibility and raises the risk of confirmation bias.

No Blinding in Image Analysis: The expert conducting ultrasound assessments likely knew the applied dose, which may have influenced frame selection or interpretation, even if unintentionally.

Absence of Control for Postmortem Tissue Degradation: Tendon tissue undergoes biochemical and structural changes postmortem that could influence echogenicity or responsiveness to galvanic current.

2.5 Statistical Analysis

Statistical analysis was performed using IBM SPSS Statistics version 29.0 (IBM Corp., Armonk, NY, USA). Given the exploratory nature of the study and the availability of a single measurement per dose and time point, the analysis used a descriptive, curve-fitting approach without applying inferential statistical tests.

First, the temporal evolution of the electrolytic effect, quantified by the UZ_eDose tool, was graphically represented for each of the three electrolysis protocols to visualize the dynamics and variability of the galvanic response over time. Multiple line graphs were generated, with the X-axis categorically representing time points ensuring equidistant spacing regardless of actual time in minutes, and the Y-axis showing the quantitative UZ_eDose values. The three doses were plotted together in a single figure to facilitate visual comparison. The approximate time at which the electrolytic effect returned to baseline levels was estimated for each dose through visual analysis and linear interpolation between the closest data points to the baseline value. Due to the lack of replicates and the exploratory design of the study, results were interpreted descriptively, and no inferential statistical comparisons were conducted between doses.

Subsequently, mathematical modeling was applied to describe the temporal dynamics of the observed effect at each dose. SPSS's Curve Estimation procedure was used, with the dataset segmented by dose to generate separate models for each protocol. Various regression models were explored, including linear, logarithmic, exponential, quadratic, cubic, inverse, and power functions, to identify the best-fitting model for the observed trend. For each model, the coefficient of determination (R^2) and the statistical significance of the fit were recorded. The models with the highest explanatory power (i.e., highest R^2) were selected for descriptive interpretation.

3. Results

3.1 Temporal Evolution of the Ultrasound-Detected Electrolytic Effect According to Dose

Displays the quantitative evolution of the electrolytic effect observed via UZ_eDose across the three application protocols. The scores reflect the magnitude of the gasification effect observed on ultrasound—higher values indicating a greater galvanic response due to hydrogen gas. For

all groups, the pre-treatment value (0.64) corresponded to the baseline echogenicity of the tendon tissue in the absence of electrolysis. The subsequent measurements illustrate how each dose induced distinct patterns of echogenic change over time (Table 1).

Table 1. Temporal evolution of the electrolytic effect (UZ_eDose values) for each dose protocol.

Time	Pre		Post											
	Inmed	30"	1'	2'	3'	4'	5'	10'	20'	30'	1h	6h	12h	24h
Dose A	0.64	2.31	3.59	3.57	2.42	4.57	3.77	2.64	4.84	5.6	2.22	1.96	0.64	0.64
Dose B	0.64	0.36	1.09	0.53	0.39	-1.55	1.96	3.53	0.34	0.41	4.24	4.42	0.64	0.64
Dose C	0.64	3.62	3.74	2.74	5.13	2.32	3.29	1.43	0.31	8.5	-0.85	3.11	5.25	3.02

Values correspond to the quantitative scores obtained using the UZ_eDose tool. Higher scores indicate greater echogenic change consistent with gasification. Pre-treatment value (Pre) reflects baseline tissue echogenicity without electrolysis. Dose A: 3x3x3 protocol. Dose B: combined the standard 3x3x3 protocol with a subsequent bath using three needles, applying a continuous current of 1 mA until a total energy of 1,000 mJ was delivered. Dose C: consisted exclusively of the three-needle bath protocol at 1 mA, applied until a cumulative energy of 14,000 mJ was reached, without the initial standard application.

Dose A (3x3x3 protocol) showed a gradual increase peaking at 20 minutes (5.60), followed by a return to baseline between 6 and 12 hours. The baseline value was 0.64. Following application, a progressive increase in the galvanic effect was observed, with a noticeable rise from the first minutes and a peak around 20 minutes (5.60). Subsequently, a steady decline was observed, with a return to baseline values beginning approximately 6 hours later. In other words, the electrolytic effect induced by Dose A showed a gradual reduction, reaching values close to the pre-treatment level around 360 minutes (6 hours), and remained stable thereafter.

Dose B demonstrated more variable responses, including negative values, but also normalized by 6 hours. The pre-treatment value was also 0.64. In contrast to Dose A, the temporal evolution showed greater variability, including negative values at minute 3 (-1.55). Although peaks of electrolysis were detected at minutes 5 (3.53) and 60 (4.42), no clear sustained trend was observed. Eventually, as in Dose A, the values returned to baseline (0.64). That is, although Dose B presented more variability over time, the ultrasound values also returned to baseline levels at approximately 360 minutes, remaining stable thereafter.

Dose C (high cumulative charge via prolonged three-needle bath) produced the highest and most persistent changes, with peaks at 20 minutes (8.50), sustained alterations up to 12 hours, and incomplete normalization at 24 hours. The baseline value was again 0.64. After application, the galvanic effect was more pronounced but less predictable. Starting at 0.64, there was a sharp increase, reaching a peak at 20 minutes (8.50)—the highest value recorded across all doses. However, the temporal evolution was highly irregular, with negative values at 30 minutes (-0.85) and even at 24 hours (-1.79). No consistent return to baseline values was observed, with wide variability persisting at longer time points. In summary, Dose C did not show a sustained return to pre-treatment levels. Although lower values were reached between 360 and 720 minutes, the pattern remained highly erratic, with marked fluctuations and negative scores still present at the final time point evaluated (24 hours).

3.2 Model Fit and Temporal Evolution Analysis of the Electrolysis Degree for Each Dose

Figure 2 displays the individual values obtained with the UZ eDose tool for each of the three application protocols, without any model fitting, to visualize the dispersion and variability of

the measurements. Given that only one measurement is available per time point, the results are interpreted descriptively, without statistical inference, and serve to compare the temporal dynamics across the different doses visually. Dose A shows a greater concentration of high scores, especially within the first 20–30 minutes, followed by an apparent decline starting around minute 60. Dose B presents more dispersed values, with pronounced fluctuations and even negative scores at specific time points, reflecting a more irregular evolution. Dose C exhibits the most extreme values, including high peaks (above 8) and negative scores, without a discernible pattern of sustained decline, highlighting its greater variability.

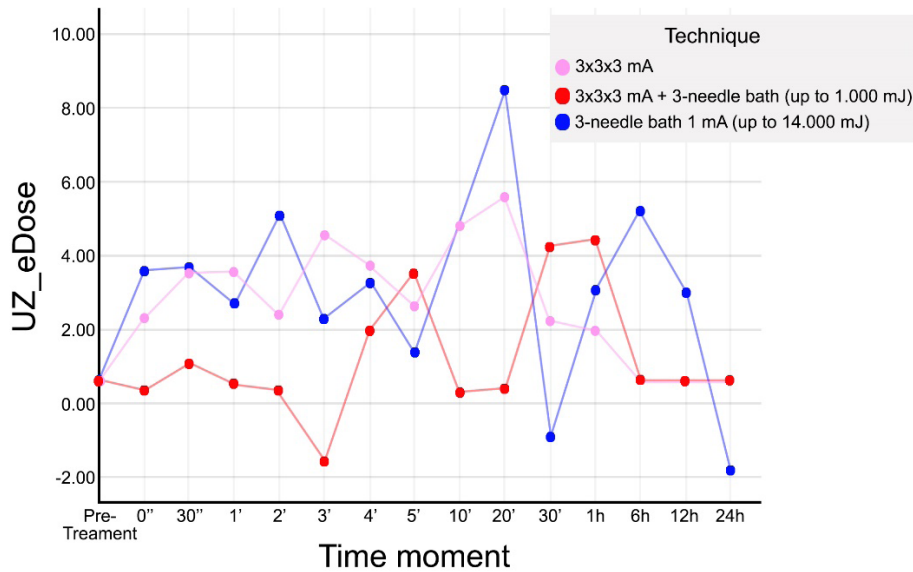


Figure 2. Dispersion of quantitative electrolysis scores (UZ eDose) for each dose at the different time points. Graphical representation of the quantitative scores obtained with the UZ eDose tool across post-treatment time points for the three evaluated doses.

3.3 Dose A: Model Fit and Analysis

The first protocol (Dose A) exhibited a curvilinear pattern, with a progressive increase in UZ eDose values, reaching a peak around the sixth point (4 minutes), followed by a gradual return toward baseline. A model-fitting analysis was conducted to characterize the temporal evolution of ultrasound-detected changes after applying Dose A (Table 2). Among the models tested (linear, logarithmic, exponential, quadratic, and cubic), the quadratic model showed the best fit, with a coefficient of determination (R^2) of 0.641 and statistical significance ($p = 0.002$). This model suggests that the echogenic response evolves nonlinearly over time, following a trajectory marked by an initial increase and a subsequent decline (or vice versa, depending on the direction observed in the graph). The cubic model also demonstrated a good fit ($R^2 = 0.648$), though its greater complexity makes interpretation more challenging due to the number of parameters.

Table 2. Fit of different regression models to describe the temporal evolution of ultrasound changes following Dose A.

Model	R ²	p-value
Linear	0.079	0.311
Logarithmic	0.000	0.953
Quadratic	0.641	0.002
Cubic	0.648	0.008

Model	R ²	p-value
Exponential	0.134	0.179

3.4 Dose B: Model Fit and Analysis

The second application, Dose B, exhibited greater variability, with values remaining close to baseline for most of the follow-up period. As with the previous dose, various regression models were applied to describe the temporal evolution of the quantitative ultrasound response (Table 3). Due to negative values in the measurements, models requiring strictly positive values—such as exponential, logarithmic, power, compound, and logistic models—could not be computed. Among the available models, the cubic model provided the best fit for this dose, with a coefficient of determination (R^2) of 0.284, although it did not reach statistical significance ($p = 0.280$). The quadratic model showed a lower fit ($R^2 = 0.121$, $p = 0.461$), similar to the linear and inverse models, which also presented low explanatory power ($R^2 = 0.079$ and 0.047 , respectively). These findings suggest that the temporal evolution of the ultrasound-based variable in Dose B was more irregular and less clearly defined compared to Dose A, with no consistent curvilinear trend observed during the follow-up period. The exponential model could not be computed because the dataset contains negative values, which are incompatible with this type of regression analysis.

Table 3. Regression model fitting for the temporal evolution of ultrasound changes following Dose B.

Model	R ²	p-value
Linear	0.079	0.310
Logarithmic	0.081	0.305
Inverse	0.047	0.440
Quadratic	0.121	0.461
Cubic	0.284	0.280
Exponential	Not calculated	—

3.5 Dose C: Model Fit and Analysis

Dose C also exhibited a more irregular behavior, with fluctuations over time. The same curve-fitting procedure was applied to analyze the temporal evolution of the ultrasound-based variable following the third dose (Table 4). However, the presence of negative values in the measurements prevented the estimation of models that require exclusively positive inputs, such as exponential, logarithmic, power, and logistic models. Among the models evaluated, none provided an adequate fit to describe the temporal evolution for this dose. The quadratic model yielded a coefficient of determination (R^2) of 0.090, and the cubic model yielded an R^2 of 0.097, both without statistical significance ($p > 0.05$). Linear and inverse models also showed poor fit, with R^2 values of 0.016 and 0.011, respectively. These results indicate that the temporal evolution observed for Dose C does not follow a clear or consistent curvilinear pattern, suggesting

greater variability or dispersion in the ultrasound measurements over time. The exponential model could not be computed because the dataset contains negative values, which are incompatible with this type of regression analysis.

Table 4. Curve fitting of different regression models describing the temporal evolution of electrolysis degree for Dose C.

Model	R ²	p value
Linear	0.016	0.658
Logarithmic	0.000	0.948
Inverse	0.011	0.707
Quadratic	0.090	0.569
Cubic	0.097	0.761
Exponential	Not calculated	–

4. Discussion

This study investigated the temporal evolution of the ultrasound-detectable effect of percutaneous electrolysis on cadaveric patellar tendon, using the UZ_eDose tool for quantitative assessment. The three different protocols exhibited distinct behaviors. Dose A showed a more stable and predictable pattern, with a progressive increase followed by a sustained return to baseline approximately six hours post-treatment. Dose B presented greater variability but also returned to near-baseline values within a similar time frame. In contrast, Dose C displayed a more irregular response, with higher peaks, increased dispersion, and no consistent return to baseline at later follow-up intervals.

The differences observed across protocols can be attributed to the distinct characteristics of each percutaneous electrolysis application. Dose A, based on the classic 3×3×3 protocol, elicited a more controlled and transient response, likely due to the short pulse duration and moderate intensity, which tend to induce a localized and manageable galvanic effect. From a physiological standpoint, this response aligns with previous literature indicating that moderate-intensity galvanic current can generate a controlled inflammatory reaction that promotes tissue repair without overwhelming the surrounding structures^(2–7). Dose B, which combined a standard protocol with a low-intensity galvanic bath (1 mA up to 1,000 mJ), resulted in greater variability. This may be explained by a cumulative effect, in which the initial inflammation was enhanced by subsequent gas formation and pH alterations induced by the low-intensity bath. At the chemical level, electrolysis generates hydroxide ions (OH⁽⁻⁾) and hydrogen gas (H₂) at the cathode, as well as protons (H⁺) and oxygen gas (O₂) at the anode, leading to pH shifts and the formation of gas microbubbles within the tissue⁽¹⁸⁾. These microbubbles are visible via ultrasound and represent a key indicator of the electrolytic effect⁽⁷⁾; however, excessive accumulation may interfere with the return to baseline and with quantification of the response. Dose C, consisting solely of a high-dose, long-duration bath (14,000 mJ), exhibited an erratic pattern and failed to return to baseline within the observation window. This may reflect tissue saturation and extensive diffusion of electrochemical products, which could impair reabsorption and stabilization. Prior studies have suggested that, beyond a certain threshold, the electrolytic effect becomes so pronounced that it compromises ultrasound visibility due to excessive gasification—particularly when combining long application times and higher intensities^(7,17). This

underscores the idea that not only the total dose (mC), but how the dose is delivered (i.e., the interaction between time and intensity), plays a decisive role in shaping the magnitude and behavior of the tissue response⁽⁶⁾. Moreover, some authors have reported that application time alone may contribute meaningfully when ultrasound visibility is preserved, while its influence diminishes when excessive gas formation limits assessment⁽⁷⁾. This is consistent with our findings, where Dose C may have exceeded this threshold, resulting in tissue saturation and a loss of quantifiable signal stability.

To our knowledge, this is one of the first studies to objectively and quantitatively monitor the time course of the ultrasound-visible effect induced by percutaneous electrolysis using a dedicated tool such as UZ_eDose. While existing studies have provided qualitative or physiological descriptions of tissue response^(2–7), few have focused on the temporal behavior of the effect or its modulation by different dosing protocols. In a recent analysis, intensity emerged as the most relevant parameter in explaining the magnitude of the ultrasound response, followed by application time when visibility was preserved⁽⁷⁾. Our results expand upon these findings by showing how the temporal persistence of the galvanic effect also varies with protocol type, not only in magnitude but in the dynamics of resolution. This aligns with previous experimental findings in cells, where differences in biological markers (e.g., IL1B, LDH) were observed despite identical total electrical charge, suggesting that intensity and time are not interchangeable⁽⁸⁾. Our data further supports the concept of a saturation threshold, beyond which the electrolytic effect becomes excessive and persistent. In Dose C, this likely explains the failure to return to baseline within the monitoring period. This finding reinforces the importance of personalizing electrolysis parameters not only by intensity and duration but also by considering their interactions and cumulative effects over time. Significantly, such saturation points may compromise ultrasound-based monitoring itself, highlighting the need to define maximum safe limits for reliable assessment^(7,17). By integrating temporal quantification and applying UZ_eDose to monitor return-to-baseline dynamics, our study provides novel insight into the “washout” behavior of the electrolytic effect—an aspect not addressed in most prior investigations. This may have significant clinical implications for guiding treatment intervals and determining appropriate dosing strategies.

Understanding the approximate “washout time” or return to baseline after electrolysis could be critical for optimizing treatment frequency and tailoring protocols to individual responses. The UZ_eDose tool could support real-time monitoring of the galvanic effect, facilitating personalized decision-making based on objective data. The main strengths of this study include the use of a validated, quantitative measurement tool (UZ_eDose) and a standardized experimental design in cadaveric tissue, which enabled precise control over application parameters and temporal measurements. Moreover, this study helps us understand the behavior of the gas effect at different doses, showing that the effect is not proportional to intensity $\times$ time or to the accumulated electrical energy, but rather exhibits a different behavior that we are not yet fully able to explain. However, this study presents several limitations that must be acknowledged. First, the lack of experimental replicates for each dose and time point prevents robust inferential analysis and limits the generalizability of the findings. Each protocol was applied only once per time interval, limiting the estimation of within-condition variability and confining the study to a descriptive, exploratory level. Second, the *in vitro* model using cadaveric patellar tendon—while

offering high control over application parameters—does not reproduce the full complexity of in vivo biological responses. Key physiological mechanisms such as inflammation, cellular metabolism, and tissue perfusion, which play a critical role in the regenerative processes triggered by percutaneous electrolysis, are absent in this context. Postmortem tissue heterogeneity and potential alterations related to storage conditions (e.g., temperature, hydration, pressure) may have influenced ultrasound signal behavior and the evolution of the observed galvanic effect. Future research should include a larger number of samples and replicate assessments, as well as studies involving different tissue types and in vivo models. Validating UZ_eDose for clinical monitoring could open new avenues for individualized and optimized electrolysis-based interventions. In addition, exploring the interaction between application parameters (intensity, duration, pulse frequency) and the persistence of ultrasound-detectable changes could enhance our mechanistic understanding of the technique.

5. Conclusions

This in vitro study provides a quantitative description of the temporal evolution of ultrasound-visible changes induced by percutaneous electrolysis on the cadaveric patellar tendon. Among the three protocols tested, Doses A and B returned to near-baseline values approximately 6 hours post-treatment. At the same time, Dose C exhibited greater dispersion and lacked a consistent stabilization pattern. These findings suggest that the temporal profile of electrolysis effects depends on the dosing strategy applied. Although promising, these results must be interpreted with caution, given the limited sample size, absence of replication, and the inherent constraints of an in vitro model. Nonetheless, the UZ_eDose tool appears to be a valuable resource for monitoring and quantifying the ultrasound-visible effects of percutaneous electrolysis. Further validation and clinical application of this methodology could lead to more personalized, evidence-based electrolysis protocols in musculoskeletal practice.

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Editorial information

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Dates

Received: 18.09.2025

Accepted: 19.10.2025

Published: 21.11.2025

Author Contributions

Conceptualization. M.M.-U., J.R.-S. and S.B.-A.; methodology. M.M.-U., J.R.-S. and S.B.-A.; formal analysis. M.M.-U. and C.L.-d.-C.; investigation. M.M.-U., J.R.-S., S.B.-A., I.R.-A., C.L.-d.-C. and I.A.-C.; data curation. M.M.-U.; writing—original draft preparation. M.M.-U., J.R.-S.; writing—review and editing. all authors; supervision. M.M.-U. and J.R.-S.; All authors have read and agreed to the published version of the manuscript.

Institutional Review Board Statement

The study was conducted in accordance with the Declaration of Helsinki. and approved by the Local Ethics Committee of the Universitat Internacional de Catalunya with the number CBAS-2023-11 (Date: 27 October 2023).

Informed Consent Statement

The samples are from anatomical donors at the anatomy laboratory of the Universitat Internac-ional de Catalunya (Spain). Participants in this study signed a written consent to donate their body for research.

Acknowledgments

The authors are thankful to body donors that enable the study of anatomy

Funding

This research received no external funding.

Data Availability Statement

The data presented in this study are available on request from the corresponding author.

Conflicts of Interest

The authors declare no conflicts of interest.

Suggested citation

Malo-Urriés M, Rodríguez-Sanz J, Borrella-Andrés S, Albarova-Corral I, Ríos-Asín I, López-de-Celis C. Quantifying the temporal resolution of gas-induced ultrasound changes following percutaneous electrolysis in tendon tissue: a cadaveric study. Invasive Physiother Musculoskelet Med. 2025;1:e17. doi: 10.63360/ipmm.v1.e17

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