

COVER PAGE

Official Title of the Study:

MRI-Based Artificial Intelligence Prediction of Fluoroscopic C-Arm
Angles for Lumbar Transforaminal Epidural Steroid Injections: A
Prospective Accuracy Study

NCT Number:

Not yet assigned

Date of the Document:

October 11, 2026

MRI-Based Artificial Intelligence Prediction of Fluoroscopic C-Arm Angles for Lumbar Transforaminal Epidural Steroid Injections: A Prospective Accuracy Study

Study Protocol and Statistical Analysis Plan

Study Design and Type

This study is a prospective, observational, and methodological accuracy study to be conducted in the Physical Medicine and Rehabilitation Department, Algology Division at Marmara University (Pendik Training and Research Hospital and Asaf Ataseven Annex Building Algology Outpatient Clinics). It will include patients who have been scheduled for a lumbar transforaminal epidural steroid injection (TFESI) as a result of routine clinical evaluation for lumbar radicular pain.

The decision to perform TFESI will be made independently of the research protocol, within the scope of routine clinical practice based on the patient's clinical findings and imaging results. Participation in the study will not affect the TFESI indication, the selection of the target level and side, the procedural technique, the medications used, or the clinical decisions made during the procedure.

The C-arm angle predictions made by artificial intelligence (AI) will be performed before the TFESI procedure and recorded on the research data form. The physician performing the procedure will be blinded to the angles predicted by the AI and will determine the C-arm position solely according to their own clinical assessment and fluoroscopic images. The angles recommended by the AI will not be used for C-arm positioning during the patient's actual procedure.

Study Population and Patient Selection

Adult patients who present to the Algology Outpatient Clinic during the study period, who are scheduled for unilateral or bilateral, single or multi-level TFESI within routine clinical practice due to lumbar radicular pain, and who meet the inclusion/exclusion criteria will be consecutively included in the study. For each patient, age, gender, height, body weight, and body mass index (BMI), along with the level(s) and side for the TFESI, will be recorded. These demographic and anthropometric variables will not be provided as input to the AI; they will be evaluated in secondary analyses as potential patient characteristics that may influence the AI prediction error.

Unit of Analysis

The primary unit of analysis in the study will be each level-side combination (injection target) where TFESI is performed. For example, a right L5 TFESI will be evaluated as one injection target, while a left L5 TFESI will be evaluated as a separate injection target. Similarly, if right L4 and right L5 TFESI are performed on the same patient, two separate injection targets will be recorded.

In patients undergoing bilateral or multi-level TFESI, the AI evaluation for each injection target will be performed separately, and the fluoroscopic C-arm angles used during the procedure will be recorded individually. Since data belonging to multiple injection targets can be obtained from the same patient, it will be assumed that these observations are not completely independent from each other, and intra-patient clustering will be taken into account in the statistical analyses.

Acquisition and Standardization of Lumbar MRI Images

No additional MRI imaging will be performed on patients for research purposes. Lumbar MR images obtained within the last 6 months prior to the procedure as part of the patients' routine clinical evaluation and available in the hospital's PACS system will be used. The images to be presented to the AI for each injection target will be selected using a pre-determined standard method. The following three T2-weighted MR images will be used for each target in the AI evaluation:

- **Midsagittal T2-weighted section:** Used to evaluate the sagittal orientation of the target disc space, the relationship of vertebral endplates, and the segmental lumbar slope.
- **Target side parasagittal T2-weighted section:** Used to evaluate the target neural foramen, pedicle, and foraminal anatomical relationships.
- **Axial T2-weighted section corresponding to the level where the pedicles of the target vertebra are widest:** Used to evaluate vertebral rotation, pedicle-facet relationship, and axial anatomical orientation at the target level.

In patients undergoing bilateral procedures, the right and left sides of the same level will be evaluated as separate injection targets, and the parasagittal image belonging to the target side will be selected separately for each side. The same number and type of images will be presented to the AI for all patients. Image selection will be carried out according to the criteria defined at the beginning of the research. Patient name, protocol number, date of birth, and other personal identifying information on the MR images will be removed and the images will be anonymized before being transferred to the AI system.

Prediction of C-Arm Angles with Artificial Intelligence

ChatGPT will be used for AI-based evaluation in the study. The AI model/version used at the beginning of the study will be recorded, and the same model will be used throughout the study as much as possible. For each injection target, the AI will only be presented with: the lumbar level to be injected, the side of the procedure, and three standardized T2-weighted lumbar MR images. Age, gender, height, body weight, BMI, and the actual fluoroscopic angles determined by the operator during the procedure will not be reported to the AI. A single standardized prompt, created at the beginning of the study and not to be changed during the study, will be used in all evaluations. By evaluating the anatomical features in the presented MR images, the AI will be asked to report its prediction for obtaining the appropriate fluoroscopic projection for TFESI at the relevant level and side as a single numerical value for: the oblique C-arm angle and its direction in degrees, and the cranial or caudal C-arm angle and its direction in degrees. The numerical predictions provided by the AI in its first response will be recorded on the AI Prediction Registration Form (APPENDIX-1) without any correction, additional guidance, or re-querying. The actual procedural angles determined by the operator will not be reported to the AI later, and the prediction will not be repeated based on the operator's result for the same injection target.

TFESI Procedure and Determination of Reference Fluoroscopic C-Arm Angles

TFESI procedures will be performed under fluoroscopy guidance by an experienced interventional pain physician as part of routine clinical practice. The target level and side, needle advancement technique, contrast use, and drugs to be administered will be determined according to routine practice in line with the patient's clinical needs and will not be changed due to the research. The physician performing the procedure will be blinded to the AI predictions. The initial C-arm position and all subsequent adjustments will be performed by the operator in the manner used in routine clinical practice.

Standardization of Patient Positioning

TFESI procedures will be performed while the patients are in the prone position. In order to standardize the possible effect of patient positioning on lumbar lordosis and segmental vertebral orientation during the procedure, the positioning method used in routine clinical practice will be kept as constant as possible throughout the study. Whether support is used under the abdomen/pelvis will be recorded for each patient. In case a support is used, the aim will be to use the same type and approximately the same placement method throughout the study.

Since MR images are obtained in the supine position and fluoroscopic reference angles are obtained in the prone procedural position, it is accepted that position-dependent segmental orientation differences may affect the craniocaudal C-arm angle in particular. In order to evaluate this possible effect objectively, a true AP fluoroscopic image will be obtained at the target level at the beginning of the procedure before the needle is advanced, and the cranial/caudal C-arm angle required for proper alignment of the relevant vertebral endplates will be recorded. This value will also be recorded as a procedural indicator of segmental sagittal orientation in the prone procedural position.

- **Reference oblique angle** will be defined as the oblique angle at the C-arm position where the anatomical relationships between the pedicle, vertebral body, and superior articular process on the target side are optimally visualized to allow the needle to be advanced into the targeted transforaminal path.
- **Reference craniocaudal angle** will be defined as the cranial or caudal angle at the C-arm position where the relevant endplate, pedicle, and foraminal anatomical relationships at the target vertebral level are optimally visualized for the procedure.

For each injection target, the oblique angle and its direction, and the cranial/caudal angle and its direction shown on the C-arm device when the optimal fluoroscopic projection is achieved before the needle is advanced will be recorded in degrees. These values will be considered as the reference fluoroscopic C-arm angles in the study. In bilateral or multi-level procedures, C-arm angles will be recorded separately for each injection target.

Blinding and Independence of Assessments

The AI evaluation will be completed prior to the TFESI procedure. The physician performing the procedure will not see the AI predictions and will determine the reference C-arm angles independently. The AI will not be given any information about the C-arm angles determined by the

operator during the procedure either. Thus, it will be ensured that AI predictions and clinical reference values are obtained independently of each other.

Data Collection

Age, gender, height, body weight, and BMI will be recorded for each participant. For each injection target, the following data will be recorded separately:

- TFESI level and side,
- Oblique angle and direction predicted by AI,
- Cranial/caudal angle and direction predicted by AI,
- Reference oblique angle and direction determined by the operator,
- Reference cranial/caudal angle and direction determined by the operator.

In the study, AI predictions will be recorded with the AI Prediction Record Form (Appendix-1), and the reference fluoroscopic C-arm angles determined by the operator during the procedure will be recorded independently of the AI predictions with the Reference Fluoroscopic C-Arm Angle Record Form (Appendix-2). Both forms will then be matched in the research database via the study participant code and injection target.

Outcome Measures

The primary outcome measures of the study will be the absolute error (degrees) between the oblique and craniocaudal C-arm angles predicted by the AI and the reference angles determined by the operator during the procedure. Oblique and craniocaudal angles will be evaluated separately.

Secondary outcome measures are the evaluation of:

- Mean Absolute Error (MAE),
- Proportion of AI predictions within $\pm 3^\circ$ of the reference angle,
- Proportion of AI predictions within $\pm 5^\circ$ of the reference angle,
- Agreement between AI predictions and reference angles,
- Systematic bias and 95% limits of agreement between the two methods,
- Variation of prediction error according to the target lumbar level,
- The relationship of prediction error with patient characteristics such as age, gender, height, body weight, and BMI.

Sample Size

The primary objective of the study is to evaluate the accuracy and agreement between the fluoroscopic C-arm angles predicted by AI and the reference C-arm angles determined by an experienced operator during the procedure. The Intraclass Correlation Coefficient (ICC) was based on the sample size calculation. An ICC value of 0.60 between AI predictions and operator-

determined reference angles was accepted as the lowest acceptable agreement level (H0), while an ICC value of 0.80 was accepted as the expected/strong agreement level (H1). Based on a two-sided significance level of $\alpha=0.05$ and 80% statistical power, it was calculated that approximately 51 independent evaluable observations are required. Because TFESI can be applied bilaterally or at multiple levels in the study, measurements belonging to more than one level-side combination can be obtained from the same patient. Considering that these measurements obtained from the same patient are not entirely independent of each other, instead of increasing the sample size, multiple injection targets will not be accepted as independent patients, and the basic sample size will be planned over the number of patients. Accordingly, it is aimed to reach at least 60 evaluable patients for the primary analysis. Considering the data losses that may occur due to missing or unevaluable MR images, incomplete procedure records, or unevaluable AI outputs, as well as the planned secondary analyses regarding target lumbar levels, a total of 80 patients are planned to be included in the study. As a result of bilateral and multi-level applications, the total number of evaluable level-side combinations is expected to be higher than the number of patients. Assuming an average of approximately 1.3–1.5 injection targets per patient, it is expected that approximately 100–120 injection targets from 80 patients will be evaluated. However, these targets will not be considered as independent samples, and the correlation between measurements obtained from the same patient will be taken into account in statistical analyses.

Statistical Analysis

Analyses in the study will be performed at both the patient level and the injection target (level-side combination) level. Continuous variables will be presented as mean $\pm$ standard deviation or median (interquartile range) depending on their distribution characteristics, while categorical variables will be presented as numbers and percentages. The oblique and craniocaudal C-arm angles predicted by the AI and determined by the operator will be evaluated separately. As the primary accuracy measure of the study, the absolute error (degrees) between the AI prediction and the reference angle determined by the operator will be calculated for each injection target, and overall prediction performance will be reported with Mean Absolute Error (MAE) and 95% confidence interval. In addition, the mean prediction error (signed error/bias) and, if necessary, Root Mean Square Error (RMSE) will be calculated. To evaluate clinically acceptable prediction accuracy, the rates of AI predictions falling within $\pm 3^\circ$ and $\pm 5^\circ$ of the reference angle determined by the operator and their 95% confidence intervals will be calculated. The agreement between AI predictions and operator-determined reference angles will be evaluated using the Intraclass Correlation Coefficient (ICC) and 95% confidence interval. Bland-Altman analysis will be applied to evaluate systematic bias and individual-level agreement between the two measurements; the mean difference (bias) and 95% limits of agreement will be reported. Since there may be measurements belonging to multiple injection targets from the same patient in patients undergoing bilateral or multi-level TFESI, these observations will not be considered independent. Intra-patient clustering formed by measurements obtained from the same patient will be addressed with appropriate repeated measures methods. When evaluating factors that may affect prediction error, mixed-effects regression models containing a random intercept at the patient level will be used when necessary. Appropriate methods for repeated measures obtained from the same patient will also be used in the Bland-Altman assessment. In secondary analyses, the relationship of AI prediction error with target lumbar level, procedure side, age, gender, height, body weight, and BMI will be investigated. Stratified analyses according to target lumbar levels will be performed if there is a

sufficient number of observations. The statistical significance level will be accepted as two-sided $p < 0.05$.

Use of Artificial Intelligence and Data Security

ChatGPT, provided by OpenAI, will be used for AI-based image evaluation in the research. All AI evaluations to be carried out within the scope of the research will be performed using the Temporary Chat feature. In addition, the "Improve the model for everyone" option in the data control settings of the account used will be turned off prior to the start of the research and kept off throughout the study. This way, the contents transferred to the AI system within the scope of the research will not be permitted to be used for model development/training purposes. According to OpenAI's current data policies, conversations held within Temporary Chat are not saved to the chat history, do not create memory, and are not used for model development/training purposes. A copy of Temporary Chat data can be kept on the systems for a maximum of 30 days for security and abuse monitoring purposes, after which it is deleted.

Limitation of Data Transferred to the AI System

Patients' original DICOM files will not be transferred to the AI system within the scope of the research. For each injection target, MR sections pre-defined in the research protocol will be selected via the hospital's PACS system and converted into a static image format that does not contain DICOM header information. Before the images are transferred to the AI system, all direct identifying information associated with the patient or the imaging process will be removed from the images. In this context; name and surname, Turkish ID number, date of birth, hospital protocol number, imaging/accession number, and other direct identifying information on the image will not be transferred to the AI system. The research participant code belonging to the patient will also not be given to the AI system.

Research Data to be Presented to the AI

For each injection target, only the following will be presented to the AI system: the lumbar level to be injected for TFESI, the side where the procedure will be performed, and T2-weighted MR image sections standardized according to the study protocol and stripped of direct identifying information. The patient's age, gender, height, body weight, BMI, name-surname, Turkish ID number, date of birth, hospital protocol number, research participant number, contact information, or detailed clinical history will not be transferred to the AI system.

Standardization of AI Evaluation

A separate Temporary Chat session will be used for each injection target. The same AI model and the same standardized prompt determined at the beginning of the study will be used in all evaluations. The oblique and craniocaudal C-arm angle predictions given by the AI in its first evaluation will be recorded in the research database by the researcher; no additional routing, correction, or re-prediction will be made on the same images based on the operator's result. Matching between the patient and the AI output will only be performed in the researcher's secure

research database, and the patient or research code that could provide this matching will not be transferred to ChatGPT.

Clinical Use of AI Results

The C-arm angle predictions generated by the AI will be used solely for research purposes. These predictions will not be used in planning the patient's treatment or in applying the TFESI procedure. The physician performing the TFESI procedure will not be aware of the predictions generated by the AI and will determine the C-arm angles independently based on their own clinical evaluation and fluoroscopic images as in routine clinical practice. Therefore, the AI evaluation will not alter the treatment to be applied to the patient, the intervention technique, or clinical decisions in any way.