Diagnostic X-Ray

White paper

Using landmark identification in AI enabled 'Smart Collimation Thorax' to empower radiographers and to personalize patient care

A new approach to chest X-ray imaging

Every year, 3.1 billion diagnostic exams, like X-rays, are performed globally[1]. Many X-ray exams are upright standing chest images in radiography rooms. Radiographers handle these exams repetitively, manually setting the system height and adjusting collimation for each patient individually, following the ALARA (As Low As Reasonably Achievable) principle. They rely on their training and experience to position the patient's internal anatomy correctly for Posteroanterior (PA) and Lateral (LAT) chest images. Insufficient training and experience can result in positioning or collimation errors, leading to rejected images. In a study by Little et al[2] positioning/collimation turned out to be the most common reject reason, accounting for 67.5% of rejected images (of overall rejection rates ranging from 13% to 24.5%). This was followed by incorrect technique (14.4%) and patient motion (8.1%). Repeating these exams to correct errors further strains radiographers' time and resources, exacerbating their already high workload. This growing burden highlights the increasing demand for automation and workflow solutions in radiography.

Automation could help streamline repetitive tasks, reduce errors, and improve image quality, thus decreasing the need for repeat exams. In fact, 23% of technologists believe that automation could make certain tasks more efficient[3], offering a potential solution to ease the pressure on radiographers and enhance the overall efficiency of diagnostic imaging.

Smart Collimation Thorax- an AI enabled feature to provide personalized detector height alignment and collimation proposals for upright standing chest exams

Philips is addressing these challenges by developing tools to support radiographers in their routine workflows. Smart Collimation Thorax (SCT) is one of these tools, based on Artificial Intelligence (AI), and offers assisted detector height alignment and collimation proposals for upright standing chest X-ray exams in adult patients.

This document

This paper describes the development and testing of the AI models used in Smart Collimation Thorax. In the first section, the scientific development (training and validation) and the data used for development and for testing are described. Next, the methodology to test the performance of these models is outlined, with results then provided. This paper then provides a summary and discussion. It concludes with outlining the workflow results achieved through use of SCT from a separate study in a simulated environment with 12 radiographers.

AI Models in Smart Collimation Thorax

Detector height and collimation prediction by SCT models

The SCT feature includes two sub-features:

- Assisted detector height alignment: offering a personalized proposal for the height of the wallstand detector, based on the patient's anatomy (available for chest PA views)
- Assisted Collimation: offering a personalized proposal for the collimated area, based on the patient's anatomy (available for chest PA and LAT views)

Hence, SCT provides the system user with a proposal for an individualized detector height alignment adapted to the patient's height and a collimation field adapted to the estimated lung field of the respective patient.

The SCT feature is based on multiple AI models, which detect patient specific landmarks that are indicative of the extent of the lung and predict the parameters of interest: the detector height and the patient's lung field. The final proposal is based on the following steps:

1. As input, these models use a depth image from a 3D camera integrated into the collimator at the point of time of activating SCT and predict patient specific landmarks.
2. When activating the Assisted detector height alignment, a detector height proposal is directly derived from the patient specific landmarks. For Assisted Collimation, the patient's lung field (lung bounding box) is first predicted based on the detected landmarks. Subsequently, margins around the lung field and geometrical system restrictions are considered in the final collimation proposal.
3. Finally, plausibility checks are performed. If these checks are passed, the detector height / collimation is proposed to the user by SCT. If needed, these proposals by SCT can be adapted manually by the system operator.

This approach is illustrated for Assisted Collimation in Figure 1, showing exemplary depth images (top: PA, bottom: LAT) as well as the landmark prediction and collimation proposal. All three steps are visualized:

1. The left column shows the input- the depth image of the patient from the camera view.
2. The middle column shows the depth image of the patient from a focal point of view including detected landmarks.
3. The right column shows the depth image of the patient from a focal point view including proposed collimation by SCT, which is predicted based on the detected landmarks.

More detailed information on the models is provided in[4].

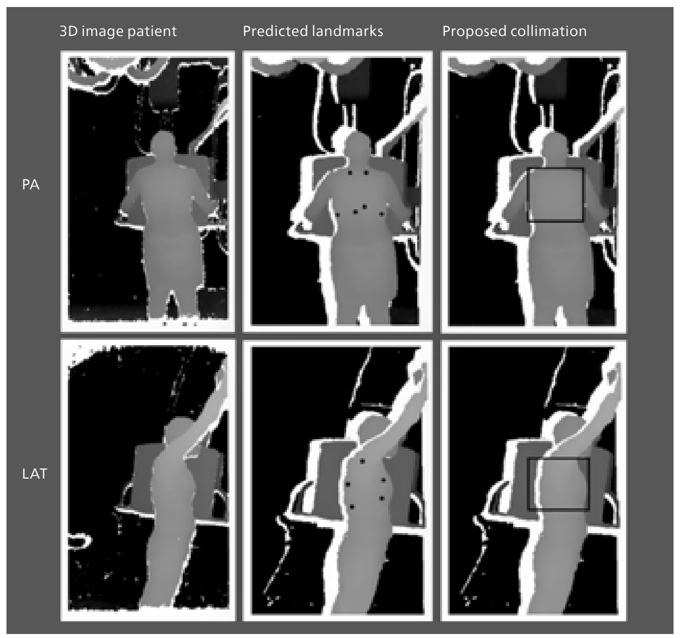

Figure 1: Exemplary 3D images (PA and LAT view) showing landmark prediction and collimation proposal.

Model development

In various development cycles, the models were trained and validated (development stage). Based on the validation performance results, the hyperparameters of the models were optimized and the generalizabiliy of the models on unseen data sets was estimated prior to the final evaluation. The performance of the final models was tested using a completely unseen test data set (testing stage). Below, a description of the data used for both stages (development and testing) is provided.

Data used for development and testing

The data used for development and testing was collected at six clinical sites from five different countries in Europe and two sites in the United States of America. To achieve high data quality, multiple sites were selected with a broad geographical distribution. This way, a high variability of system settings and ways of working was considered. Upright standing chest exams were collected during routine clinical practice from adult patients performed on the DigitalDiagnost C90 X-ray system with an integrated 3D depth camera. The acquired data contains depth camera sequences and X-ray images of PA and LAT views from over 3000 patients. The data was collected during clinical routine to ensure a wide variety of patient characteristics, for example in terms of sex, age and Body Mass Index (BMI). Since LAT images with different tube head angles were collected, the models can process data from a rotated tube head.

Model training was based on 2274 PA views and 2148 LAT views, while 279 PA views and 269 LAT views were used for validation. The test data set for final evaluation contained 755 PA views and 586 LAT projections from both inpatient and outpatient settings. Exemplary data sets are shown in Figure 2. This figure also shows examples of a rotated tube head, as described above.

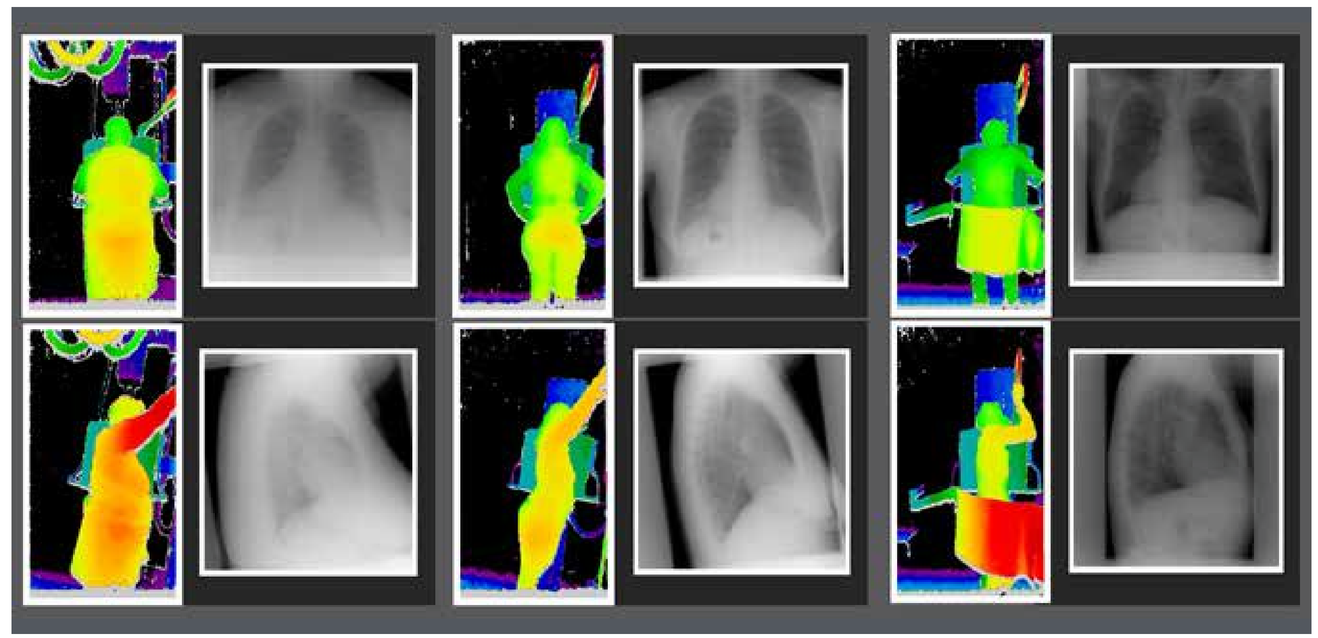

Figure 2: Exemplary data sets (PA and LAT views) collected at several clinical sites in Europe including 3D image (depth information displayed via color gradation) and corresponding X-ray image.

Ground truth

To enable development and testing of the AI models, ground truth was generated. According to clinical guidelines (American College of Radiologists- ACR) the collimation should include both lung apices and the costophrenic sulci [5]. Ground truth is defined as the lung bounding box which is in line with the clinical guidelines and is equivalent to the minimum collimation to cover the lung field. For this purpose, anatomical landmarks were annotated on the collected X-ray images by international clinical experts, radiographers who are certified to acquire X-ray images in clinical settings. For model training, the annotated landmarks are mapped onto the 3D image and used as input parameters (see Figure 3).

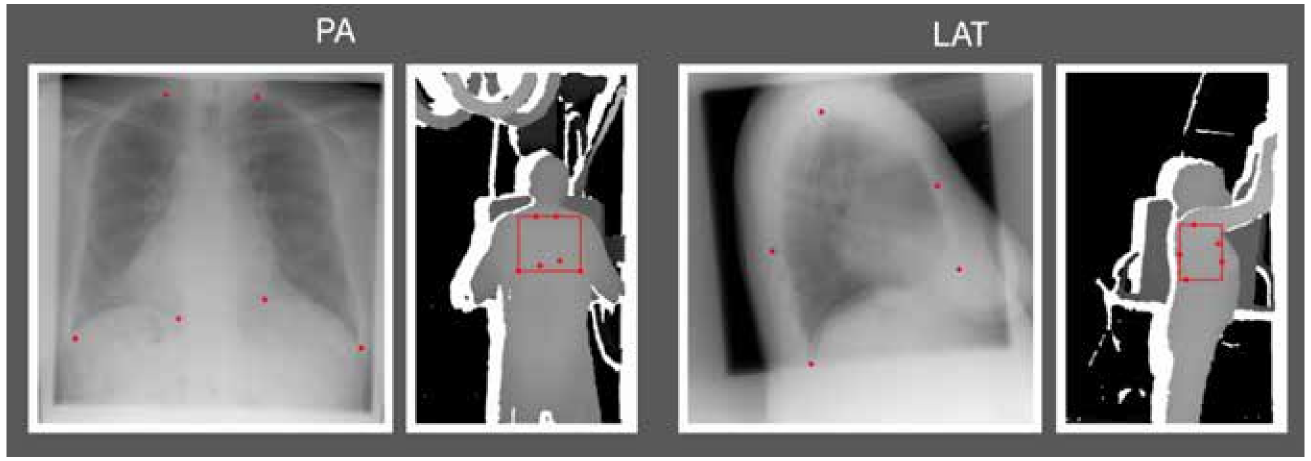

Figure 3: Exemplary 3D and X-ray images (PA and LAT view) to visualize annotation and model training input. Left side: collected X-ray image (collimation set by user) including landmarks annotated before training. Right side: 3D image of patient from focal point view showing landmarks mapped onto 3D image (which is used as training input) and lung bounding box.

Methods for testing the performance of the models

Retrospective data analysis on the collected test dataset was conducted to test the performance of the models. This testing included claim substantiation. The detector height proposal by SCT was compared to the detector height chosen by the system user during data collection. Correspondingly, the collimation proposal by SCT (Assisted Collimation) was mapped onto the X-ray image and compared to the collimation set by the system user for the respective data set. The detector height and the collimation set by the operator were recorded by geometrical sensors and are available in the meta data of the collected data sets. Minimum sample size for testing has been calculated and was met.

Detector height alignment performance testing

It was tested whether the proposed detector height alignment by SCT places the wallstand detector equally often in an appropriate imaging position as the user. The number of height settings where the upper or the lower border of the lung field (lung bounding box) are not on the detector, are counted as inappropriate positions. These are used for comparison between the user height alignment and the detector height proposal by SCT.

Collimation parameters analyzed

The aim of the evaluation was to show that the proposed collimations by SCT are at least non-inferior to the collimations set by the user. The following parameters were investigated regarding the collimation: *unnecessary X-ray exposed area, over collimation, uniformity, first time right collimations*. The definitions of these performance parameters are described below.

- The area exposed beyond the lung bounding box is considered *unnecessarily exposed area*. To test this parameter, both the area beyond the lung bounding box of the collimation set by the user and the collimation proposed by SCT were calculated and compared.
- *Over collimation* refers to collimation settings which result in an X-ray image that does not cover the entire lung field, i.e. the lung is cropped (cut off) on the X-ray image. The number of cases with over collimation was counted for the user collimation and the collimation suggested by SCT and compared.
- *Uniformity* refers to the extent in which collimations are uniform. Uniform collimations means that the distances between each collimation border and the respective lung bounding box border are of a similar magnitude from image to image. The standard deviations of the distances are calculated, considering the different image sides and the clinical sites of the test data set, and aggregated to an overall uniformity measure.

A visualization of all three performance parameters is provided in Figure 4

1) The left image shows an example of less unnecessary X-ray exposed area; the area that was unnecessary exposed by the user in comparison with the proposal by SCT leads to less unnecessary exposed area.
2) The center image shows an example of a cropped lung due to over collimation by the system user
3) The right image illustrates the concept of uniformity: blue arrows indicate the distances between the lung bounding box to the respective collimation proposed by SCT on all four image sides, which are used to assess the parameter uniformity.

First time right collimation is defined as a collimation which neither shows over collimation nor a larger unnecessarily exposed area comparing user collimation and the collimation proposal by SCT. According to ACR guidelines 'the radiographic beam should be appropriately collimated to include the structures listed while limiting exposure of the remainder of the patient' [5]. To investigate this parameter, the collimation proposed by SCT was compared with the user collimation, considering over collimation and unnecessary exposed area.

Failure analysis

A failure analysis was performed to provide more transparency on how often SCT does not provide a proposal. In case the model cannot detect landmarks with high confidence, or the plausibility checks performed on the predicted collimation field are not passed, SCT prevents incorrect results and does not propose a detector height or collimation. In such cases, the system provides a message to the user indicating that no prediction could be made. Failure reasons can be multiple, including another person being in the field of view, or a prediction that deviates too much from usual proposals.
The failure rate is calculated as the ratio of the number of failed cases to all cases evaluated and are provided for both sub-features; Assisted detector height alignment (PA view) and Assisted Collimation (PA and LAT view). In addition, the failed cases have been reviewed manually by technical experts, and the reasons for failure have been investigated.

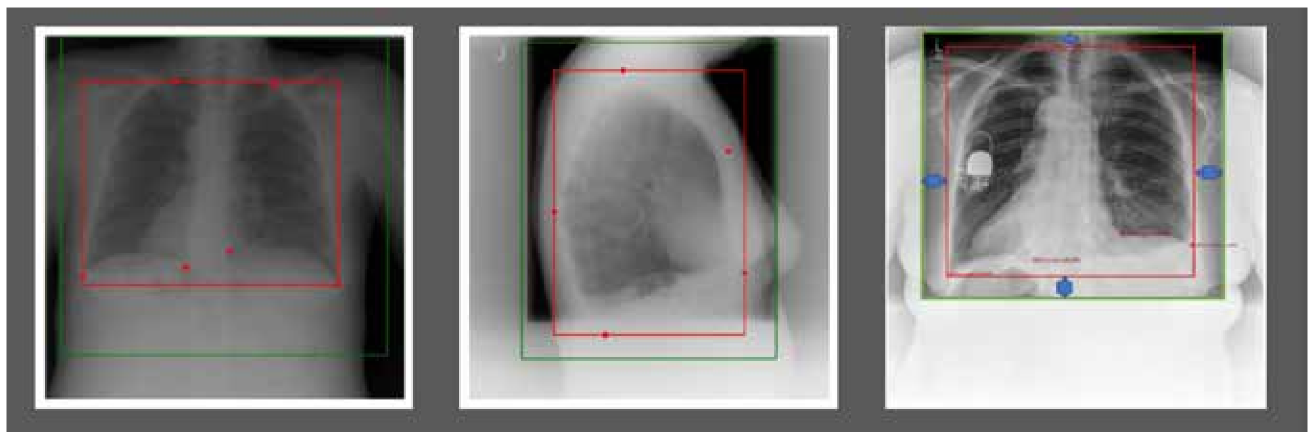

Figure 4: Exemplary X-ray images from collected data sets including lung bounding box (in red) for visualization purposes and proposed collimation by SCT (in green).

Test results of the performance analysis

In this section, the results for all performance parameters of SCT as described in section 3, and the failure rates for the sub-features Assisted detector height alignment (PA view) and Assisted Collimation (PA and LAT view) will be provided.

Results – detector height alignment

The comparison between SCT and the user regarding detector height alignment was performed using a chi-square method. An adjusted one-sided alpha of 0.0083 was used in this analysis. Non-inferiority testing was performed with a non-inferiority margin of 0.015 (N=645). SCT proposed 3 positions in which the entire lung field cannot be imaged on the detector (0,47% of the total cases) and the user 8 (1,24% of the total cases). The result for non-inferiority testing is significant with $p<0.0001$. This means the proposed detector height alignment by SCT places the wallstand detector equally often in an appropriate imaging position as the user.

Results – unnecessary exposed area

To investigate the parameter unnecessary X-ray exposed area, a paired t-test was performed. An adjusted one-sided alpha of 0.0083 was used in these analyses. The mean values of the unnecessarily exposed area were calculated for both the collimation proposal by SCT and the user collimation. The difference between these means is statistically significant with a p-value of $p<0.0001$, for both PA views (N=644) and LAT views (N= 474). Therefore, it can be stated that SCT proposed collimations show a significant decrease in unnecessary X-ray exposed area for PA as well as LAT views.

The test results are shown in Table 1 for the PA projection and in Table 2 for the LAT projection.

	Mean (cm²)	Mean difference (SCT – user) cm²	98.34% confidence intervals	p-value
SCT	653.52			
User	789.90			
Statistical comparison		-136.38	(-152.20; -120.57)	<.0001

Table 1: Statistical testing of the unnecessarily exposed area (area beyond the lung bounding box) for PA projections

	Mean (cm²)	Mean difference (SCT – user) cm²	98.34% confidence intervals	p-value
SCT	781.52			
User	932.91			
Statistical comparison		-151.39	(-170.61; -132.16)	<.0001

Table 2: Statistical testing of unnecessarily exposed area (area beyond the lung bounding box) for Lat projections

Results – over collimation
The number of cases with over collimation were compared using a chi-squared method. No adjustment of alpha was made in this comparison.

Superiority testing for PA views (N=634) shows a p-value of 0.03 for the number of cases with over collimation for the algorithm (n=17) versus the user (n=36) with a 95% two-sided confidence interval (-0.0519; -0.0080). Consequently, SCT proposed collimations lead to statistically fewer cases of over collimation for PA views.

Superiority testing for LAT views (N=457) shows a non-significant difference between the numbers of cases; the number of cases with overcollimation was higher for the algorithm (n=43) versus the user (n=5) (95% two-sided confidence interval (0.0547; -0.1116). Consequently, these analyses imply that SCT proposed collimations do not lead to fewer cases of over collimation for LAT views.

Results – uniformity
If the overall uniformity measure is less than unity, the collimation proposed by SCT has a lower variability than the collimation set by the user, on average across all hospitals included in the test data set and sides of the X-ray image. In that case, it is shown that SCT proposed collimations are more uniform than user collimations. This section provides the overall uniformity measure for both views.

The overall uniformity measure for the PA view (N=644) is 0.8239. As this value and the upper bound of the 95% CI (0.7562; 0.8837) are below one, it is demonstrated that SCT proposed collimations show statistically more uniformity for PA projections. For the LAT view (N=474), the overall uniformity measure is 0.9544 which is below one indicating that SCT proposed collimation is more uniform for the LAT view as well. However, the result is not statistically meaningful with a 95% confidence interval (0.8818; 1.0384), as the upper bound is slightly above one.

Results – first time right collimation
When comparing the number of cases of first time right collimations, a 95% confidence interval of the difference is given using a normal approximation method. Table 3 shows the results for PA views (N=634). SCT resulted in 484 (76.34%) first time right collimations, the user performed 110 first time right collimations (17.35%). The difference is 58.99% with a 95% confidence interval of (54.56%; 63.42%), which is statistically meaningful. Thus, it is statistically more likely to have first time right collimations for the PA view.

	Number (%) of cases of first time right collimations	Number (%) of cases of No first time right collimations	Total Cases	Difference	95% two-sided confidence intervals
SCT	484 (76.34%)	150 (23.66%)	634		
User	110 (17.35%)	524 (82.65%)	634		
Statistical comparison				0.5899	(0.5456; 0.6342)

Table 3 Statistical testing of first time right collimations for PA views

Table 4 shows the results for LAT views (N=457). SCT resulted in 329 (71.99%) first time right collimation proposals, while the user performed 84 first time right collimations (18.38%). The difference is 53.61%, with a confidence interval of (48.17%; 59.05%) which is statistically meaningful. The analysis showed that with SCT, it is statistically more likely to have first time right collimations for the LAT view.

	Number (%) of cases of first time right collimations	Number (%) of cases of No first time right collimations	Total Cases	Difference	95% two-sided confidence intervals
SCT	329 (71.99%)	128 (28.01%)	457		
User	84 (18.38%)	373 (81.62%)	457		
Statistical comparison				0.5361	(0.4817; 0.5905)

Table 4: Statistical testing of first time right collimations for LAT views

Results – failure rates
Failure rates are reported in Table 5. Investigating the reason for failure, it became clear that the main failure reason for Assisted Collimation for LAT views is that no detection was possible, meaning that too few landmarks were detected, or the constellation of detected landmarks was implausible. Manually reviewing the failure cases, it was confirmed that the landmark prediction was correctly identified to be erroneous as the landmarks were not capturing the lung field or the field size would exceed the detector area. In these cases, SCT correctly did not deliver a proposal.

SCT functionality	Total number of cases	Number of failed cases	Failure rate in %	95% confidence intervals
Assisted Collimation PA views	755	3	0.40%	(0.0000; 0.0085)
Assisted Collimation LAT views	586	22	3.75%	(0.0222; 0.0529)
Assisted Detector Height Alignment	755	3	0.40%	(0.0000; 0.0085)

Table 5: Results of the failure analysis

Summary and discussion

Summary
In this white paper, we described the development and testing of the AI models used in Smart Collimation Thorax. Performance testing was done for both sub-features; Assisted Collimation and Assisted detector height alignment. Performance testing showed a superior performance by Assisted Collimation compared to the system user, for most of the performance parameters examined. The performance of Assisted Detector Height Alignment is non-inferior to the user with statistical significance. This means SCT places the wallstand detector equally often in an appropriate imaging position as the user. Failure analysis demonstrated that SCT provides a proposal for most patients, but in few cases it cannot, of which the user is informed.

Smart Collimation Thorax – Results on Performance Evaluation

- The proposed detector height alignment by SCT places the wallstand detector equally often in an imaging position for each patient in which the entire lung field can be imaged on the detector, as the user
- Smart Collimation Thorax proposed collimations show a significant decrease in unnecessary X-ray exposed area for Posterior Anterior (PA) as well as Lateral (LAT) views
- Smart Collimation Thorax proposed collimations lead to fewer cases of over collimation for Posterior Anterior views
- Smart Collimation Thorax proposed collimations show more uniformity for Posterior Anterior (PA) views
- With Smart Collimation Thorax, it is more likely to have first time right collimations, both for Posterior Anterior (PA) as well as Lateral (LAT) views

Discussion
As described in section 2, to achieve a high data quality, multiple sites were selected with a broad geographical distribution. This way, a high variability of system settings and ways of working was considered. Data have been collected during clinical routine to ensure a wide variety of patient characteristics, for example in terms of sex, age and BMI. In the final data set for the performance testing of the algorithm, 51% of patients were women, 37% of patients were aged between 45 and 64, and 37% were aged 65 or older. Patients in this data set had a BMI ranging from below 18.5 kg/m^2 to over 30.5 kg/m^2. In this white paper, the following performance parameters have been investigated for SCT, unnecessary X-ray exposed area, over collimation, uniformity and first time right collimations. It could be shown with statistical significance that compared to the user, SCT proposed collimations show a decrease in unnecessary X-ray exposed area for both PA and LAT projections.

Regarding over collimation, a statistically meaningful decrease was observed for the PA view. This could not be shown for the LAT view, indicating a way of working by the system users that focusses on avoiding over collimation and considering that the field of view can be reduced after exposure. This phenomenon has been described in literature as 'collimation creep'[6]. Collimations by SCT statistically display more uniformity for PA projections as compared to the user. For LAT views, results indicated that SCT proposed collimations are more uniform, but the result is not statistically meaningful. It is to be expected that improved uniformity of X-ray images will facilitate reading of images.

The comparison between SCT and the user in terms of first time right collimations showed for both projections that the probability of first time right collimations is statistically higher using SCT than applying a collimation set by the user. This result underlines the potential for quality improvement by integrating SCT into the standard clinical workflow.

In future studies, real-world evidence might provide valuable insights into the actual use and effectiveness of SCT. By examining data from clinical settings, it is possible to assess the impact of these tools on reject rates, offering a clearer picture of how they contribute to reducing errors and improving image quality. Additionally, real-world evidence can help quantify the health economic benefits of SCT, particularly in terms of time savings for radiographers, which can translate into more efficient resource utilization, lower operational costs, and improved patient throughput across healthcare facilities.

Smart Collimation Thorax: Using landmark identification in AI enabled Smart Collimation Thorax to empower Radiographers and personalize Patient Care in chest X-ray imaging

Both sub-features of SCT, Assisted Detector Height Alignment and Assisted Collimation, were successfully tested for PA and LAT views. This analysis showed the potential of SCT in terms of performance improvement in detector height alignment and collimation.

SCT addresses key challenges in radiology, such as varying levels of staff training and experience as well as improper collimation. The functionalities can therefore be a valuable support for radiographers supporting their workflow during upright standing chest exams and for radiologists in daily practice.

In this analysis, a comparison was made between the system user and the SCT functionalities. In clinical practice, both SCT and the user cooperate. The user can benefit from the support provided by a technology that provides a detector height and collimation specific to the predicted position of the patients' lung and remains the final decision maker. The proposal can be overridden by the user, if the proposal appears not plausible or if a different setting is preferred.

Combining the data-based prediction by SCT with the skills and experience of a system user by using SCT consciously, it is to be expected that even better performance results can be achieved.

Smart Collimation Thorax – impact on workflow

As part of a Philips internal user study, 12 radiographers were invited to a Philips lab environment to use the SCT functionality and provide their feedback. After a short introduction and training, all participants were requested to perform a simulated PA chest exam with and without SCT and to answer some short questions. The following experiences / feedback have been provided- see Figure 5:

Smart Collimation Thorax – Results on Workflow improvements (simulated use with 12 radiographers)

- Smart Collimation Thorax reduces exam time up to 35 seconds -resulting in a time saving up to 20 minutes daily for your medical team[1]
- 11 out of 12 users (91%) think Smart Collimation Thorax can reduce human error caused by manual and repetitive tasks
- 11 out of 12 users (91%) like triggering Smart Collimation Thorax from the wall stand control panel as it enables them to stand with their patient during positioning and collimation
- 10 out of 12 users completed a PA chest X-ray exam faster with the use of SCT, than without the use of SCT.

1 Compared to not using SCT on the Radiography 7300 C, validated by 12 clinicians in a Philips' development environment. Daily time saving calculation based on 35 adult upright chest patients per day. Results may vary. The average Time saving is 8.1 sec.

Figure 5: Lab study with 12 radiographers- workflow results

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