REVIEW PAPER, REVIEW ARTICLE (PREGLEDNI RAD)

Impact of Pitch Factor on CT Examination Quality

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Abstract

Aim: The objective of this study is to determine whether changing the pitch factor on CT devices affects the quality of the CT scan.

Methods: By using a syntax of keywords and searching the literature, we found 170 potentially relevant articles. Following the application of exclusion and inclusion criteria, we reviewed the complete texts of 39 articles, of which 20 were finally included in the analysis because they met the established criteria for image quality and radiation dose in relation to the pitch factor.

Results: Low Pitch MSCT vs. High Pitch DSCT (11 studies): In 8 studies (72.7%), it was found that the subjective image quality was the same. In 3 studies (27.3%), subjective image quality was subjectively lower with low pitch MSCT than with high pitch DSCT. Crucially, all 11 studies confirmed that a lower radiation dose was used with high pitch DSCT, and a higher dose was used with low pitch MSCT. Low Pitch vs. High Pitch MSCT (3 studies): All three papers found that the subjective image quality was equal regardless of whether low or high pitch was used. In all three cases, low pitch MSCT used higher radiation doses to achieve the same image quality as high pitch MSCT. Low Pitch vs. High Pitch DSCT (6 studies). In three studies, image quality was found to be the same, and in three cases, the image quality was subjectively lower with low pitch DSCT. However, in all 6 cases of low pitch DSCT, higher radiation doses were used compared to high pitch DSCT.

Conclusion: This research did not find a statistically significant influence of the pitch factor on image quality in multi-slice CT devices, but it confirmed that a high pitch factor significantly contributes to the reduction of the patient's radiation dose.

Keywords: computed tomography, pitch factor, CT scan

1. Introduction

The speed of the table movement is an important scanning parameter managed by radiologic technologists when determining CT scanning protocols. The concept known as the pitch factor is an index that denotes the length of the table movement during a single tube rotation. The pitch factor is closely related to both image quality and patient dose. Generally, reducing the pitch factor increases image quality but also increases the radiation dose, while a lower radiation dose is achieved by increasing the pitch factor, simultaneously leading to a potential reduction in image quality [1]. In multi-slice CT devices (MSCT), increasing the pitch factor does not reduce image quality proportionally, unlike in single-slice CT devices [2]. Recent development of the high pitch (p=3.2) cardiac and vascular imaging technique enables table movement speeds greater than 430 mm/s. This technique is also known as "Flash Mode." Today, the dual-source high pitch protocol is standard for imaging thoracic and abdominal organs in departments where the technology is available. This protocol neutralizes motion artifacts caused by breathing and heart activity, achieving better image quality while simultaneously reducing the radiation dose, which is an imperative of modern radiological diagnostics [3, 4].

Research by Beeres and colleagues in 2015 showed that the high pitch technique is not equally desirable for scanning all anatomical regions. Specifically, the amount of ionizing radiation delivered by the high pitch technique for abdominal organs was found to be insufficient for adequate diagnostic image quality [5].

The purpose of this research is to determine whether image quality is compromised by increasing the pitch factor in single-source CT devices (MSCT) and dual-source CT devices (DSCT) that are most commonly available in radiology departments. In accordance with good radiological practice and the fundamental principles of radiation protection, the application of the lowest possible patient dose while preserving image quality and diagnostic information is desirable.

1.1. Definition of the Pitch Factor

According to the original definition for a single-slice CT device (SSCT), the pitch factor is the length of table movement per single tube rotation divided by the slice thickness, which corresponds to the beam width (Beam Pitch), according to the formula [6]:

$$P \quad \frac{\mathrm{T}}{\mathrm{W}} \qquad P \quad \frac{\text{slice thickness (mm) table feed per rotation } 360^{\circ}}{\text{beam width (mm)}}$$

Source: https://pubmed.ncbi.nlm.nih.gov/12110725/

A slice thickness of 5 mm and a table movement of 7.5 mm per tube rotation give a pitch of 1.5. Since slice thickness is equivalent to the beam width in SSCT devices, a pitch factor of 1 means that the beam width during rotation continues immediately next to the beam width of the previous rotation. This is referred to as the Helical Pitch. A pitch factor greater than 1 indicates a gap between the beams of the previous rotation, and a smaller pitch factor indicates overlapping X-ray beams (Overlapping), which simultaneously means a double dose to the scanned body part, which is unacceptable in clinical practice [6].

The formula for calculating the pitch factor for MSCT and DSCT is:

$$P \quad \frac{\mathrm{T}}{\mathrm{nxT}} \qquad P \quad \frac{\text{tabel feed (mm)per rotation } 360^{\circ}}{\text{total beam collimation (mm)}}$$

Source: https://pubmed.ncbi.nlm.nih.gov/12110725/

According to this definition, the pitch factor is calculated as follows:

Pitch =15 mm / (4×5 mm) = 0.75. Since the beam pitch is the most accurate formula for calculating the table movement speed, it is applicable to all CT devices [7].

1.1.1. Pitch Factor and "Z-Sampling" in MSCT Devices

Since data in helical scanning mode is collected at a specific angle (depending on the spiral pitch), linear interpolation algorithms (Linear Interpolation, LI) are used to obtain slices in the orthogonal axial plane. The most commonly used algorithms are 360∘ LI and 180∘ LI, which allow for the reconstruction of slices in the orthogonal axial plane, similar to sequential scanning [8]. The interpolation algorithm enables scanning with a larger pitch factor, which results in greater table movement and greater body coverage in a shorter time, without compromising longitudinal resolution. In CT devices with a larger number of detectors (sixteen or more), the problem of cone beam artifacts arises. Because the X-rays do not fall parallel onto the detectors during tube rotation, their overlap generates a cone beam artifact. The Z-filter interpolation algorithm is used to reduce cone beam artifacts and to reconstruct axial slices in MSCT devices [9]. Dynamic focus technique improves longitudinal resolution and eliminates rotation artifacts, such as "windmill" artifacts, regardless of the pitch factor size. Thanks to this technology, it is possible to perform the most demanding diagnostic procedures with a high pitch factor without compromising quality [10].

1.1.2. Influence of Pitch Factor on Scanning Parameter

The various factors influencing image quality, such as the signal-to-noise ratio (SNR) on the CT image, are most easily explained through the quantity of X-ray photons reaching each individual detector. To optimize the scanning protocol, we must consider the relationship between scanning parameters (number of reconstruction layers according to detector collimation, table movement, kilovolts (kV), milliampere-seconds (mAs), tube rotation speed) and image parameters (slice thickness, SNR, and contrast-to-noise ratio, CNR). Higher kV values allow a greater amount of radiation to penetrate the patient to the detectors. A greater mAs value is proportional to slice thickness, in terms of a larger quantity of radiation photons collected on the detectors. A faster tube rotation speed achieves a shorter radiation sampling time on the detectors, but image noise primarily depends on the number of X-ray photons on the detectors, without neglecting the reconstruction filters used. When the amount of radiation is increased, i.e., the product of the radiation quantity and the scanning time (mAs), the image quality increases, and the image noise decreases, simultaneously increasing the radiation dose. The term effective mAs is defined as the product of the delivered photon quantity (mA) with the tube rotation time (s), divided by the pitch factor size (mA×s/pitch). Increasing the pitch factor increases image noise, and the system automatically increases the tube heating current to compensate for the increased pitch factor. If the effective mAs does not change, image quality and radiation dose remain unchanged [11].

1.2. Doses in CT Diagnostics

Specific dose quantities are used in Computed Tomography to describe patient exposure. Computed Tomography Dose Index (CTDI) measures the dose along a series of slices along the patient's longitudinal axis, and Dose-Length Product (DLP) represents the total dose delivered during the entire examination. We use effective dose to compare doses with other sources and devices that produce ionizing radiation [12]. CTDI represents the average absorbed dose along the Z-axis from a series of continuous patient radiation exposures. It is measured from a single axial CT scan (one X-ray tube rotation) and is calculated by dividing the integrated absorbed dose by the beam width.

In theory, CTDI estimates the average absorbed dose within the central part of the scanned volume, which relates to the Multiple Scan Average Dose (MSAD) and requires multiple radiation exposures. For CTDI measurements, two polymethyl methacrylate (artificial glass) cylinders of 14 cm length are standardized. A 16 cm diameter phantom is used for head CTDI values, and a 32 cm diameter phantom for the body. To display the radiation dose for a specific protocol that always includes several scans, the overlap and gap in the radiation dose resulting from successive rotations of the radiation source are key. This is addressed by introducing a dose quantity called Volume CTDI (CDTIvol). CTDIw represents the average absorbed dose in the x and y directions, while CTDIvol represents the average absorbed dose across the x, y, and z directions, which is dependent on the pitch factor size according to the formula: CTDIvol = CTDIw/pitch. DLP represents the product of the dose index and the scan length (L), according to the formula: DLP = CT-DIvol×L. The effective dose is not measured directly, but is obtained by reading the DLP value on the device and multiplying it by a specific weighting factor. The effective dose is expressed in millisieverts (mSv).

2. Aim of the work

The objective of this research is to determine how changing the size of the pitch factor on CT devices affects the quality of the CT scan. The purpose of this research is to provide radiologic technologists and radiology specialists with unambiguous, evidence-based answers to select the optimal pitch factor size for achieving the best possible image quality while prioritizing the minimal delivered radiation dose.

3. Methods and Materials

3.1. Literature Search Strategy

A comprehensive literature search was conducted from March to August 2018 to identify all relevant studies. The search was initiated in the bibliographic databases expected to contain articles related to the pitch factor in biomedicine and healthcare: MEDLINE/PubMed and Web of Science (WoS).To identify randomized controlled trials, a combination of controlled vocabulary and keyword searching was used in MEDLINE with the following syntax: ((((pitch factor*)) AND (computed tomography OR dual source*)) AND (radiation OR dose) AND (image quality* OR dose*)). The following terms were used for a customized search strategy, combined with the Boolean operators AND / OR: pitch factor, computed tomography, dual source CT, low pitch, high pitch, image quality, dose.

3.2 Inclusion and Exclusion Criteria

The study included only Randomized Controlled Trials (RCTs**)** and comparative prospective studies conducted from March 2003 to August 2017.

Further inclusion criteria were: Studies comparing high and low pitch values in multi-slice CT and dual-source CT devices; English-language articles only; Categorical description based on the subjective assessment of image quality by at least two reviewers; The existence of numerical data based on objective measurements of image quality (SNR, CNR, HU units); Numerical data on the radiation dose.

The exclusion criterion were studies comparing the relationship of the pitch factor in single-slice CT devices.

3.3. Data Selection and Study Extraction

Study selection was performed using the PRISMA protocol (displayed in Figure 1). Titles and abstracts were reviewed, followed by the assessment of full texts and data extraction, judging whether the study was suitable for inclusion based on the previously defined inclusion and exclusion criteria.

By using the keyword syntax and searching the literature, we found 170 potentially relevant articles. After applying the exclusion and inclusion criteria, we reviewed the complete texts of 39 articles, of which 20 were finally included in the analysis because they corresponded to the established criteria for image quality and radiation dose in relation to the pitch factor. The following study characteristics were collected: high pitch value, low pitch value, radiation dose value, qualitative assessment of image quality, type of CT device, number of subjects, year of publication, and country where the research was conducted. From the selected twenty studies, results regarding the

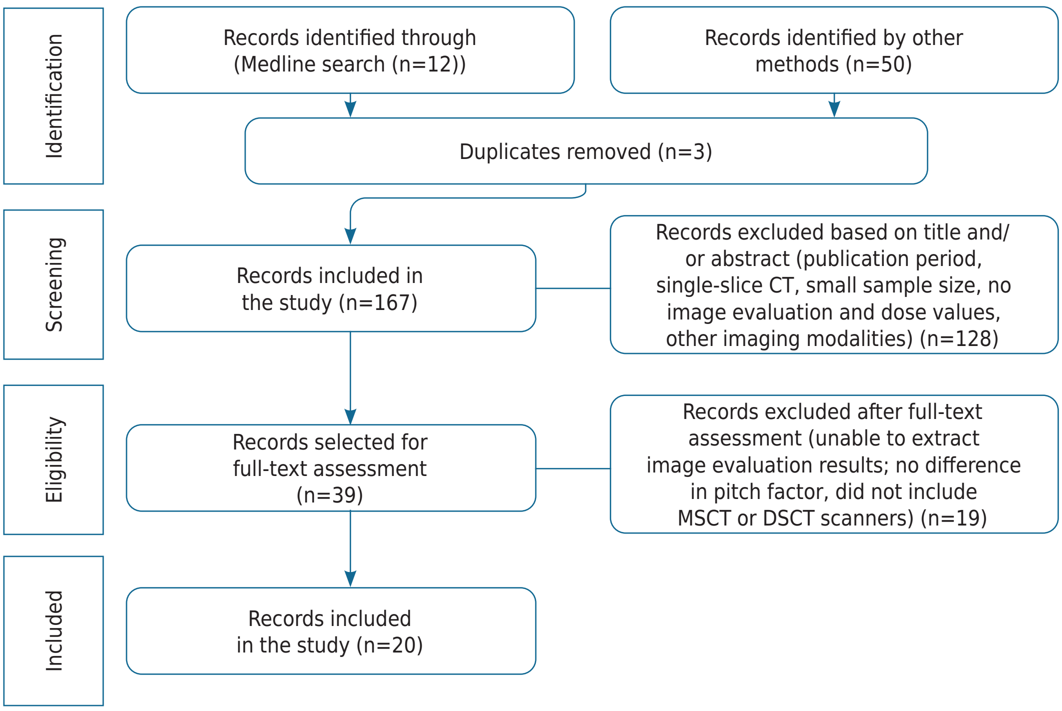

Figure1. Flowchart of the systematic review on the pitch factor's influence on CT imaging quality

influence of high and/or low pitch factor in multi-slice and dual-source CT devices on the predetermined outcomes of interest (radiation dose and qualitative assessment of image quality) were extracted and entered into MS Excel tables.

3.4. Data Analysis

For data analysis, the included studies were first grouped according to the type of device they compared: whether they compared the same type of device at different pitches (low pitch MSCT vs. high pitch MSCT, or low pitch DSCT vs. high pitch DSCT) or compared different devices at different pitches (low pitch MSCT vs. high pitch DSCT). Given that the main outcome was the subjective assessment of the resulting image quality, it was concluded that the extracted data were not suitable for meta-analysis, and a descriptive analysis of the obtained results was performed.

4. Results

Of the 20 studies included in the research:

- 11 (55%) studies compared the influence of high and low pitch on MSCT and DSCT devices.
- 6 (30%) studies compared only high and low pitch on DSCT devices.
- 3 (15%) studies compared only high and low pitch on MSCT devices.

Table 1. Comparison: Low Pitch MSCT vs. High Pitch DSCT (11 Studies**)**

	MSCT[1] (n[3] =11)	DSCT[2] (n=11)
	Pitch L[4]	Pitch H[5]
Image Quality – Lower	3[6] (27,3%)	0
Image Quality – Same	8[7] (72,7%)	8[7] (72,7%)
Image Quality – Higher	0	3[6] (27,3%)

[1] **MSCT** – multi slice computed tomography
[2] **DSCT** – dual source computed tomography
[3] **n** – number of studies
[4] **L** – pitch low
[5] **H** – pitch high
[6] **The** data is the same, but the image quality is higher/ lower compared to the other device
[7] **The** data is the same

Dose Comparison (11 Studies): In all eleven studies, a lower radiation dose was used with high pitch DSCT, and a higher radiation dose was used with low pitch MSCT.

Table 2. Comparison Low Pitch MSCT vs. High Pitch DSCT (11 Studies) in relation to the radiation dose

	MSCT[1] (n[3] =11)	DSCT[2] (n=11)
	Pitch L[4]	Pitch H[5]
Lower dose	0	11[6]
Same dose	0	0
Higher dose	11[6]	0

[1] **MSCT** – multi slice computed tomography
[2] **DSCT** – dual source computed tomography
[3] **n** – broj radova
[4] **L** – pitch low
[5] **H** – pitch high
[6] **The** data is the same

Summary: In 8 studies, subjective image quality was the same. In 3 studies, high pitch DSCT with a lower radiation dose yielded subjectively better image quality than low pitch MSCT with a higher dose.

Table 3. Comparison: Low Pitch MSCT vs. High Pitch MSCT (3 Studies)

	MSCT[1] L[2] pitch (n[4] =3)	MSCT H[3] pitch (n[4]=3)
Image Quality – Lower	0	0
Image Quality – Same	3	3
Image Quality – Higher	0	0

[1] **MSCT** – multi slice computed tomography
[2] **L** – pitch low
[3] **H** – pitch high
[4] **n** – number of studies

Dose Comparison (3 Studies): In all three cases, low pitch MSCT used a higher radiation dose to achieve the same image quality as high pitch MSCT**.**

Table 4. Comparison Low Pitch MSCT vs. High Pitch MSCT (3 Studies) in relation to the radiation dose

	MSCT[1] L[2] pitch (n[4] =3)	MSCT H[3] pitch (n[4]=3)
Lower dose	0	3
Same dose	0	0
Higher dose	3	0

[1] **MSCT** – multi slice computed tomography
[2] **L** – pitch low
[3] **H** – pitch high
[4] **n** – number of studies

Table 5. Comparison: Low Pitch DSCT vs. High Pitch DSCT (6 Studies)

Comparison	DSCT L[2] pitch (n[4] = 6)	DSCT H[3] pitch (n[4] = 6)
Image Quality – Lower	3 (50%)	0
Image Quality – Same	3	3
Image Quality – Higher	0	3

[1] **DSCT** – dual source computed tomography
[2] **L** – pitch low
[3] **H** – pitch high
[4] **n** – number of studies

Dose Comparison (6 Studies): In all six cases, low pitch DSCT used a higher radiation dose compared to high pitch DSCT.

Table 6. Comparison Low Pitch DSCT vs. High Pitch DSCT (3 Studies) in relation to the radiation dose

	DSCT L[2] pitch (n[4] =6)	DSCT H[3] pitch (n[4]=6)
Lower dose	0	6
Same dose	0	0
Higher dose	6	0

[1] **DSCT** – dual source computed tomography
[2] **L** – pitch low
[3] **H** – pitch high
[4] **n** – number of studies

Summary: In 50% of the studies, low pitch DSCT resulted in lower image quality than high pitch DSCT. However, in all 6 cases, low pitch DSCT used higher radiation doses to achieve image quality, even in the 50% of studies where the quality was rated as lower.

5. Discussion

New generations of CT devices using modern systems for automatic dose optimization (AEC) generally show that changing the pitch factor does not significantly affect the radiation dose or image quality. Available literature also suggests that radiation dose and noise are primarily determined by AEC system parameters specified by the device manufacturer [14]. The results of this study summarize the existing evidence on the impact of the pitch factor size on scanning quality, while considering the delivered radiation dose. Our research confirmed the hypothesis that increasing the pitch factor does not change the image quality. Furthermore, the study demonstrated that a high pitch method delivers a lower radiation dose when assessing image quality, which can be explained by the fact that most included studies (72.7%) compared low pitch MSCT with high pitch DSCT [16, 18, 19, 24, 28, 29, 30]. Our results are consistent with the research of Xu and colleagues in 2011, who found a significant reduction in radiation dose ($p < 0.05$) using a high pitch factor in DSCT devices while maintaining image quality [25]. In 27.3% of the results, image quality was rated as lower with low pitch MSCT than with high pitch DSCT [19, 22, 23]. This may be due to the fact that low pitch MSCT often scanned the thoracic region, where the natural motion artifacts (heart activity and breathing) resulted in poorer image quality. This contrasts with the research of Ghadir and colleagues in 2012, which showed that the high pitch factor in dual-source CT (128 DSCT) resulted in a lower radiation dose with preserved image quality compared to multi-slice CT (64 MSCT) for coronary artery imaging [32]. The results also suggest that image quality remained the same even when comparing the same type of device (two MSCT or two DSCT devices) in relation to the pitch factor, unlike the radiation dose, which varied [15, 17, 26, 27, 30, 31]. The obtained results align with expectations, as the studies used the standard high pitch scanning protocol for thoracic and abdominal organs. The outcome of the results in our research was confirmed based on both objective and subjective parameters of image quality. Image quality was assessed by measuring the Signal-to-Noise Ratio (SNR), the Contrast-to-Noise Ratio (CNR), and signal within Regions of Interest (ROI), which corresponds to attenuation coefficients measured in Hounsfield Units (HU). The subjective image quality assessment in the research involved the rating of two or more independent reviewers based on predefined criteria. Our research had some limitations. Only systematic reviews and meta-analyses were not included; the subjective image quality assessment did not include more than two independent reviewers in all studies; and the results of only two device groups were compared, regardless of their specific technical characteristics. The strength of the results would be increased by including other objective parameters that influence image quality in CT (Body Mass Index (BMI), length of the scanned body part, reconstruction algorithms, and kV/mAs values). Despite the limitations of our research, it is possible to offer specific proposals for future prospective research on the pitch factor according to CT device technical specifications, with an emphasis on achieving the lowest possible radiation dose (low dose), which remains a challenge in CT diagnostics.

6. Conclusion

Based on the obtained research results and a review of the available literature, the following conclusions can be drawn:

This research did not find a statistically significant influence of the pitch factor on image quality in multislice CT devices, but it confirmed that a high pitch factor significantly contributes to the reduction of the patient's radiation dose. When considering the application of low and high pitch factors in MSCT and DSCT, the subjective image quality was found to be the same, or image quality was subjectively better with high pitch DSCT. In all eleven studies comparing low pitch MSCT and high pitch DSCT, a lower radiation dose was applied for the patient with high pitch DSCT, and a higher radiation dose was applied with low pitch MSCT during scanning. Conclusively, high pitch DSCT used lower radiation doses even when comparing the same types of devices using low and high pitch factors. This research confirmed that the choice of pitch factor does not significantly affect image quality, in contrast to the patient's radiation dose. It can be concluded that by properly selecting the pitch factor, we can achieve image quality that meets the clinical question while simultaneously achieving a significant reduction in patient radiation dose.

All data in this paper are part of the results of the master's thesis „Impact of pitch factor on CT examination quality" written at the University Department of Health Studies, University of Split [33].

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Utjecaj *pitch* faktora na kvalitetu CT snimanja

Sažetak

Cilj ovog istraživanja je utvrditi utječe li se promjenom veličine *pitch* faktora kod CT uređaja na kvalitetu CT snimanja. U istraživanju je postavljena hipoteza da povećanjem *pitch* faktora ne utječemo na kvalitetu CT snimanja. Uporabom sintakse ključnih riječi te pretraživanjem literature pronašli smo 170 potencijalno relevantnih članaka. Nakon primjene isključnih i uključnih kriterija pregledali smo cjelovite tekstove 39 članaka, od kojih je 20 na koncu uključeno u analizu našeg istraživanja, jer su odgovarale postavljenim kriterijima kvalitete slike i doze zračenja u odnosu na *pitch* faktor. Od 11 studija koje su uspoređivale *low pitch* MSCT i *high pitch* DSCT, u 8 studija (72,7%) dobiveno je da je subjektivna kvaliteta slike ista. U 3 studije (27,3%) dobiveno je da je subjektivno kvaliteta slike manja s *low pitch* MSCT-om nego s *high pitch* DSCT-om. U svih jedanaest studija koje su uspoređivale *low pitch* MSCT i *high pitch* DSCT kod high pitch DSCT-a upotrebljavana je manja doza zračenja, a kod *low pitch* MSCT-a veća doza zračenja**.** Tri rada uspoređivala su samo *low i high pitch* kod MSCT uređaja. U sva tri rada pronađeno je da je subjektivna kvaliteta slike jednaka, bez obzira na to koristi li se *low ili high pitch*. Pri korištenju *low pitch* MSCT-a za postizanje jednake kvalitete slike kao na *high pitch* MSCT-u korištene su više doze zračenja u sva tri slučaja. U ukupno 6 radova koji su uspoređivali subjektivnu kvalitetu snimke *low pitch* DSCT-a i *high pitch* DSCT-a, u tri studije pronađeno je da je kvaliteta snimke ista, a u tri slučaja da je kvaliteta slike manja s *low pitch* DSCT-om. Međutim, u svih 6 slučajeva *low pitch* DSCT-a korištene su veće doze zračenja u odnosu na *high pitch* DSCT kako bi se postigla bolja subjektivna kvaliteta slike u tih 50% studija. Ovim istraživanjem nije dokazano kako postoji statistički značajan utjecaj *pitch* faktora na kvalitetu slike kod višeslojnih CT uređaja, ali je potvrđeno kako *high pitch* faktor značajno utječe na smanjenje doze zračenja bolesnika.

Ključne riječi: kompjuterizirana tomografija, pitch faktor, CT snimanje