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This is an official journal of the Slovenian Society of Radiographers with external reviews. The purpose is to publish articles from all areas of diagnostic imaging (diagnostic radiologic technology, CT, MR, US and nuclear medicine), therapeutic radiologic technology and oncology.
The articles are professional and scientific: results of research, technological assessments, descriptions of cases, etc.

Spoštovane kolegice in spoštovani kolegi!

Pred Vami je prva številka revije Medical imaging and Radiotherapy journal, ki je posodobljena različica revije Bilten, le-ta od letošnjega leta izhaja izključno v angleškem jeziku. Do takšne odločitve je v uredništvu revije prišlo zato, ker želimo naše več kot kakovostne raziskave predstaviti širšemu krogu bralcev, kar nam s slovenskim jezikom žal ne more uspeti. Takšna odločitev je bila soglasno sprejeta na skupščini društva leta 2019. Revija ima sedaj tudi svojo spletno stran, ki je dostopna na povezavi http://mirtjournal.net/index.php/home. Od letošnjega poletja naprej je na omenjeni spletni strani arhiv vseh člankov, ki so bili objavljeni v reviji Bilten od začetka izhajanja leta 1983 pa vse do danes. Prav tako smo posodobili navodila za avtorje člankov. Oddaja člankov sedaj poteka preko sistema Open Journal System oz. OJS zato vas prosim, da si pred oddajo članka ustvarite uporabniški račun, ki vam bo omogočal oddajo in ustvarjal vaš arhiv vseh oddanih člankov. Upam, da vas bo širši nabor bralcev spodbudil, da predstavite tudi vaše raziskave in celotnemu svetu pokažete kakovost in znanje, ki ga premoremo slovenski radiološki inženirji. Odločili smo se tudi, da boste sedaj revijo prejemali v elektronski obliki po elektronski pošti, s čimer bomo poskrbeli za čistejše okolje.
Ker je revija na voljo širšemu krogu bralcev pričakujemo tudi raziskave od kolegov iz celega sveta, kar bo našo revijo še dodatno obogatilo in nam omogočilo širši pogled in znanje iz našega področja. Revija še vedno ostaja brezplačna in prosto dostopna vsem bralcem na spletni strani revije in v bazah, ki revijo indeksirajo.
Sporočam vam, da smo letos imeli čast, da smo se kot država predstavili na enemu izmed največjih kongresov radiologije na svetu – ECR, v sklopu EFRS meets, ki je zaradi trenutne pandemije po svetu potekal virtualno. Zahvaljujem se vsem štirim predavateljem, ki so pripravili odlična predavanja, vsak s svojega specialnega področja.
Na temo pandemije COVID-19 je Društvo radioloških inženirjev skupaj z Zbornico radioloških inženirjev, Katedro za radiološko tehnologijo Zdravstvene fakultete in Združenjem radiologov že tretje leto zapored pripravilo Mednarodni dan radiologije in radiološke tehnologije (IDOR – International day of Radiology) z več kot 350 udeleženci. Dogodek je, tako kot vsi v letošnjem letu, potekal virtualno. Imeli smo možnost poslušati odlična predavanja s strani naših kolegov radioloških inženirjev in zdravnikov radiologov ter mikrobiologa.
V imenu društva bi se rad zahvalil vsem radiološkim inženirjem, ki trenutno profesionalno in s ponosom opravljajo svoj poklic, kljub zelo težkemu stanju v državi in po svetu, ki ga je povzročila pandemija COVID-19. V ta namen smo v DRI pripravili tudi plakat v podporo, ki ga najdete na koncu revije, prav tako pa ste ga prejeli po e-pošti, v kolikor bi si ga želeli natisniti.
Ostanite varni in zdravi,

Nejc Mekiš
Glavni urednik MIRTJ

Dear colleagues,

I would like to present you the first issue of Medical imaging and Radiotherapy journal, an updated version of the Bulletin: Newsletter of the Slovenian Society of Radiographers and is now published solely in English language. The editorial board has come to this decision so high-quality research can be presented to a wider circle of readers, which cannot be done if the journal is published in Slovenian language. Such a decision was unanimously adopted at the assembly of the Society in 2019. From this year onwards, the journal also possesses a website that can be accessed on the link http://mirtjournal.net/index.php/home. From this summer, an archive of all articles published in the journal Bulletin from the beginning of its publication in 1983 until today can be found on the mentioned website. We have also updated the instructions for authors. The article submission process is now run by the Open Journal System (OJS), therefore I would like to kindly ask you to create a user account, which will allow you to submit your article and also automatically create your personal archive. I hope that a wider range of readers will encourage you to present your research and show the whole world the quality and knowledge that the Slovenian radiographers have. We have also decided that you will now receive the journal via e-mail in the pursuit of the cleaner environment.
As the journal is now available to a wider circle of readers, we also expect to receive manuscripts from colleagues from all over the world, which will further enrich our journal and provide us with a broader view and knowledge in our field. The journal remains free and is freely available to all readers on the journal's website and in the databases that index the journal.
I would like to inform you that this year we have had the honor of presenting ourselves as a country at one of the largest radiology congresses in the world – ECR, as a part of the EFRS meets session, which took place in the virtual environment due to the current pandemic around the world. I would like to thank all four lecturers who prepared excellent lectures, each from their own field.
This year's International Day of Radiology (IDOR) topic was COVID-19 pandemic. The Slovenian Society of Radiographers together with the Slovenian Chamber of Radiographers, the Medical imaging and radiotherapy department at the Faculty of Health Sciences and the Association of Radiologists, organized International day of Radiology and Radiologic technology with more than 350 participants. The event, like all events this year, took place in the virtual environment. We had the opportunity to listen to excellent lectures from our fellow radiographers and radiologists and microbiologists.
On behalf of the Society, I would like to thank all radiographers who are currently professionally and proudly pursuing their profession, despite the very difficult times in the country and around the globe caused by the COVID-19 pandemic. For this purpose, Slovenian Society of Radiographers prepared a poster in support. It can be found at the end of the journal, and be received by e-mail if anyone would like to print it out.
Stay safe and healthy,

Nejc Mekis
Editor-in-chief of MIRTJ

Original article

HOW DOES THE REDUCTION OF GLANDULAR TISSUE EFFECT THE FORCE AND BREAST THICKNESS IN MAMMOGRAPHY?

KAKO VPLIVA ZMANJŠANJE ŽLEZNEGA TKIVA NA SILO IN DEBELINO DOJKE PRI MAMOGRAFSKEM SLIKANJU?

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ABSTRACT

Purpose: To determine whether breast thickness decreases with menopause after the reduction of glandular tissue. We also wanted to know how the decrease in breast thickness affects the compression force and the average glandular dose.

Methods: In this project, we collected data regarding the compression force, breast thickness and mean glandular dose of 300 patients who had mammographic imaging in two views: CC (craniocaudal) and MLO (mediolateral oblique) view. The data were divided into three age groups: 100 patients aged 50 to 55, 100 patients aged 60 to 65 and 100 patients aged 70 to 75 years. We used basic statistical tests for measurement purposes, while we used the Shapiro–Wilk test to check normality and the Kruskal–Wallis test to compare the differences.

Results and discussion: We presented the results and comparisons in the tables and box plot graphs for CC and MLO views of the left and right breast for compression force, breast thickness and MGD. In the CC view of the both breasts, we found that there were statistically significant differences in thickness between groups 1 and 3, and differences in MGD between groups 1 and 2, and 1 and 3. In the MLO view of both breasts we found that compression force does not increase with the age of patients, which can be attributed to the different size and density of breasts, and different compression force. Higher compression force results in lower MGD and breast thickness.

Conclusion: In the CC view of left and right breast, there is no statistically significant differences in compression force, but thickness and MGD changed between some groups. In the MLO view, only MGD changed. For further research, we recommend taking measurements on a larger sample, and concurrently considering and examining other factors that may affect breast thickness, compression force and MGD.

Keywords: mammographic imaging, compression force, mean glandular dose, breast thickness, glandular tissue

IZVLEČEK

Namen: Ugotoviti, ali se debelina dojke z leti po menopavzi zmanjšuje glede na zmanjšanje žleznega tkiva pri mamografskem slikanju. Zanimalo nas je tudi, kako zmanjšanje debeline dojke vpliva na kompresijsko silo in povprečno žlezno dozo.

Metode: V nalogi so bili zajeti podatki o kompresijski sili, debelini dojke in povprečni žlezni dozi 300 pacientk, ki so imele opravljeno mamografsko slikanje v dveh projekcijah, tj. CC (kraniokavdalna) in MLO (mediolateralna poševna) projekcija. Podatke smo razdelili v tri starostne skupine po 100 pacientk: od 50 do 55 (skupina 1), 60 do 65 (skupina 2) in 70 do 75 let (skupina 3). Za izračun smo uporabili osnovne statistične teste; za preverjanje normalnosti vzorca Shapiro-Wilk test, za primerjavo razlik pa Kruskal-Wallis test.

Rezultati in razprava: Pri CC projekciji obeh dojk smo ugotovili, da obstajajo statistično značilne razlike v debelini med 1. in 3. skupino, ter razlike v MGD med skupinama 1 in 2 ter 1 in 3. Pri MLO projekciji obeh dojk so bile razlike statistično značilne pri MGD, in sicer med 1. in 2. ter 1. in 3. skupino. Pri CC in MLO projekciji leve in desne dojke smo ugotovili, da se kompresijska sila ne viša z višjo starostjo pacientk, kar se da pripisati različnim strukturam dojk in različni sili kompresije. Posledično bi se vidneje znižala tudi povprečna žlezna doza in debelina.

Zaključek: Pri primerjavi kompresijske sile pri CC projekciji leve in desne dojke ni statistično značilnih razlik med skupinami, debelina in MGD pa se med nekaterimi starostnimi skupinami razlikujeta. Pri MLO projekciji se spreminja le MGD. Za nadaljnje raziskave v prihodnosti priporočamo zajem meritev na večjem vzorcu ter sočasno upoštevanje in preučitev še ostalih faktorjev, ki lahko vplivajo na debelino dojke, silo kompresije in MGD.

Ključne besede: mamografija, kompresijska sila, povprečna žlezna doza, debelina dojke, žlezno tkivo

INTRODUCTION

Mammography is a radiology examination of the breast using X-rays. The exam is fast, reliable and accessible (1). It is the most efficient method for (early) breast cancer screening. Tumours with a diameter of only a few millimetres (mm) can be detected. This method has led to a decrease in the breast cancer mortality rate by 20 to 40% (2). Compression is used in mammography and it is applied using a compression paddle to fix and compress the breast, which facilitates a better signal-to-noise-ratio, the higher homogeneity of the field and thus a high-quality diagnostic mammogram, as well as a lower average glandular dose (3, 4).

The breast is essentially composed of fatty, connective and glandular tissue. Over the years, the glandular tissue may undergo atrophy and is transformed into fatty tissue, the connective tissue becomes less firm and the amount of collagen is reduced (5). Glandular, i.e. epithelial tissue is composed of lobules - TDLU (terminal ductal lobular unit), lobuli glandulae mammariae (lobules of mammary gland) and ductuli lactiferi (lactiferous ducts)(6).

A mammogram not only depends on the technical quality of the examination, but also on the tissue content of the examined breast. Younger breasts are composed of more glandular and less fatty tissue, and thus produce an image of dense and relatively homogenous tissue. During and after menopause when fatty tissue is prevalent in breasts, a mammogram is relatively transparent (7). A mammogram image of glandular tissue is radiopaque, whereas fatty tissue is radiolucent, which means that a higher content of fatty tissue results into a more dark and transparent mammogram (6).

When preparing for imaging, it is important for the radiographer to place the patient in an appropriate position, which can have a significant effect on the quality of a mammogram, dose load and the patient's perception of imaging (8).

Our aim is to determine whether mammography detects a decrease of breast thickness over the years in the postmenopausal period and how the reduced breast thickness affects the compression force and the mean glandular dose (MGD).

METHODS

A retrospective research method was used, combined with secondary data analysis. The research was conducted between

Table 1: Descriptive statistical properties for compression force for all three age groups of patients

Age group	Average (N)	Standard deviation (N)	Median (N)	Minimum (N)	Maximum (N)
From 50 to 55	106.23	24.01	107.50	9.70	164.00
From 60 to 65	108.55	24.37	106.50	53.00	158.00
From 70 to 75	104.86	22.85	105.00	1.07	174.00

Table 2: Descriptive statistical properties for thickness for all three age groups of patients

Age group	Average (mm)	Standard deviation (mm)	Median (mm)	Minimum (mm)	Maximum (mm)
From 50 to 55	53.69	13.04	56.00	20.00	76.00
From 60 to 65	51.57	12.24	53.00	24.00	79.00
From 70 to 75	49.19	12.65	49.50	16.00	79.00

Table 3: Descriptive statistical properties for mean glandular dose for all three age groups of patients

Age group	Average (mGy)	Standard deviation (mGy)	Median (mGy)	Minimum (mGy)	Maximum (mGy)
From 50 to 55	1.40	0.55	1.31	0.66	3.90
From 60 to 65	1.16	0.34	1.08	0.65	2.49
From 70 to 75	1.13	0.33	1.08	0.59	2.85

Table 4: Statistical analysis of results for the CC view of left breast

Variable	Pair	Percentage difference	Kruskal-Wallis test	Post hoc analysis
Compression force	1-2	2%	0.460	
	1-3	-1.3%		
	2-3	-3.4%		
Thickness	1-2	-4%	0.043	0.653
	1-3	-8%		0.037
	2-3	-5%		0.661
MGD	1-2	-17%	< 0.001	< 0.001
	1-3	-19%		< 0.001
	2-3	-3%		1.000

29 April 2019 and 30 May 2019 in the Ljubljana Community Health Centre (Unit Centre), on a SIEMENS MAMMOMAT INSPIRATION mammogram machine.

We obtained the permission of the head of the Radiology Department in the Ljubljana Community Health Centre, the chief radiographer of the same centre and the Commission of the Republic of Slovenia on Medical Ethics prior to the research. In this study, we collected data regarding patients who had mammographic imaging in two views, i.e. the CC (craniocaudal) and MLO (mediolateral oblique) projection. We collected data regarding the compression force, breast thickness and MGD of 300 patients. They were divided into three age groups: 100 patients aged 50 to 55 (Group 1), 100 patients aged 60 to 65 (Group 2) and 100 patients aged 70 to 75 years (Group 3). All data were captured from anonymised DICOM files and processed using the IBM SPSS STATISTICS program (version 25). We used basic statistical tests for measurement purposes, while we used the Shapiro–Wilk test to check sample normality. The Kruskal–Wallis test and the Dunn Bonferroni post hoc analysis were used to compare the differences in data. The results were shown in form of tables and graphs. A standard statistical level of risk of 5% was taken into account in verifying hypotheses.

RESULTS

The measurement results of the CC and MLO views of left and right breasts were presented. The data are broken down according to the compression force, breast thickness and mean glandular dose for each breast separately. The results were compared for each age group.

Craniocaudal view of left breast (CC)

Tables 1-3 show the basic descriptive statistical properties for compression force, breast thickness during the compression and MGD. Table 4 shows the results of statistical analysis.

Craniocaudal view of right breast (CC)

Tables 5-7 show the basic descriptive statistical properties for compression force, breast thickness and MGD. Table 8 shows the results of statistical analysis.

Table 5: Descriptive statistical properties for compression force for all three age groups of patients

Age group	Average (N)	Standard deviation (N)	Median (N)	Minimum (N)	Maximum (N)
From 50 to 55	107.31	18.93	108.00	46.00	146.00
From 60 to 65	113.18	21.09	110.00	63.00	166.00
From 70 to 75	108.05	19.16	105.50	55.00	180.00

Table 6: Descriptive statistical properties for thickness for all three age groups of patients

Age group	Average (mm)	Standard deviation (mm)	Median (mm)	Minimum (mm)	Maximum (mm)
From 50 to 55	53.75	13.25	55.50	20.00	83.00
From 60 to 65	50.94	12.42	50.00	23.00	78.00
From 70 to 75	49.46	11.79	51.00	17.00	77.00

Table 7: Descriptive statistical properties for mean glandular dose for all three age groups of patients

Age group	Average (mGy)	Standard deviation (mGy)	Median (mGy)	Minimum (mGy)	Maximum (mGy)
From 50 to 55	1.42	0.56	1.35	0.70	4.01
From 60 to 65	1.15	0.31	1.12	0.67	1.99
From 70 to 75	1.12	0.26	1.07	0.68	2.05

Table 8: Statistical analysis of results for the CC view of right breast

Variable	Pair	Percentage difference	Kruskal-Wallis test	Post hoc analysis
Compression force	1-2	-5%	0.106	
	1-3	-1%		
	2-3	5%		
Thickness	1-2	5%	0.028	0.317
	1-3	8%		0.024
	2-3	3%		0.910
MGD	1-2	19%	< 0.001	< 0.001
	1-3	21%		< 0.001
	2-3	3%		1.000

Mediolateral oblique view of left breast (MLO L)

Tables 9-11 show the basic descriptive statistical properties for compression force, breast thickness and MGD. Table 12 shows the results of statistical analysis.

Mediolateral oblique view of right breast (MLO R)

Tables 13-15 show the basic descriptive statistical properties for compression force, breast thickness and MGD. Table 16 shows the results of statistical analysis.

DISCUSSION

A CC projection of the left breast showed that the compression force does not increase with respect to our three age groups. By increasing the force, the thickness of the compressed breast reduces, which means that the mean glandular dose should decrease. In our case, the thickness differs in the first and the third group, where the thickness of the breast in the first group is highest and lowest in the third group. Waade et al. (4) determined that at some level a higher compression force no longer leads to a lower breast thickness; it only causes a more painful and unpleasant examination for the patient. Our study established that the MGD of the first group is higher than the MGD of the second and third group, while there are no differences in MGD between the second and third group. Compared to other tissues, glandular breast tissue is most sensitive to ionising radiation. Therefore, the highest mean glandular dose is expected in the first group and the lowest in the third group. A Sydney study compared the differences in compression force in cases when patients alone compress the breast and on the other hand when radiographers perform the compression. It was determined that the compression force is many times lower when the compression is done by radiographers. Consequently, the breast thickness differed by up to 11 mm (9). According to a six-year study by Mercer et al., (10, 11) the applied force also depends on the radiographer who performs the examination. When a patient was imaged by different radiographers, statistically significant differences occurred. It is likely that a higher compression force on the breast could have been applied more often in our study, without causing discomfort or pain to the patient. However, it would to some

Table 9: Descriptive statistical properties for compression force for all three age groups of patients

Age group	Average (N)	Standard deviation (N)	Median (N)	Minimum (N)	Maximum (N)
From 50 to 55	126.14	30.88	122.50	32.00	188.00
From 60 to 65	129.94	32.06	132.00	1.30	187.00
From 70 to 75	125.04	29.99	122.50	1.30	191.00

Table 10: Descriptive statistical properties for thickness for all three age groups of patients

Age group	Average (mm)	Standard deviation (mm)	Median (mm)	Minimum (mm)	Maximum (mm)
From 50 to 55	54.61	14.33	57.50	22.00	81.00
From 60 to 65	52.69	14.62	54.00	24.00	82.00
From 70 to 75	52.97	14.02	54.50	16.00	84.00

Table 11: Descriptive statistical properties for mean glandular dose for all three age groups of patients

Age group	Average (mGy)	Standard deviation (mGy)	Median (mGy)	Minimum (mGy)	Maximum (mGy)
From 50 to 55	1.45	0.56	1.35	0.67	3.64
From 60 to 65	1.23	0.38	1.16	0.64	2.22
From 70 to 75	1.25	0.37	1.18	0.68	3.21

Table 12: Statistical analysis of results for the MLO view of left breast

Variable	Pair	Percentage difference	Kruskal-Wallis test	Post hoc analysis
Compression force	1-2	-3%	0.270	
	1-3	1%		
	2-3	4%		
Thickness	1-2	4%	0.331	
	1-3	3%		
	2-3	-1%		
MGD	1-2	15%	0.002	0.004
	1-3	14%		0.016
	2-3	-2%		1.000

extent cause a reduction in breast thickness as well as in mean glandular dose. Poulos and McLean (9) discovered a connection between the size of a breast and the force that can be applied. Larger breasts allow for a higher force. Since numerous data were obtained from anonymous DICOM files, it is not clear whether older women had larger breasts, which could be one of the reasons for a non-decreasing compression force in age groups.

According to Hoflehner et al., (12) there are two categories of breasts: firm and soft. The thickness of soft breasts after the applied force of 80 N accounts for 40 mm, while it is higher for firm breasts. For each subsequent 30 N, the thickness changes by 1 to 4 mm. The thickness of soft breasts under similar conditions changes by more than 4 mm (9). In our research, the patients were divided into age groups. However, the category (firm or soft breasts) was not determined for patients from individual age groups.

There were no differences in the compression force nor in the thickness of the compressed breast in the mediolateral oblique projection for any of the age groups, but there were statistical differences in mean glandular dose between the first and the second group, and the first and the third group. The dose and quantity of glandular tissue were lower.

Menstrual function and thus reproductive abilities of women cease in menopause, which is connected to undesired changes in body weight and its composition. Generally, the body weight increases and results in higher body fat (13). If we assume that the women in our study also gained weight and breast density during the menopausal period, our results are fairly expected. The larger and denser the breast is, the higher the thickness and consequently the mean glandular dose will be. The difference in breast density for women from the first, second and third groups is therefore smaller or non-existent. Thus, the differences between data for the three age groups are smaller.

CONCLUSION

According to literature, it was expected that a higher age group and thus a greater atrophy of glandular tissue would result in an increasing compression force on the breast, a decreasing tissue thickness as well as a mean glandular dose. We determined that there are no statistically significant differences in the CC view of left and right breasts. The only exceptions were thickness, which only decreases between the first and third age group, and MGD, which decreases between

Table 13: Descriptive statistical properties for compression force for all three age groups of patients

Age group	Average (N)	Standard deviation (N)	Median (N)	Minimum (N)	Maximum (N)
From 50 to 55	122.34	34.13	125.00	1.01	186.00
From 60 to 65	124.68	23.99	122.50	65.00	182.00
From 70 to 75	127.40	34.40	123.00	1.06	190.00

Table 14: Descriptive statistical properties for thickness for all three age groups of patients

Age group	Average (mm)	Standard deviation (mm)	Median (mm)	Minimum (mm)	Maximum (mm)
From 50 to 55	54.28	13.94	57.00	18.00	78.00
From 60 to 65	51.45	13.78	53.00	22.00	86.00
From 70 to 75	52.71	14.09	54.00	18.00	82.00

Table 15: Descriptive statistical properties for mean glandular dose for all three age groups of patients

Age group	Average (mGy)	Standard deviation (mGy)	Median (mGy)	Minimum (mGy)	Maximum (mGy)
From 50 to 55	1.45	0.58	1.32	0.71	3.86
From 60 to 65	1.22	0.37	1.14	0.66	2.76
From 70 to 75	1.24	0.33	1.18	0.70	2.54

Table 16: Statistical analysis of results for the MLO view of right breast

Variable	Pair	Percentage difference	Kruskal-Wallis test	Post hoc analysis
Compression force	1-2	-2%	0.642	
	1-3	-4%		
	2-3	-2%		
Thickness	1-2	5%	0.246	
	1-3	3%		
	2-3	-2%		
MGD	1-2	16%	0.001	0.002
	1-3	14%		0.017
	2-3	-2%		1.000

the first and second group and between the first and third group. In the MLO view of left and right breasts, only the MGD changes between the first and the second group, and the first and the third group, while the other two parameters remain the same. Our research did not prove that the breast thickness decreases over time in the postmenopausal period and therefore does not affect the compression force and dose load for the patient, as expected. Since the results failed to meet our expectations, it would be recommended in further studies to increase the sample and also take other factors into account. By reviewing literature, we came across the following factors: breast size, categorisation into soft and firm breasts, appropriately applied compression force, review of mammograms. It would also be advisable to conduct research in another field of mammographic diagnostics.

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Case report

TWO CASES OF MRI-INDUCED SKIN BURNS

PRIMERA OPEKLIN NA KOŽI PRI MAGNETNO RESONANČNEM SLIKANJU

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ABSTRACT

Purpose: The purpose of this paper is to present two cases of MRI-induced skin burns.

Materials and methods: Both cases were imaged using a GE Optima™ MR450w 1.5T scanner. A combination of anterior and posterior arrays were used. In both cases, patients were placed in the headfirst prone position.

Results and discussion: In the first case, there was a red area on the skin and a white blister appeared after 15 minutes. A closed conducting loop was created in the patient's body, which caused increased local temperature at the junction of her thighs. We could prevent this by using insulation, such as foam pads, which is one of eight steps for preventing MRI-induced skin burns. In the second case, there were red spots on the skin of the left and right thighs at the contact of the scrotum where a white blister appeared after 15 minutes. This could not have been prevented, even if we considered all the steps for preventing MRI-induced skin burns.

Conclusion: I reported a case of burns on a small area of skin at the junction of the patient's thighs, which we could have prevented by using insulation pads, and a case of burns on the skin at the contact of the scrotum, which we could not have prevented, even if we considered all the steps for preventing MRI-induced skin burns. However, we could have stopped the increase in the degree of the burn by recognising early signs.

Key words: MR imaging, burns, safety, radiofrequency waves, heating

IZVLEČEK

Namen: Namen tega članka je predstaviti dva primera opeklin, ki sta nastala pri MR slikanju.

Metode in materiali: Oba primera smo slikali z magnetnoresonančnim tomografom GE Optima 450w 1,5T. Uporabili smo sprejemno tuljavo za trup (ang. anterior array) in hrbtenico (ang. posterior array). Oba pacienta sta ležala na hrbtu z glavo proti tomografu.

Rezultati in razprava: V prvem primeru se je med slikanjem pojavila rdečina, na kateri je čez 15 minut nastal še bel mehur. V pacientkinem telesu se je ustvarila prevodna zanka, ki je povzročila lokalno segrevanje na notranji strani stegen in posledično je na tem mestu nastala opeklina. Temu bi se lahko izognili z namestitvijo izolativne blazinice, kar je eden od osmih korakov, ki jih lahko upoštevamo za preprečitev opeklin med MR slikanjem. V drugem primeru sta se rdečini pojavili na koži levega in desnega stegna ob skrotumu, na katerih je čez nekaj minut nastal bel mehur. Temu bi se težko izognili, tudi če bi upoštevali ukrepe za preprečitev opeklin.

Zaključek: Predstavil sem primer opeklin, ki so nastale zaradi manjšega stika kože na stegnih, ki bi jih lahko preprečili z namestitvijo blazinice med stegni, ter primer opeklin na koži stegen ob skrotumu, ki ju ne bi mogli preprečiti, lahko pa bi, ob razumevanju mehanizma nastanka le-teh in v komunikaciji s pacientom, prepoznali zgodnje znake ter preprečili poglabljanje stopnje opekline.

Ključne besede: MR slikanje, opekline, varnost, radiofrekvenčni pulzi, segrevanje

INTRODUCTION

Since magnetic resonance imaging (MRI) has been used, there has not been any scientific proven cases of relevant long-term adverse effects on body cells or organisms (1).
Modern magnetic resonance scanners, which are used for clinical purposes, use a very strong static-magnetic field, additional gradient magnetic fields and short high-frequency waves from radiofrequency (RF) fields to excite protons. RF waves are transmitted by the coil/array that induces high-frequency current in tissues (2). Using the energy from the impulses, the average magnetisation of proton is distorted. We can only achieve this if the frequency of radiofrequency waves is identical to the frequency of core precessing in the magnetic field, and if these cores are perpendicular to the static-magnetic field. We can control the angle of magnetisation through the appropriate power and duration of RF waves. In MRI, we most often angle the magnetisation of the cores to 90 degrees so that it precesses around the axis of the static-magnetic field with Larmor frequency. That is how magnetic current in an RF array is adjusted and thus electrical voltage is induced. At 90 degrees, electrical voltage is at its highest, as it has the widest possible projection at the surface when it is perpendicular to the static-magnetic field (3).
Most of the RF energy that is used for MRI is transformed into heat within the patient's tissue. Energy absorption in MRI is measured in specific absorption rate (SAR); it is the power absorbed per mass of tissue (W/kg). Higher body temperature of the patient due to RF wave exposure also depends on the patient's thermoregulation system, the duration of exposure, the energy accumulation rate and the environment where the patient is during the imaging process (4).
Soon after MR was introduced for clinical purposes, the first articles appeared on risks due to increased temperature in the imaging process (5, 6). It has been proven that the local temperature can increase and result in burns during MRI. Most injuries occur with patients who were attached to life function monitoring devices and whose skin was in contact with sensors or conductors (7). The human body is a conductor and therefore burns can occur even if there are no implants or active electrical devices. A closed conducting loop in the patient's body can thus be created if a patient lies with his hands clasped or if a thumb is touching a thigh (8).
Organ shape and layers of insulating fat can have an impact on how the induced electrical voltage flows. This may lead to increased local temperature (9). Knopp et al. described a case in which a closed conducting loop was created through the torso and legs. The contact area between the calf muscles comprised two adjacent skin layers that consisted of approximately 2 mm of subcutaneous fat. They assessed that the average power absorbed in a layer of subcutaneous fat of 1 cm3 was 1.5 W, which was enough to cause RF-induced burns. In this area, the local temperature could reach up to 43oC, which does not cause immediate pain, but is sufficient to induce tissue necrosis. Initially, third-degree burns are painless, as pain receptors under the skin are destroyed first (10). Friedstad Jonathan et al. described an unusual case of two third-degree burns that occurred on the ring finger of the right hand and on the left forearm during MRI (11).

AIM

The aim of this paper is to present two cases of MRI-induced skin burns, raise awareness and introduce measures to prevent such complications.

METHODS

Both cases were imaged using a GE Optima™ MR450w 1.5T scanner. A combination of anterior and posterior arrays was used.

Case 1:
MRI of low-grade liposarcoma of an 82-year-old patient's rectus femoris muscle. We performed a protocol for soft tissue tumour that includes T1, T2, T2 pulse sequences with signal saturation from fat (FS) and a diffusion-weighted sequence in the axial plane and axial, coronal and sagittal T1 FS sequence after the application of a contrast agent. The patient was placed in the headfirst prone position during the examination. The patient stated at the end of the process that she felt heat between the thighs.

Case 2:
MRI of the rectum of a 74-year-old patient. We performed a standard rectal protocol that comprised a T2 sagittal sequence, paraxial (imaging plane planned through the cancer-infected rectum area) and paracoronal (imaging plane perpendicular to the paraxial plane) plane, followed by a diffusion weighted sequence in the paraxial plane and a T2 sequence for lymph node display in the axial plane. The patient was placed in the headfirst prone position during the examination. After the examination, the patient stated that he felt heat in the testicle area.

RESULTS AND DISCUSSION

Case 1:
There were no peculiarities during the examination, except at the end the patient complained about the increased temperature between her thighs. At the junction of her thighs, there was a red area on the skin and a white blister appeared after 15 minutes (Image 1). The female patient was referred to a surgeon who cared for the wound and provided her written instructions on how to care for the burn.

Image 1: Photograph of the medial side of the thigh with burns on both sides

The MR images (Image 2) show that the local temperature increased and caused the burns at the junction of the patient's thighs. It is stated in the results of the examination that, compared with the previous MR examination a subcutaneous fat oedema was evident, which probably contributed to the higher conductivity of this area.

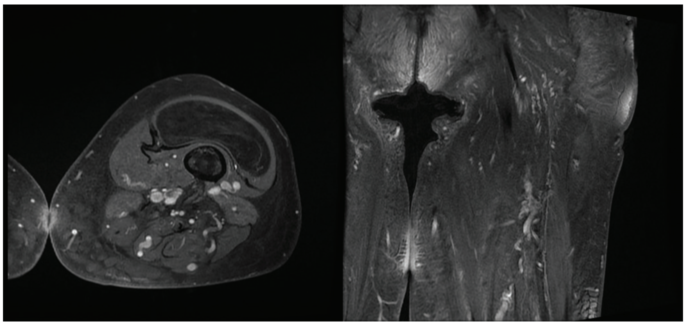

Image 2: Left, T1 image of a saturated signal from the adipose tissue after the application of the contrast agent in the axial plane. Right, T1 image of a saturated signal from the adipose tissue after the application of the contrast agent in the coronal plane.

During MRI, a conducting loop was created in the patient's body, which is schematically presented in Image 3. As the result of magnetic induction in the body (L_{array}), an electric voltage, which is influenced by the resistance of the individual tissue (R_{skin}), flows through patient's body. The entire resistance of the loop is presented with R_{array}. In border areas between fat, skin and air, an electrical charge is created according to a similar principle as in an ordinary electric capacitor. Capacitance is dependent on a distance between the tissues and the ability to accumulate electrical charge in an individual tissue (R_{skin}). In our case, it is the border between the fat and the skin. A virtual capacitor with C_{air} is also created between the skin of left and right thighs. In the worst-case scenario, the capacitance is high enough to create an electrical current through every tissue, meaning it can increase the temperature in border areas and cause burns (8).

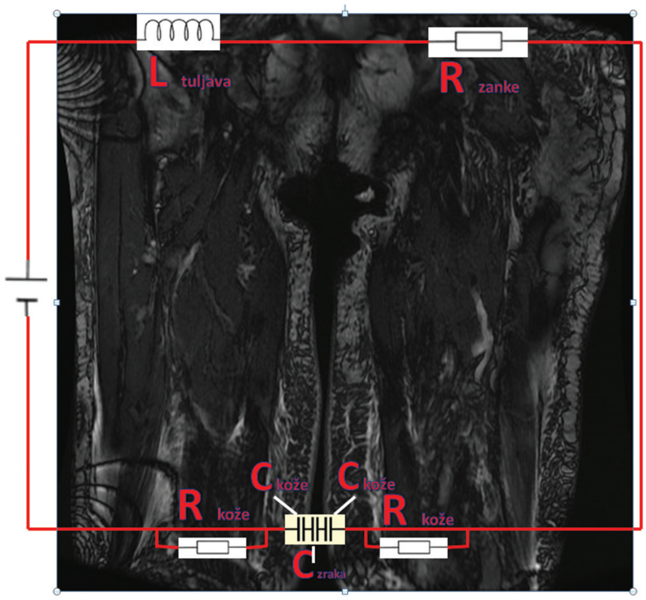

Image 3: Schematic diagram of a closed conduction loop that appeared in the patient's body in the process of MRI. Loop induction (L_{array}), loop resistance (R_{array}), skin resistance (R_{skin}), skin capacitance (C_{skin}), air capacitance (C_{air})

We could prevent this by using insulation between the thighs, such as foam pads, at least 1 cm thick, which would prevent the creation of a closed conduction loop.

With an increase in the number of MR examinations and better MR scanners there is also an increase in the number of burns reported. Skin damage is the most common reason for a report of an unwanted event (Hardy and Weil, 2010). For this reason, the ISMRM (International Society for Magnetic Resonance in Medicine) prepared a poster that everyone can print for free and hang in the MR diagnostic clinics and that systematically describes steps to prevent MR burns.

1. We systematically check for implants or other metal objects in the patient's body, and everything that is unknown to us is deemed MR Unsafe.
2. We systematically check that every object that enters the MR space is MR Safe or MR Conditional; we always check that all conditions for MR safety have been met. All metals, including non-ferromagnetic metals, can heat up and cause burns.
3. Before the examination, every patient strips down to their underwear and puts on a cotton hospital robe.
4. For examination, we prepare the patient so that there is no skin contact (hands on the hips, crossed arms or legs).
5. While preparing the patient, we use insulation foam pads on skin to skin contact spots, skin to conductors and skin to a scanner wall spots.
6. We prevent loops on array conductors and other medical devices.
7. Imaging is done on a normal operative level, using the lowest possible SAR.
8. We continuously observe and listen to patients to ensure that everything is all right. We are aware of any signs of increased temperature. Sedated patients are connected to a life function monitoring device that is MRI Conditional (12).

Case 2:

There were no peculiarities during the examination, except at the end the patient complained about increased temperature

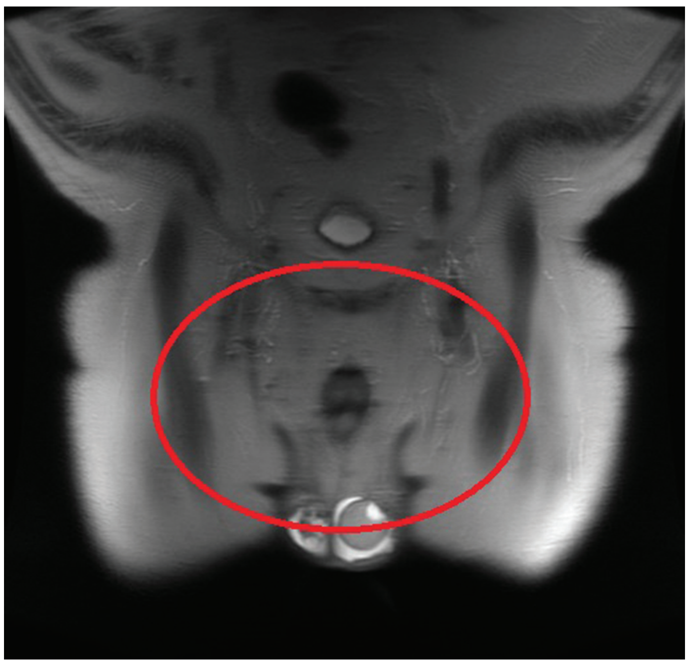

Image 4: Localiser in the coronal plane. The red line indicates the trajectory of the closed conducting loop.

on the skin around his thighs, in the scrotum area. There were red spots on the skin of the left and right thighs at the contact of the scrotum where a white blister appeared after a few minutes. We cared for the wound and provided him instructions for cooling the wound.
This could not have been prevented, even if we considered all the steps for preventing MRI-induced skin burns. A similar case occurred in Sweden, but was not described in literature. The skin burn appeared under the breast where an air pocket formed in the inframammary fold and a closed conduction loop was created around it.

CONCLUSION

With an increase in the number of MR examinations and better MR scanners around the world, a growing number of cases of MRI-induced burns can be expected. The aim of this article is to present an example of burns on a small area of skin at the junction of the patient's thighs, which we could have prevented by using insulation pads. Another example shows the occurrence of skin burns at the contact of the thighs and scrotum, which we could not have prevented. However, by communicating with patients, understanding the mechanism behind the burns and by recognising early signs, we could have stopped the increase in the degree of the burn.

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Original article

MAGNIFICATION ERROR IN RADIOGRAPHS OF CERVICAL SPINE IN LATERAL PROJECTION

VELIKOST VRATNIH VRETENC V STRANSKI PROJEKCIJI

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ABSTRACT

Purpose: The main purpose of this study was to determine how the distance between the cervical spine and the image receptor on the one hand and the distance between the source and the image receptor on the other affects the image size of the cervical vertebrae. Moreover, it was important to understand how the entrance skin dose varies when the distance between the object to image receptor and the distance source to image receptor changes.

Methods: The theoretical part of this study was carried out based on an analysis of the readings, the practical part was carried out on a head, neck and trunk phantom at the radiological laboratory of the Faculty of Health Sciences (University of Ljubljana).

Results: When the object to image receptor distance (OID) was increased from 24 to 39 cm, the image size of the vertebra increased by 23% at a source to image receptor distance (SID) of 115 cm. At an SID of 150 cm, it increased by 17% and by 11% at an SID of 180 cm. When SID was decreased from 150 to 115 cm at an OID of between of 24 and 29 cm, the entrance skin dose increased by 26%. As the OID was increased further, the entrance skin dose (ESD) was even higher. Similarly, the ESD decreased with an increase in SID. For example, when SID was increased from 150 to 180 cm at an OID of between 24 and 29 cm, the ESD decreases by 8.5%.

Discussion and conclusion: The results indicate that the lateral radiography of the cervical spine should be performed at a SID of 150 cm. By doing so, it is assured that a proper image size is obtained, and the entrance skin dose is not harmful to the patient.

Keywords: source to image receptor distance (SID), object to image receptor distance (OID), lateral radiography of the cervical spine, entrance skin dose (ESD)

IZVLEČEK

Namen: Želeli smo ugotoviti, kako oddaljenost vratnih vretenc od slikovnega sprejemnika in oddaljenost gorišča od slikovnega sprejemnika vplivata na velikost vratnih vretenc na rentgenogramu in vstopno kožno dozo pri slikanju vratne hrbtenice v stranski projekciji.

Metode dela: V teoretičnem delu smo podatke pridobili z deskriptivno metodo, s čimer smo želeli preučiti obstoječo literaturo. Podatke za praktičen del smo pridobili s pomočjo eksperimentalne metode raziskovanja, na podlagi meritev na fantomu glave, vratu in trupa v radiološkem laboratoriju Zdravstvene fakultete Univerze v Ljubljani.

Rezultati: Pri povečanju razdalje objekt—slikovni sprejemnik (ROS) iz 24 na 39 cm se vretence pri razdalji gorišče—slikovni sprejemnik (RGS) 115 cm poveča za 23 %, pri RGS 150 in 180 cm pa za 17 % in 11 %. Pri zmanjšanju RGS iz 150 na 115 cm, pri ROS med 24 in 29 cm, se vstopna kožna doza (VKD) poveča za 26 %, pri ROS med 30 in 34 cm, za 31 %, pri ROS med 35 in 39 cm za 35 %. Pri zvečanju razdalje RGS iz 150 na 180 cm, pri ROS 24 do 29 cm, se VKD zmanjša za 8,5 %, pri ROS med 30 in 34 cm, za 11,6 %, pri ROS od 35 do 39 cm za 12,5 %.

Razprava in zaključek: Meritve so pokazale, da je priporočljivo stransko slikanje vratne hrbtenice na razdalji RGS 150 cm ustrezno iz dveh razlogov: z večjo RGS vplivamo na manjšo povečavo objekta na rentgenogramu in hkrati zmanjšamo vstopno kožno dozo pacientu.

Ključne besede: razdalja gorišče–slikovni sprejemnik (RGS), razdalja objekt–slikovni sprejemnik (ROS), slikanje vratne hrbtenice stransko, vstopna kožna doza (VKD)

INTRODUCTION

Lateral radiography of the cervical spine (X-ray) is a basic diagnostic examination. The basic projections are the anteroposterior (AP) and lateral projections, which show possible pathological changes (1). When imaging the cervical spine laterally, the anatomical features of the imaging area and the physical properties of the X-ray beam must be taken into account in order to achieve an optimal and diagnostically useful radiograph. Important parameters that must be taken into account are the following: source to image receptor distance (SID), object to image receptor distance (OID) and source to object distance (SOD). They impact the distortion of an object in a radiograph (2).

Factors that impact the image quality

Distortion is the incorrect display of the size and form of an object in a radiograph. Due to the divergence of the X-ray beam, every object looks larger on a radiograph than its natural size (2). In order to achieve the lowest possible magnification, which affects the spatial resolution of the image, we must reduce the OID as much as possible and increase the SID (1, 3). These parameters are particularly important in lateral imaging of the cervical spine, as cervical vertebrae cannot be adjacent to the image receptor due to the width of the shoulders. Since the object is distant from the image receptor due to anatomical properties, we can reduce the magnification on a radiograph by increasing SID from 115 to 150 cm. Magnification factor can be calculated according to the formula below (1, 4):

$$\textit{Magnification factor (Mf)} = \frac{\text{SID}}{\text{SOD}} = \frac{\textit{object image size}}{\textit{natural object size}}$$

Two independent studies to address the magnification of the cervical vertebrae on a radiograph were conducted with the aim of determining the connection between the body mass index (BMI) and the magnification of cervical vertebrae in lateral projection. Both studies included body measurements of the second and fifth cervical vertebrae. The size of the cervical vertebrae on a radiograph were compared to their size on magnetic resonance (MR) and computed tomography (CT) images. Ravi and Rampersaud (5) included 250 patients in their analysis and discovered that there is a statistically significant correlation between the magnification of cervical vertebrae on a radiograph and BMI. Shigematsu et al. (6) conducted a study on 54 patients and did not identify a statistically significant correlation between the magnification of cervical vertebrae and BMI.

Entrance skin dose

Entrance skin dose (ESD) is defined as the absorbed dose measured on the central beam axis at the position of the patient or phantom surface. It is a sum of the direct radiation beam and backscattered radiation from the patient (7). ESD is calculated using the following formula:

$$\textit{ESD} = \textit{BSF (backscatter factor)} \cdot \textit{Y (tube output)} \cdot \left(\frac{100}{\textit{SOD}}\right)^2 \cdot \textit{It}$$

When the voltage in the conduit and the product of tube current and time (It) remain constant, the radiation intensity decreases by the square of the distance. The increase in SID leads to a lower ESD. The automatic exposure control (AEC) system adjusts the exposure so that the signal-to-noise ratio remains the same, regardless of the accelerating voltage that is used to accelerate the electrons in the X-ray tube and regardless of the thickness of the imaging object. The AEC system adjusts the mAs product so that the radiation intensity on an image receptor remains the same, regardless of the changed distance of the image receptor from the source of radiation (8, 9).
Zdešar et al. (10) stated in their research report about the radiation of patients in ordinary radiographic examinations at the Slovenj Gradec General Hospital that an average ESD of the lateral imaging of the cervical spine remains the same, i.e. 0.98 mGy, at the SID of 115 cm to 145 cm. The measurement was conducted on ten patients with an average weight of 74 kg, using the AEC system.
A research conducted by Joyce et al. (11) aimed to determine the impact of SID on ESD. The AEC, a flat panel detector and accelerating voltage of 65 kV were used. The source to image receptor distances used were 150 cm, 180 cm and 210 cm. An increase in the distance from 150 cm to 210 cm led to a decrease in ESD by 37.4%. The dose also decreased by 22.9% when the distance was increased from 150 cm to 180 cm.

AIM

The aim of the study was to determine how the distance of the cervical vertebrae from the image receptor and the source to image receptor distance impact the size of the cervical vertebrae on the radiograph and entrance skin dose during the lateral imaging of the cervical spine.
The following research questions were raised:

1. Does the source to image receptor distance impact the size of vertebrae on a radiograph during the lateral imaging of the cervical spine?
2. Does the object to image receptor distance impact the size of vertebrae on a radiograph?
3. How does the entrance skin dose change at different source to image receptor distances?

METHODS

In the theoretical part, we obtained data using a descriptive method and studied existing literature. The data for the practical part were obtained using an experimental research method, based on the measurements on a head/neck/torso phantom in the radiology laboratory at the Faculty of Health Sciences, University of Ljubljana.
In order to make a connection with practical lateral imaging of the cervical spine, we chose a man with the broadest shoulders and a woman with the narrowest shoulders in the population of 40 students. They were placed against a tripod, in the same way as in the lateral projection of the cervical spine so that the shoulder was adjacent to the tripod. We measured the distance from the spinous process of the seventh cervical vertebra to the tripod. Based on the obtained measurements, we changed the object to image receptor distance by 1 cm, from 24 cm to 39 cm.

The measurements were performed on a Siemens Multix/ Vertix X-ray machine, with the source size of 1 mm and total filtration of photon beam of 2.5 mm of aluminium (1.5 mm Al own filtration and 1 mm Al additional filtration). The imaging was conducted against a Vertix wall tripod, with a grid ratio of 13:1, with 70 lamellae per centimetre where the optimum source to image receptor distance was 150 cm (± 20 cm). We used the AEC system for imaging and chose an X-ray tube voltage of 70 kV, according to the DIMOND III (12) recommendations.

We used a PBU 60 head/neck/torso phantom (Kyotokagaku Co., Ltd, Japan) with an attenuation coefficient, which equals a person of 165 cm in height and 50 kg in weight. It was placed against the tripod in the supine position. The central beam was placed at the height of the fourth cervical vertebra. The direction of the central beam was perpendicular to the vertebrae and CR plate (Figure 1).

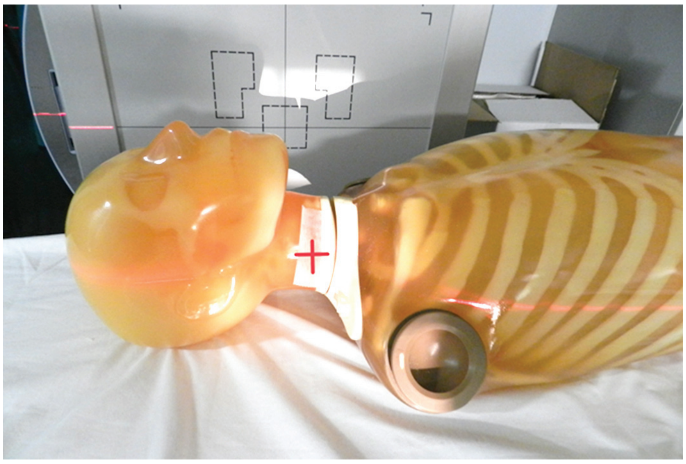

Figure 1: PBU 60 head/neck/torso phantom (Kyotokagaku Co., Ltd, Japan) in the position for the lateral imaging of the cervical spine (Cesar and Grkman, 2019)

We used a CR plate measuring 18 cm × 24 cm that was placed in the wall tripod transversally. The radiograph shows the entire cervical spine and the first two thoracic vertebrae.

We changed the object to image receptor distance by 1 cm between the distances of the spinous process of the cervical vertebra from 24 cm to 39 cm. Each change in the OID was imaged at three source to image receptor distances, i.e. 115 cm, 150 cm and 180 cm.

At all OID and SID distances, we measured the size of the upper and bottom edge of the fifth cervical vertebra and calculated the magnification factor using the following formulas:

$$SOD = SID - OID$$

$$Mf = \frac{SID}{SOD} = \frac{\text{object image size}}{\text{natural object size}}$$

ESD was measured at every OID and SID. ESD was calculated using the formula below:

$$ESD = BSF \cdot Y \cdot \left(\frac{100}{SOD}\right)^2 \cdot It$$

The output of the device (Y), with which the measurements were performed, was 35.5 µGy/mAs at SID of 100 cm. The backscatter factor (BSF) equalled 1.33 at a field size of 20 cm × 20 cm (surface 400 cm^2); we used a CR plate measuring 18 cm × 24 cm in size (surface 432 cm^2). Since there is no data for this value, we used the data of BSF at a field size 20 cm x 20 cm for the calculation of ESD. For the calculation of the distance between the source and the point in the neck (source to object distance (neck)) where X-ray photons enter the patient's body, we subtracted SOD and the distance from spine to the edge of skin on the neck that was 6 cm from SID.

RESULTS AND DISCUSSION

Vertebra size

We measured the vertebra width while changing the OID from 24 cm to 39 cm at different SID. Figure 2 clearly shows that the vertebra width increased with a higher OID. At SID of 115 cm, the vertebra size increased by 23%, at 150 cm by 17% and at 180 cm by 11%.

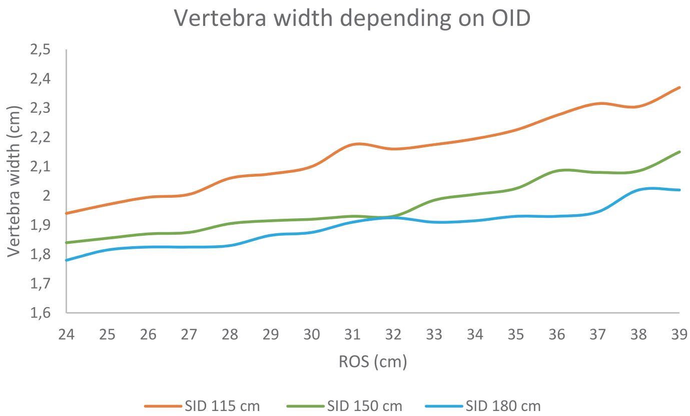

Figure 2: Illustration of vertebra width at a changing OID

We calculated the magnification factor. In theory, it can be calculated from SOD and SID. We determined that vertebrae increased by 24.9% when OID was increased from 24 cm to 39 cm at SID of 115 cm, and by 16.1% and 12.3% at SID of 150 cm and 180 cm, respectively. Figure 3 also shows that the curve is steeper at SID of 115 cm than at 150 cm and 180 cm.

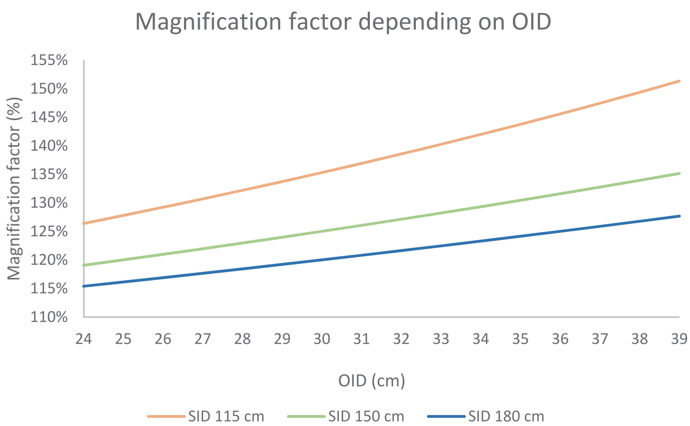

Figure 3: Magnification factor was calculated from SID and SOD

In practice, the magnification factor can be calculated from object size on a radiograph and natural object size. The difference in magnification factor when OID was increased from 24 cm to 39 cm at SID of 115 cm was 29%, and 19.5% and 13% at SID of 150 cm and 180 cm, respectively (Figure 4).

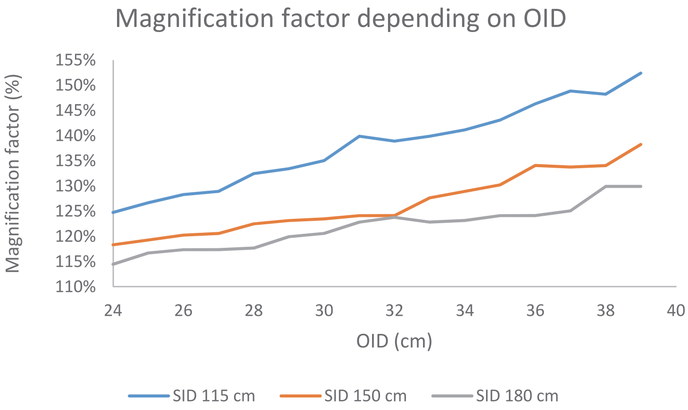

Figure 4: Magnification factor calculated from the natural size of vertebrae and the size of vertebrae on a radiograph

Table 1: Comparison of calculated magnification from SID and OID, and from the object image size and natural object size at a change in OID from 24 cm to 39 cm

SID (cm)	SID/OID (%)	Object image size / natural object size (%)
115	24.9	29.0
150	16.1	19.5
180	12.3	13.0

If we compare the calculated magnification factors in terms of theory and practice, (Table 1) there are slight deviations. The difference is due to the fact that a precise measurement of the length of such a small object on the image is difficult due to the use of a computer mouse. It nevertheless provides information on the image size with an accuracy of a few millimetres. For a more accurate measurement, it would be necessary to count the number of pixels in the image.

There were two studies conducted regarding image magnification. They, however, provided contradictory results. Ravi and Rampersaud (5) discovered that there is a statistically significant correlation between the magnification of cervical vertebrae on a radiograph and body mass index. On the other hand, Shigematsu et al. (6) did not find a statistically significant correlation between the magnification of cervical vertebrae on the image and body mass index. If we want to compare our research to the aforementioned existing studies, we must presuppose that the body mass index grows with an increase in shoulder width, i.e. an increase in OID. We identified a correlation between the body mass index and magnification of cervical vertebrae on the image, as the magnification on the image was higher at an increased OID.

Entrance skin dose

Our aim was to determine the effect of OID and SID on the entrance skin dose. The ESD was calculated based on the product of current and time (mAs) that was recorded by the AEC system. When OID was increased from 24 cm to 39 cm, the dose increased the most at SID of 115 cm, i.e. by 66%. At SID of 150 cm, it increased by 42%, and at 180 cm by 32%.

SID of 150 cm is used in practice for lateral imaging of the cervical spine. We calculated changes in ESD when SID was decreased to 115 cm and when it was increased to 180 cm. Decreasing SID from 150 cm to 115 cm, a slightly higher entrance skin dose enters the patient, while an increase in SID from 150 cm to 180 cm resulted in a slightly lower ESD entering the patient (Figure 5).

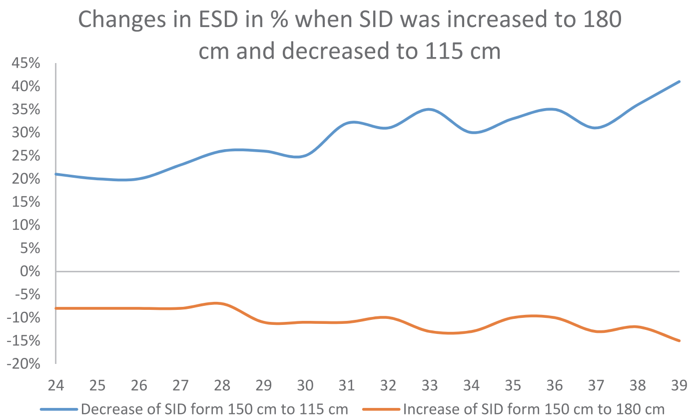

Figure 5: Changes in ESD in % when SID was increased to 180 cm and decreased to 115 cm

For practical applicability, OID between 24 cm and 39 cm was divided into three groups: narrow shoulder girdle (24 cm to 29 cm), middle shoulder girdle (30 cm to 34 cm) and broad shoulder girdle (35 cm to 39 cm). ESD decreased when OID was reduced and SID was increased. A decrease in SID from 150 cm to 115 cm for narrow shoulder girdle resulted in an increase in ESD by 26%. The increase in ESD was 31% for middle shoulder girdle and 35% for broad shoulder girdle. An increase in SID from 150 cm to 180 cm for narrow shoulder girdle resulted in a decrease in ESD by 8.5%. The decrease in ESD was 11.6% for middle shoulder girdle and 12.5% for broad shoulder girdle.

In order to evaluate our results, we compared them to two studies that measured the entrance skin dose. Automatic exposure control was used in all studies, while our research conditions differed in terms of the choice of imaging system and the characteristics of subjects. We used a CR system and a phantom simulating a 50 kg patient, while Zdešar et al. (10) used a film-reinforcing foil imaging system and an average patient weight of 74 kg. The aforementioned differences resulted into deviations in ESD. The average ESD stated by Zdešar (10) was 0.98 mGy at SID between 115 cm and 145 cm. Our doses were significantly lower: ESD was 0.37 mGy at SID of 115 cm, 0.29 mGy at 150 cm and 0.26 mGy at 180 cm.

Joyce et al. (11) changed SID from 150 cm to 180 cm and 210 cm, respectively. A flat panel detector, AEC system and accelerating voltage of 65 kV were used. They determined that at an increase in SID from 150 cm to 210 cm resulted in a decrease in ESD by 37.4%, while an increase in SID from 150 cm to 180 cm resulted in a decrease in ESD by 22.9%. Our measurements showed that an increase in SID from 150 cm to 180 cm resulted in an average decrease in ESD by 11%. For example, a decrease in SID from 150 cm to 115 cm resulted in an increase in ESD by 31%. If we wish to compare our study to Joyce's (11), we only take into account the average values of ESD that were measured when SID was increased from 150 cm to 180 cm. Deviations in results probably occurred due to a different accelerating voltage and detection system.

CONCLUSION

The aim of our study was to determine the effect of SID and OID on the object distortion in an image. We were also interested in how different SIDs impact ESD.

We found during the research that an increase in SID resulted in a decrease in magnification in an image, while an increase in OID resulted in a bigger object size in the image. Increasing SID resulted in a reduction in a patient's ESD.

Measurements showed that lateral imaging of the cervical spine at SID of 150 cm is recommendable for two reasons. A higher SID results in a smaller object magnification on a radiograph, while we reduce the entrance skin dose for the patient, despite a higher product of current and time.

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Original article

IDENTIFICATION OF OCCUPATIONAL STRESSORS AMONGST RADIOGRAPHERS

IDENTIFIKACIJA STRESORJEV NA PODROČJU DELA RADIOLOŠKIH INŽENIRJEV

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ABSTRACT

Purpose: The aim of this research is to define stress and correlated factors and identify which stressors are present among radiographers in relation to their workplace.

Methods: A total of 450 radiographers received a questionnaire that covers a variety of workplace stressors, which conditions affect stress, how frequently radiographers notice stress and to what extent they use coping mechanisms. The online survey was available on the website 1ka and the results were analysed using the IBM SPSS program.

Results: A total of 236 radiographers completed the survey (52.4% response rate). Interpersonal relations and management staff cause the highest level of stress, while the most important stressor is a conflict with a supervisor (3.38). Radiographers who work in a field of radiotherapy perceive the most stress. There is no difference between a healthcare activity in relation to levels of perceived stress. We could not identify any statistically significant differences in perceived stress in relation to gender or age ($p \leq 0.05$). Radiographers who asses their relationship with co-workers and supervisors as good perceive lower levels of stress. Additionally, the same results are present with radiographers who are satisfied because they work in a multidisciplinary team ($p \leq 0.05$). Teaching new staff has a positive correlation with occupational stress development. Unnecessary radiological procedures, along with unclear roles, have no effect on the development of stress behaviour ($p > 0.05$). However, a conflict between roles has a major association ($p \leq 0.05$) with stress occurrence. The most frequent methods for reducing symptoms of stress are caring for one's health and physical appearance (3.77). It proved that communication with patients and duty work ($p < 0.05$) represent significant elements of the workload. Most radiographers think that physical conditions in the workplace could be improved.

Discussion and conclusion: The results show that radiographers notice a variety of stressors in their workplace. The most important are related to interpersonal relations. Further research should include analysis of stress within particular fields of radiography that would help to explain occupational stress.

Keywords: occupational stress, stressors, radiographer

IZVLEČEK

Namen: Namen raziskave je bil ugotoviti, katere stresorje najbolj zaznavajo radiološki inženirji (RI) na svojem delovnem mestu.

Metode dela: Anketni vprašalnik je bil posredovan 450 radiološkim inženirjem. Zanimali so nas stresorji na delovnem mestu, kateri delovni pogoji in obremenitve vplivajo na pojav stresa, kako radiološki inženirji doživljajo fizično stanje na delovnem mestu, v kakšni meri opazijo simptome stresa ter v kolikšni meri se poslužujejo načinov spoprijemanja s stresom. Anketni vprašalnik je bil izveden s pomočjo programa 1ka. Pridobljene rezultate smo analizirali s programom SPSS.

Rezultati: Anketo je rešilo 236 radioloških inženirjev oz. 52,4 %. Največ stresa zaznavajo RI zaradi medosebnih odnosov ter odnosa vodstvenih delavcev do RI, najpomembnejši stresor je konflikt z nadrejenim (3,38). Stres na delovnem mestu bolj obremenjuje zaposlene na področju radioterapije kot na diagnostičnem. Med različnimi ravnmi zdravstvenih dejavnosti ni razlik v stopnjah zaznanega stresa. Ni statistično značilnih razlik v zaznanem stresu po spolu ter po starosti ($p \leq 0,05$). Nižje stopnje stresa zaznavajo tisti, ki so v dobrih odnosih s sodelavci in nadrejenim, ter tisti, ki izražajo zadovoljstvo z delom v multidisciplinarnem timu ($p \leq 0,05$). Poučevanje novega delovnega kadra je pozitivno povezano s percepcijo delovnega stresa. Spol, starost, nepotrebni dodatni radiološki posegi niso povezani s percepcijo stresa ($p > 0,05$), prav tako ne nejasnost vlog. Ugotovili smo močno povezanost stresa in konflikta vlog ($p \leq 0,05$). Najpogostejša metoda lajšanja simptomov stresa je lastna skrb za zdravje in videz (3,77), sledijo družabna srečanja (3,69). Pomembni delovni obremenitvi sta komunikacija s pacienti in dežurstva ($p \leq 0,05$). Večina anketirancev meni, da bi lahko bili fizični pogoji na delovnem mestu boljši.

Razprava in zaključek: Raziskava je pokazala, da RI na svojem delovnem mestu zaznavajo različne stresorje. Najpomembnejši se nanašajo na odnose v samem kolektivu. V prihodnje bi bilo smiselno izvesti raziskave o stresu znotraj posameznih področij radiološke tehnologije, saj bi samo na ta način lahko pridobili najbolj jasno sliko stresa na delovnem mestu.

Ključne besede: stres na delovnem mestu, stresorji, radiološki inženir

INTRODUCTION

Today's world is full of challenges, the tempo of life is increasingly faster, and surroundings are more difficult. Consequently, more people at work are coping with stress. In Slovenia, there has been some research done on occupational stress for nurses, but none for radiographers (1). Radiographers are certified healthcare professionals who perform x-ray or magnetic resonance imaging. They are responsible for processing high quality medical images that specialists use to diagnose or track patient's disease or injury (2). They also play an important role in therapeutic treatment (e.g. radiotherapy and nuclear medicine). Rapid technological development demands highly competent and empathic radiographers.

Occupational stress

Stress is a physiological, psychological and behavioural response to internal and external stimuli (stressors) (3). It is the way our organism responds to changes in the environment (4). Stressors are all factors that cause a stress response and a slight collapse of an individual's inner balance (4) for a short period of time. Given that a stressor does not trigger stress in every person, the interpretation of such an occurrence is thus necessary (5).

Occupational stress can be defined as an imbalance between demands of the workplace and a worker's ability to perform (6). At work, radiographers face many challenges (i.e. radiation exposure, extended working hours, shift work, heavy workload, etc.) that cause stress (2). A common occurrence in the workplace is uncertainty of one's role and therefore role conflict. Inaccurate descriptions of roles and false expectations lead to role ambiguity (7). Role conflict occurs when expectations are not met, and also when an individual performs multiple different roles (8).

Strategies for coping with stress are specific ways of understanding how an individual can handle a stressful situation. We are familiar with problem-oriented and emotion-oriented coping mechanisms (9).

AIM

The aim of the research was to use existing research results and theoretical knowledge to explore the perception of stress in radiographers. Furthermore, we were interested in how the work conditions are related to the perception of stress; whether it was primary, secondary or tertiary health care or the work area of radiographers (i.e. diagnostic or radiotherapy), gender, age, superior's assistance or relationships with colleagues, educating colleagues or students, the association of multidisciplinary team's, the performance of unnecessary radiological procedures, role conflict and role ambiguity, duty hours, communication and staff shortage, physical conditions, equipment and stress-coping methods.

Based on theoretical cues, goals set and research done, we formed twelve hypotheses.

METHODS

Theoretical bases were built through the review, reading and critical assessment of literature.

The empirical part of research was done using quantitative data collection methods. We obtained data by surveying with the 1ka web program, which consisted of 29 questions. Five point Likert scales were used to gain insight to the perception of stress- and also, the use of advanced methods for statistical analysis.

The web survey lasted from 10 May 2019 to 5 June 2019. The secretary of the Slovenian Radiographer Association forwarded a survey link to all 413 members. The survey was additionally sent to some radiographers who are not members of the association.

After the research was performed, the data was processed and presented in Excel and SPSS 23.0. Using descriptive statistics, we set basic parameters (i.e. average, standard deviation, minimum and maximum), which we used to determine the stress levels of work situations with different workloads, working conditions and physical conditions. We also studied the influence of interpersonal relationships, social support, role ambiguity, role conflict, stress symptoms and stress-coping methods. Using the Shapiro-Wilk test, we verified the distribution of data and, based on the results, performed parametric and non-parametric tests. Because of different connections and variables, we used a variety of tests, namely a t-test of a single sample, one-way analysis of variance (ANOVA), a t-test of independent samples and Pearson's correlation. Statistically significant changes were p-valued (significance level: $p \leq 0.05$).

RESULTS AND DISCUSSION

A total of 236 radiographers correctly filled out the survey, which represents a response rate of 52.4%. Of that total, 72% (152) were women and 28% (59) were men. The age distribution of radiographers is equal, while the highest proportion of radiographers (31.1%) are between the ages of 20 and 30 years, followed by those between the ages of 30 and 40 years (29.2%), those between the ages of 40 and 50 years (20.6%), and those aged from 50 to 60 years (18.6%). One radiographer was above 60 years old (0.5%). Most radiographers (176 or 85.4%) work in the field of diagnostic and interventional radiology, which is expected, as it offers several different fields of employment and requires a large number of employees (Figure 1). A total of 10.7% of radiographers are employed in radiotherapy, while 3.4% work in the field of nuclear medicine.

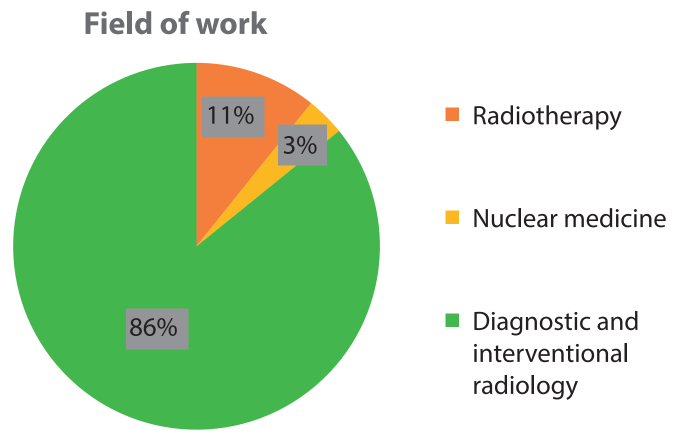

Figure 1: Field of work

Amongst radiographers who stated that they work in the field of diagnostic and interventional radiology, the majority (77.7%) work in skeletal and lung diagnostics, followed by radiographers who take images in the intensive care unit (56.6%), mammography and computer tomography, each employing 63 radiographers, i.e. 36.0%. Interventional radiology accounts for the smallest percentage, i.e. 13.1%. Most radiographers are employed by university medical centres (32.8%), followed by general hospital employees (27.0%), while the smallest percentage, 10.9% of respondents, work at the Institute of Oncology.

Certain situations proved to be remarkably stressful, others less so (Table 1). Most stress is caused by a conflict with a superior (average rating of 3.38), followed by inappropriate management style (average rating of 3.36), poor team communication and conflict with colleagues (average rating of 3.28), $p<0.05$. Less stressful situations were work conditions, shift work, work with interns and students, student mentoring, monotonous work and fear of work results. Here the average ratings were below 3, some even lower than 2. We determined that four statistically significant situations present high levels of stress for more than half of radiographers (N>118), but we did not prove how many radiographers experience stress in a given situation. We can conclude that the most relevant stressors are linked to management style and interpersonal relationships.

Table 1: Descriptive statistics of stress in work situations

Work situation	*N*	*average*	*min*	*max*
Poor team communication	218	3.28	1	5
Work conditions	223	2.49	1	5
Shift work	187	2.17	1	5
Duty work	104	2.85	1	5
Conflict with colleagues	216	3.28	1	5
Conflict with superior	210	3.38	1	5
Student mentorship	179	1.89	1	5
Work with interns/students	190	1.84	1	5
Inappropriate management style	210	3.36	1	5
Monotonous work	185	2.17	1	5
Fear of work results	202	2.23	1	5
Lack of time for required work tasks	213	2.94	1	5
Extended working hours	192	3.06	1	5
TOTAL	2.69			

Using one-way analysis of variance, we discovered that there are statistically significant differences between levels of stress for radiographers employed in different areas in the following work situations: shift work (p=0.059 – marginally significant), student mentorship (p=0.060 – marginally significant), work with students/interns (p=0.041), extended working hours (p=0.016). The majority of work situations are most stressful for radiographers employed in radiotherapy. Amongst statistically significant work situations, only extended working hours were more stressful for radiographers employed in nuclear medicine (average rating of 3.75). Using descriptive statistics, we can prove stress in a situation that has no statistically significant differences. Poor team communication caused the most stress for radiographers employed in nuclear medicine (average rating of 4.13), as well as conflict with colleagues (average rating of 3.75) and conflict with a superior (average rating of 3.75). Inappropriate management style was the most significant stressor for radiographers in the field of radiotherapy. Work situations are generally most stressful for radiographers employed in radiotherapy and slightly less for radiographers in the field of nuclear medicine. Our findings are in conflict with a study by two researchers that proved that the highest levels of stress are experienced by radiographers in the diagnostic field (10).

Amongst radiographers employed in different medical fields, there are no differences in stress perception in specific work situations (p-value>0,05). Results are consistent with a study that covered 38% of radiographers employed in secondary health care facilities, more than 35% in tertiary educational institutions and 27% employed in primary health care facilities. It was proven that there were no statistically significant differences in perceived stress amongst respondents (11).

A t-test of independent samples showed that there are no differences between gender in perceived stress; a statistically significant difference ($p\leq0,05$) was only visible in fear of work results, which proved to be more stressful for women (average of 2.34). Past gender-based studies have shown that gender does not play a role in levels of perceived stress(12). The researchers Decker and Borg proved in their 1993 study that gender has no statistically significant link to perceived stress (13).

Pearson's correlation shows that age is not a factor in perceived stress. We proved one statistically significant link (p=0,004), i.e. fear of work results, which is greater at a higher age. Other researchers (12) also proved that there is no difference in perceived stress between both age groups (p=0.07).

Pearson's correlation proved that work situations for radiographers are better and less stressful if colleagues and superiors have a good relationship and help each other. The better the relationships are between colleagues, the less stress is perceived due to poor team communication (r=-0.221), work conditions (r=-0.228), duty work (r=-0.237), conflict with colleagues (r=-0.263), and inappropriate management style (r=-0.229). We also noticed that if colleagues are willing to listen to each other's work-related problems, stress levels are lower due to poor team communication (r=-0.203), work conditions (r=-0.180), conflict with colleagues (r=-0.147) and inappropriate management style (r=-0.159). Good interpersonal relationships and social support amongst colleagues have a strong influence on occupational stress. Researchers in their study (14, 15) proved that colleagues' and staff's support is one of the most common stress sources. We also discovered how a superior's assistance can influence stress perception in different work situations. If workers receive more support and assistance from their superior, stress perception is lower due to poor team communication (r=-0.142), work conditions (r=-0.289), duty work (r=-0.231), conflict with a superior (r=-0.168), student mentorship (r=-0.190), work with interns and students (r=-0.199), inappropriate management style (r=-0.348), lack of time for required work tasks (r=-0.165) and extended working hours (r=-0.312). In all cases, there is a negative correlation, but an appropriate management style, superior's support and assistance cause lower stress perception. Receiving positive feedback from superiors ensures a 'feeling of success'.

Radiographers included in the process of training and educating new employees perceive higher amounts of stress than those who are not included. The harder it is to train a new employee, the higher amount of stress is perceived due to work conditions (r=0.135), shift work (r=0.168), duty work (r=0.256), conflict with colleagues (r=0.154), conflict with a superior (r=0.172), inappropriate management style (r=0.213), lack of time for required work tasks (r=0.136) and extended working hours (r=0.218). A strong positive correlation was evident in two cases. The higher the perception of effort in teaching new employees, the more stressful is student mentorship (r=0.654) and work with interns and students (r= 0.642). Our results were consistent with a study (11) that showed that 35.2% of those surveyed who work in teaching-research hospitals are under a great deal of stress.

Radiographers who are satisfied with team work and professional cooperation perceive less stress than those who are not of the same opinion. The more valued radiographers are by radiologists and medical specialists, the less stress is perceived in work conditions (r=-0.212), shift work (r=-0.165), duty work (r=-0.235), conflict with colleagues (r=-0.204), conflict with a superior (r=-0.255), mentorship (r=-0.187), work with interns and students (r=-0.191), inappropriate management style (r=-0.308), fear of work results (r=-0.379), lack of time for required work tasks (r=-0.238) and extended working hours (r=-0.218).

Radiographers who are of the opinion that they perform unnecessary additional procedures are neither more or less stressed than those who do not share the same standpoint. Pearson's correlation did not show any statistically significant link (p>0.05).

Our aim was to determine whether radiographers who are aware of their competence and responsibilities perceive lower levels of stress. We started analysing assertions related to role ambiguity. Radiographers who feel more responsibility perceive higher levels of stress when in conflict with a superior (r=0.141). Radiographers who know what is expected of them perceive lower levels of stress when working with interns/students (r=-0.162), inappropriate management style (r=-0.182) and fear of work results (r=-0.154). We proved that role ambiguity does not significantly affect occupational stress levels, but role conflict has a major impact on stress perception in different work situations, as nearly all assertions and situations expressed statistically significant codependency. One of the assertions about role conflict illustrated in a work situation is as follows: the more radiographers think that they work in a manner that should be different, the higher stress perception is in team communication (r=0.166), work conditions (r=0.305), shift work (r=0.217), duty work (r=0.282), conflict with a superior (r=0.139), working with interns/students (r=0.166), inappropriate management style (r=0.206), lack of time for required work tasks (0.150) and extended working hours (r=0.152). In a study done by two researchers (10), role conflict (r=0.53) also caused stronger stress perception than role ambiguity (r=-0.31).

Radiographers use different techniques for reducing stress; mostly they take care of their health and appearance by consuming healthy food (average rating of 3.77), while some seek relaxation in sport (average rating of 3.53) but it is not the most common stress coping technique used.

We also studied whether communication with patients, work duty and staff deficiency represent the most significant workloads. Work duty and communication with patients have shown statistically significant links related to stress perception in work situations (p<0.05). Those surveyed ascribe great importance to attitude towards a patient, which presents no stress to them. Stress perception rises due to poor communication when patients are uncooperative, radiographers lack time to explain directions and properly treat a patient or show empathy for the individual. Polworth (1982) made the same point in his study, which explains that work and communicating with patients are not stress factors for radiographers (17).

Using descriptive statistics, we determined that radiographers find duty work most stressful (average rating of 3.35), and that they are burdened with too much responsibility while on duty (average rating of 3.18). Pearson's correlation also showed significant links between duty work and stress levels of work situations, such as: the more stressful radiographers find duty work, the higher stress perception is due to work conditions (r=0.361), conflict with colleagues (r=0.272), lack of time for required work tasks (r=0.311), extended working hours (r=0.370). The more demanding duty work is for radiographers, the higher stress perception is due to poor team communication (r=0.295), work conditions (r=0.436), inappropriate management style (r=0.301), fear of work results (r=0.268), lack of time for required work tasks (r=0.386), and extended working hours (r=0.367). To sum up, duty work is highly stressful for radiographers.

Lack of staff did not show statistically significant links in linear correlation. Using descriptive statistics, we did, however, discover that 64.6% of radiographers think that employability is too low, while 96.6% of radiographers are of the opinion that a larger number of employees would reduce stress levels. Most radiographers are satisfied with room lighting (average rating of 3.40), although they are not as satisfied with room temperature and air flow (average rating of 2.29). They neither agree or disagree with the assertion that work premises and equipment in the department fail to meet staff needs (average rating of 3.05). The same applies to the assertion that the quality of image diagnostics is good (average rating of 3.32). Radiographers agree that equipment is well maintained (average rating of 3.64). Most radiographers think that there are not enough diagnostic devices in an institution according to the number of different procedures performed (average rating of 3.51). A study performed by Polworth (1982) exposed multiple physical stressors, including insufficient workspace with bad airflow and lighting (17).

CONCLUSION

Our research was the first research on occupational stress for radiographers in Slovenia. We determined that radiographers are subjected to occupational stress. Most problems are caused by interpersonal relationships and management. Because it was the first research of stressors, our goal was to study stressors amongst all radiographers. In the future, we suggest that every field of radiography be studied individually (nuclear medicine, radiotherapy, diagnostic and interventional radiology) or within the specific departments of certain institutions. Only in this way can we get a clear picture of the most common stress sources, so that management can take the appropriate action. We suggest more surveys about satisfaction, staff burnout and stress perception within radiological departments, as well as psychological lectures about stress and interpersonal relationships.

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Original article

IMPACT OF ACQUISITION PARAMETERS ON THE QUANTITATIVE ASSESSMENT OF PET IMAGING – ANALYSIS OF THE NEMA PHANTOM

VPLIV SLIKOVNIH PARAMETROV NA KVANTITATIVNO OCENO PET SLIKE – ANALIZA FANTOMA NEMA

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ABSTRACT

Aim: The aim of the research was to analyse the most common factors that influence SUV values.

Material and methods: In the study, I used a NEMA body phantom filled with a mixture of water and 18F-FDG in a ratio 1:4 (background/spheres), and analysed the most common factors that influence SUV values. The most common factors include the impact of the patient's body weight, the impact of time between application and PET/CT imaging, and the impact of differently prepared and administered RP activities.

Results: Different values of patient body weight, time between application and PET/CT imaging, and differently prepared and administered RF activities have a statistically significant effect on the quantitative assessment of SUVmax ($p < 0.001$) and SUVmean ($p < 0.001$).

Conclusion: The results showed that all factors can significantly influence the quantitative assessment of SUVmax and SUVmean.

Keywords: PET/CT, quantitative assessment, SUVmax, SUVmean, body weight

IZVLEČEK

Namen: Analizirati najpogostejše dejavnike, ki vplivajo na vrednosti SUV.

Materiali in metode: V raziskavi sem uporabil fantom NEMA, napolnjen z mešanico vode in 18F-FDG v razmerju 1:4 (ozadje/sfere) in analiziral najpogostejše dejavnike, ki vplivajo na vrednost SUV. Najpogostejši dejavniki vključujejo vpliv telesne teže pacienta, vpliv časa med aplikacijo in slikanjem s PET/CT in vpliv različno pripravljene in aplicirane koncentracije aktivnosti radiofarmaka (RF).

Rezultati: Različne vrednosti telesne teže pacienta, čas med aplikacijo in slikanje s PET/CT in različno pripravljene in aplicirane koncentracije aktivnosti RF statistično pomembno vplivajo na kvantitativno oceno SUVmax ($p < 0,001$ in SUVmean ($p < 0,001$).

Zaključek: Rezultati so pokazali, da lahko vsi dejavniki pomembno vplivajo na kvantitativno oceno SUVmax in SUVmean.

Ključne besede: PET/CT, kvantitativna ocena, SUVmax, SUVmean, telesna teža

INTRODUCTION

Positron emission tomography (PET) in combination with computed tomography (CT) is a hybrid imaging diagnostic method that is frequently used for diagnosis, prognosis and monitoring response to oncological therapy. The hybrid system facilitates a parallel anatomical image using computed tomography (CT) and functional image using PET. Visual assessment is the main tool for image interpretation in clinical practice. Although visual assessment may be sufficient to evaluate tumour response, a precise assessment of tumour response to therapy requires a certain form of quantification (1, 2). PET is a diagnostic imaging method that facilitates the quantitative assessment of the pathological process. The quantitative assessment enables objective and precise evaluation to predict and monitor therapeutic response so that it does not depend solely on the visual imaging assessment. Quantification in PET examinations represents an accumulated amount of radiopharmaceuticals (RP) inside the tumour and facilitates a precise division into groups of patients who experience therapeutic response and those who do not (3, 4). A quantitative analysis utilising 18F- fluorodeoxyglucose (18F-FDG) in the assessment of early therapeutic response increased the role of PET in drug development in oncology (5). Standardised uptake value (SUV) is a simplified quantitative assessment and the most frequently used method to assess accumulation of 18F-FDG PET in examinations (6, 7).

SUV is a number that stands for the accumulation activity of RF inside the tumour or the entire body that was measured after intravenous RP application in a predetermined period. SUV is normalised to the applied RF dose and factor that takes into account the distribution of RF in the whole body (8, 9). The most common factors for normalisation of RF distribution in the whole body are body weight (BW) and body surface area (BSA). Patients who undergo an 18F-FDG exam must do so on an empty stomach. Those patients have a decreased RP accumulation in the fat, which can impact body weight, and therefore, a method considering lean body mass (LBM) is used. LBM is defined as the difference between total body mass and body fat, and takes into account the mass of all organs, excluding body fat. The use of LBM for the normalisation of SUV is more appropriate for heavier patients than BW or BSA (10, 11).

Physiological and technical factors or factors that are the result of human error impact the results of the highest concentration activity (SUVmax) and average concentration activity (SUVmean). A common technical error that impacts SUV is a discrepancy in time at PET/CT and dose meter. To avoid an incorrect SUV, time on a dose meter and PET/CT should be checked daily. Data collection period is an image parameter that impacts the signal-to-noise ratio (SNR) and consequently SUV. Along with the processing parameters, SUV is also impacted by the selection of the matrix element (due to the effect of partial volume), reconstruction algorithm and normalisation factor. SUV is also dependent on the region of interest (ROI), the selection of which is impacted by the individual's choice. Most common factors that impact SUV are shown in Table 1 (8, 12-14).

Table 1: Most common factors that impact the quantitative assessment of a PET image

CAUSE	*FACTOR*	*EXPLANATION*
Technical error	Incorrect time synchronisation between PET/CT and dose meter	Incorrect SUV due to erroneous correction of RP decay
	Paravenous application of 18F-FDG	Amount of applied RF is decreased, resulting into incorrect SUV
Physical factors	Imaging parameters	Low SNR value causes a biased SUV
	Reconstruction parameters	Partial volume effect on SUV
	Selection of ROI	SUV result is highly dependent on the selection of ROI size
	Normalisation factor for SUV	SUV depends on weight, body surface and other normalisation factors for the calculation of SUV

AIM

The aim of the study was to demonstrate and analyse the most common factors that impact SUVmax and SUVmean values. The following factors were included in the analysis:

- impact of patient's body weight,
- impact of time between the application and data collection with PET/CT, and
- impact of differently prepared and applied RF concentration activity.

METHODS

A NEMA body phantom was used to analyse factors that impact the quantitative assessment of SUV (SUVmax/mean). I conducted the phantom imaging on a SIEMENS hybrid system, Biograph mCT® 128 PET/CT, which combines a 128-slice CT and LSO PET detector system with three rings. The phantom volume was 9.7 litres and consisted of six hollow spheres with diameters of 37, 28, 22, 17, 13 and 10 mm. The phantom was filled with a mixture of water and 18F-FDG in a 1:4 ratio (background/sphere). When performing the PET/CT imaging, I collected the CT data for attenuation correction first, then the PET data with the application of a single bed position. For the reconstruction of data, I used the iterative reconstruction algorithm (TrueX + TOF) that encompasses the point spread function (PSF) and time-of-flight information (TOF). SUV is most frequently normalised to body weight (BW) and is calculated using the following formula (Formula 1):

$$SUV_{BW} = \frac{ACvoi\ (MBq/ml)}{FDGdose\ (MBq)/BW\ (kg)} \qquad \text{Formula 1}$$

In Formula 1, ACvoi represents the average or highest activity concentration expressed in MBq/ml, in a defined region of

interest (ROI). FDGdose represents the dose of FDG expressed in megabequerels (MBq), while body weight (BW) is expressed in kilograms.
SUV corrected to LBM is calculated using Formula 2:

$$SUV_{LBW} = \frac{ACvoi\ (MBq/ml)}{FDGdose\ (MBQ)/LBM\ (kg)} \qquad \text{Formula 2}$$

ACvoi represents the average or highest activity concentration expressed in MBq/ml, in a defined region of interest (ROI). FDGdose represents the dose of FDG expressed in MBq. LBM value depends on the gender, body weight and height of a patient, and is calculated differently for men and women. LBM (women) = (1.07 x body weight) (kg) - 148 [body weight (kg) / body height (cm)]^2 and LBM (men) = (1.1 x body weight) (kg) - 128 [body weight (kg)/body height (cm)]^2 (15).
SUV corrected to BSA is calculated using Formula 3:

$$SUV_{BSA} = \frac{ACvoi(MBq/ml)}{FDGdose\ (MBq)/BSA\ (m^2)} \qquad \text{Formula 3}$$

ACvoi represents the average or highest activity concentration expressed in MBq/ml, in a defined region of interest (ROI). FDGdose represents the dose of FDG expressed in MBq. The height and weight of patients must be entered in the imaging or processing protocol to calculate BSA. The entered data are applied to calculate BSA, using the following formula:

BSA (m^2) = 0.007184 x body weight (kg)$^{0.425}$ x body height (cm)$^{0.725}$ (16).

I analysed the impact of incorrectly entered body weight, RP application time and prepared RP activity on SUVmax and SUVmean on a NEMA phantom. I systematically entered data in the imaging protocol and thus simulated an error. I altered the weight of the phantom (10 kg) by 10%, 20%, 30% and 40%, and analysed SUVmax and SUVmean. In terms of time impact on SUVmax and SUVmean, I simulated an error by entering times of 1, 3, 7, 15, 30, 45 and 60 minutes. By altering activity by 5% from the reference, I calculated the impact of lower and higher activity of prepared RF on the quantitative assessment of SUVmax and SUVmean.
On the images, I marked regions of interest of approximately six spheres of different sizes in the NEMA body phantom. An analysis of obtained quantitative assessments of SUVmax/mean was conducted using SPSS 25 software. The Shapiro-Wilk test was applied to assess the distribution of variables. I used the analysis of variance (ANOVA) test (repeated measures) for dependent variables in the normal distribution and the Friedman test when variables were not distributed normally. I used a p value of < 0.05 for the threshold of statistical significance.

RESULTS

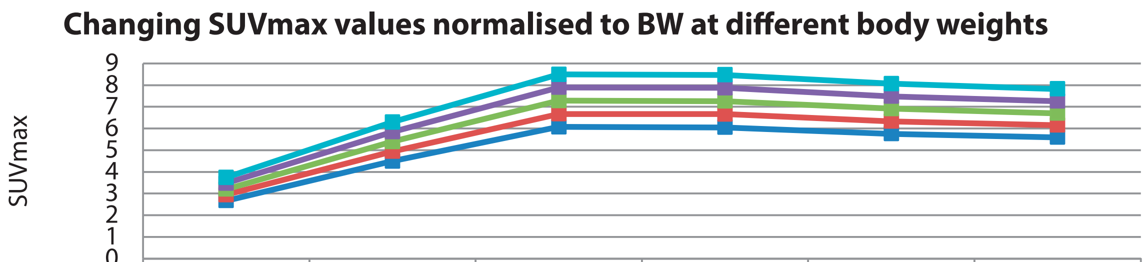
An analysis of the normalisation of SUVmax and SUVmean to BW, LBM in BSA showed a statistically significant difference at SUVmax ($p = 0.002$) and at SUVmean ($p < 0.001$). The obtained SUVmax and SUVmean values are shown in Tables 2 and 3.

Table 2: SUVmax values at different sphere volumes normalised to BW, LBM and BSA

	SUVmax value		
Sphere volume	**BW**	**LBM**	**BSA**
0.5	2.67	13.97	0.41
1.13	4.49	23.45	0.70
2.5	6.07	31.67	0.94
5.02	6.05	31.60	0.94
11.01	5.75	30.05	0.89
23.41	5.59	29.16	0.87

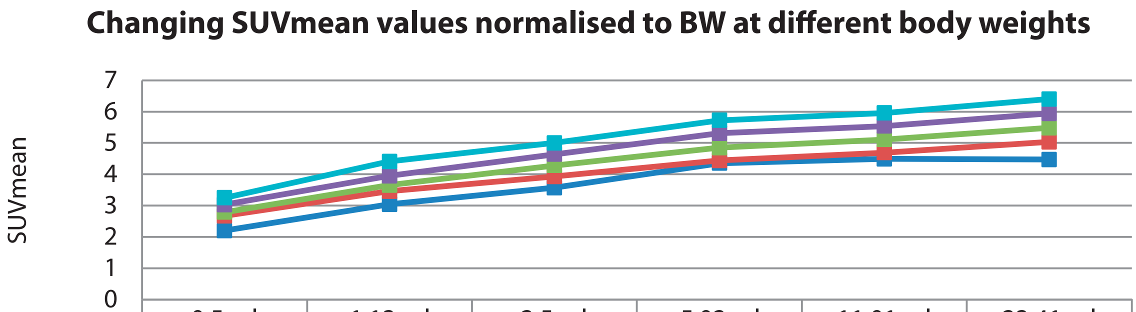
Table 3: SUVmean values at different sphere volumes normalised to BW, LBM and BSA

	SUVmean value		
Sphere volume	**BW**	**LBM**	**BSA**
0.5	2.4	12.53	0.37
1.13	3.15	16.45	0.47
2.5	3.57	23.56	0.55
5.02	4.08	21.08	0.63
11.01	4.26	22.24	0.66
23.41	4.57	23.86	0.71



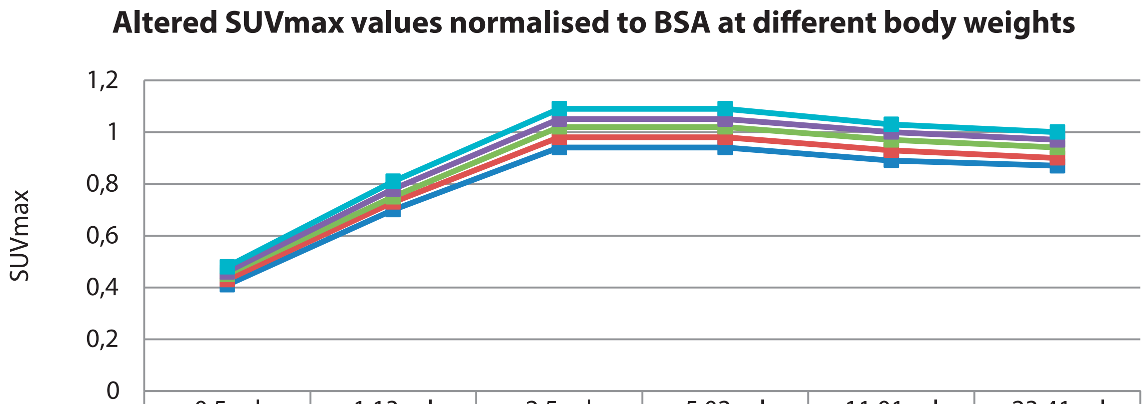
	0.5 ml	1.13 ml	2.5 ml	5.02 ml	11.01 ml	23.41 ml
10 kg	2.67	4.49	6.07	6.05	5.75	5.59
11 kg	2.94	4.94	6.67	6.66	6.33	6.15
12 kg	3.2	5.39	7.28	7.26	6.91	6.7
13 kg	3.47	5.84	7.89	7.87	7.48	7.26
14 kg	3.74	6.29	8.49	8.47	8.06	7.82

Image 1: Impact of body weight to SUVmax at different sphere volumes normalised to BW, when body weight is altered by 10% from the initial weight of the NEMA phantom (10 kg). The curves illustrate SUVmax value fluctuations at different body weights.



	0.5 ml	1.13 ml	2.5 ml	5.02 ml	11.01 ml	23.41 ml
10 kg	2.2	3.04	3.57	4.35	4.49	4.47
11 kg	2.67	3.46	3.93	4.44	4.69	5.03
12 kg	2.79	3.65	4.28	4.85	5.11	5.48
13 kg	3.03	3.95	4.64	5.31	5.54	5.94
14 kg	3.25	4.41	5	5.72	5.96	6.4

Image 2: Impact of body weight to SUVmean at different sphere volumes normalised to BW, when body weight is altered by 10% from the initial weight of the NEMA phantom (10 kg). The curves illustrate the SUVmean value fluctuations at different body weights.



	0.5 ml	1.13 ml	2.5 ml	5.02 ml	11.01 ml	23.41 ml
10 kg	0.41	0.7	0.94	0.94	0.89	0.87
11 kg	0.43	0.73	0.98	0.98	0.93	0.9
12 kg	0.45	0.75	1.02	1.02	0.97	0.94
13 kg	0.46	0.78	1.05	1.05	1	0.97
14 kg	0.48	0.81	1.09	1.09	1.03	1

Image 3: Impact of body weight to SUVmax at different sphere volumes normalised to BSA, when body weight is altered by 10% from the initial weight of the NEMA phantom (10 kg). The curves illustrate the SUVmax value fluctuations at different body weights.

The erroneous entry of body weight can have a statistically significant impact on SUVmax ($p < 0.001$) and SUVmean ($p < 0.001$) values. Image 1 and 2 show a trend of changing SUVmax and SUVmean normalised to BW, if body weight is steadily increased by 10%.

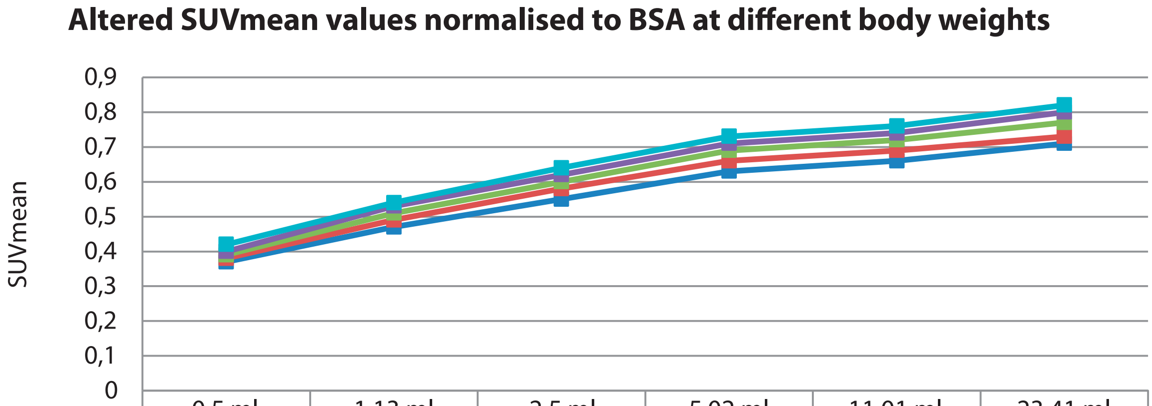
The normalisation of SUV to BSA at different body weights showed a statistically significant difference at SUVmax ($p < 0.001$) and SUVmean ($p < 0.001$). Image 3 and 4 show SUVmax and SUVmean values at different body weights.

The erroneous entry of application time in the protocol or a deviation between time on the applicator and time on PET/CT scanner showed a statistically significant difference at SUVmax ($p < 0.001$) and SUVmean ($p < 0.001$). Image 5 and 6 show deviations between different time points at SUVmax and SUVmean values.

The analysis of applied RP activity concentration showed a statistically significant difference when a 3 or more % of lower or higher intravenously RP activity concentration is applied at SUVmax ($p < 0.001$) and at SUVmean ($p < 0.001$). SUVmax and SUVmean are increasing at a lower applied activity than recommended and decreasing at higher values. Image 7 and 8 show differences in SUVmax and SUVmean values at a lower applied RP activity.

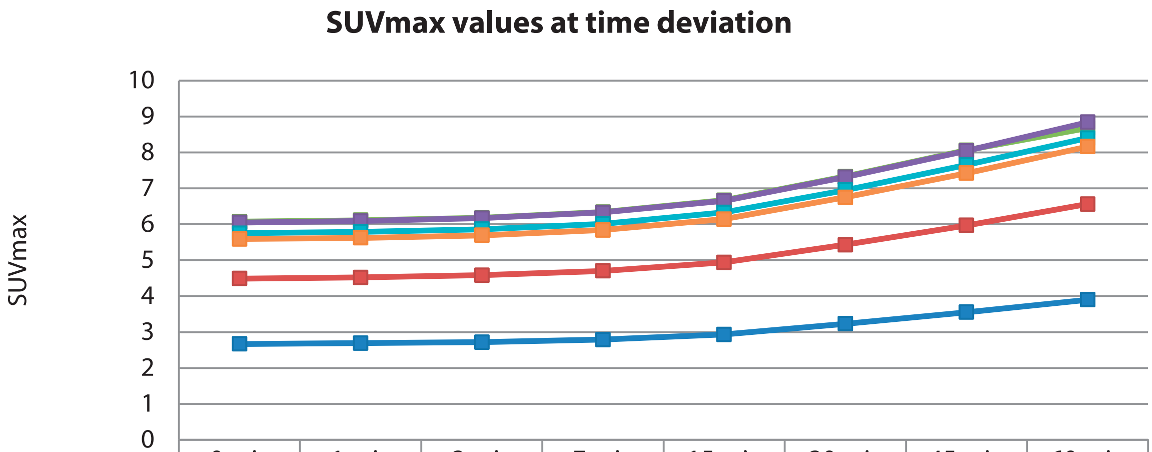
DISCUSSION

Quantitative PET/CT is an important tool for diagnosis, prognosis and monitoring the response to oncological therapy. Many factors impact the quantitative assessment of SUV PET/CT. To understand these factors, I analysed the most common factors and compared them to the results of research conducted by other authors.



	0.5 ml	1.13 ml	2.5 ml	5.02 ml	11.01 ml	23.41 ml
10 kg	0.37	0.47	0.55	0.63	0.66	0.71
11 kg	0.38	0.49	0.58	0.66	0.69	0.73
12 kg	0.39	0.51	0.6	0.69	0.72	0.77
13 kg	0.4	0.53	0.62	0.71	0.74	0.8
14 kg	0.42	0.54	0.64	0.73	0.76	0.82

Image 4: Impact of body weight to SUVmean at different sphere volumes normalised to BSA, when body weight is altered by 10% from the initial weight of the NEMA phantom (10 kg). The curves illustrate the SUVmean value fluctuations at different body weights.



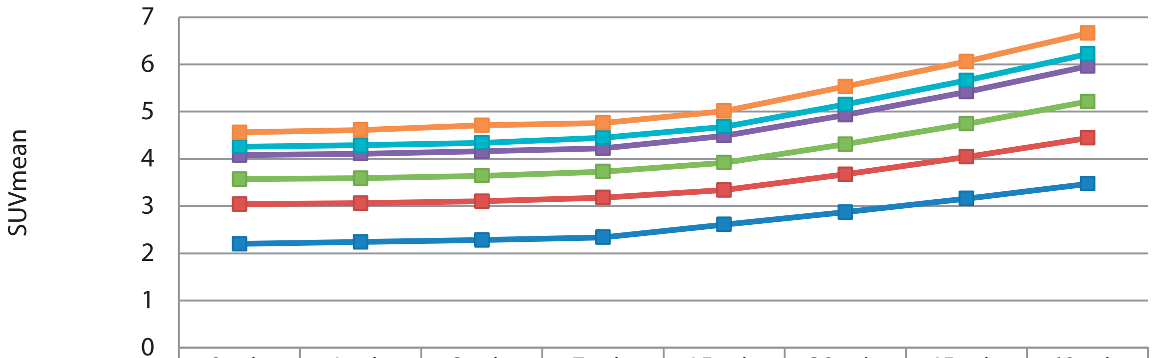
	0 min	1 min	3 min	7 min	15 min	30 min	45 min	60 min
0.5 ml	2.67	2.69	2.72	2.79	2.93	3.23	3.55	3.9
1.13 ml	4.49	4.52	4.58	4.7	4.94	5.43	5.97	6.56
2.5 ml	6.07	6.11	6.18	6.34	6.67	7.33	8.06	8.68
5.02 ml	6.05	6.09	6.17	6.33	6.65	7.31	8.04	8.84
11.01 ml	5.75	5.79	5.86	6.01	6.33	6.95	7.65	8.4
23.41 ml	5.59	5.62	5.69	5.84	6.14	6.75	7.42	8.16

Image 5: SUVmax values at different sphere volumes and time deviations as a consequence of the erroneous entry of application time or time discrepancies between applicator and PET/CT scanner. The curves illustrate the SUVmax value fluctuations at time deviation.

SUVmax and SUVmean are primarily normalised to BW. However, normalisation factors LBM and BSA are also used. Weber et al. (3), Lammertsma et al. (17), Young et al. (18) and Boellaard et al. (19) used analyses and determined that SUVmax and SUVmean normalised to BSA could have been more appropriate in examinations, particularly when patients lose weight during therapy. I conducted this research on the NEMA body phantom and compared SUVmax and SUVmean normalised to BW, LBM and BSA, and came to the conclusion that differences in body weight can have a statistically significant impact on SUVmax and SUVmean when they are normalised to BW and BSA. The results of other authors also show the impact of lost body weight during therapy to SUV. The most appropriate method for the normalisation of SUV is still the subject of discussion and thus needs to be unified with multi-centre trials (3, 8, 9, 17-19).

Time is an important parameter that impacts the quantitative assessment of SUV. The correct calculation of SUV depends on a precise cross-calibration between the PET/CT machine and the activity/dose meter (calibrator) that is used for measuring the activity concentration of applied RP for the patient. A common problem may occur as the result of an erroneous time

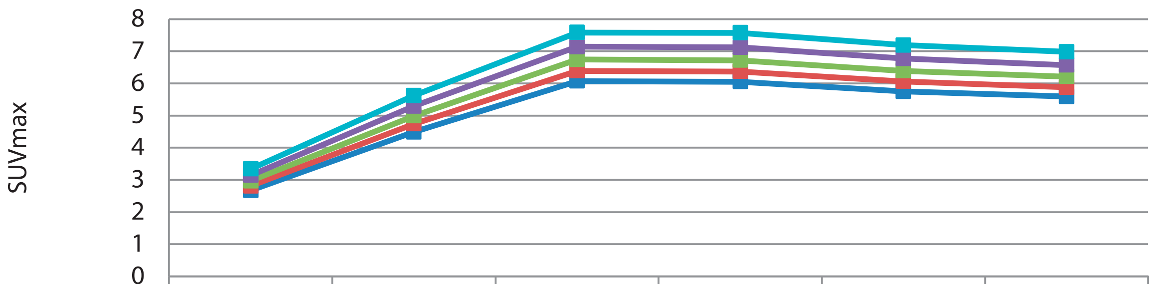
SUVmean values at time deviation



	0 min	1 min	3 min	7 min	15 min	30 min	45 min	60 min
0.5 ml	2.2	2.24	2.28	2.34	2.61	2.87	3.16	3.47
1.13 ml	3.04	3.06	3.1	3.18	3.34	3.67	4.04	4.44
2.5 ml	3.57	3.59	3.64	3.73	3.92	4.31	4.74	5.21
5.02 ml	4.08	4.11	4.16	4.22	4.49	4.93	5.42	5.96
11.01 ml	4.26	4.29	4.34	4.45	4.68	5.15	5.66	6.22
23.41 ml	4.56	4.61	4.71	4.76	5.01	5.53	6.06	6.66

Image 6: SUVmean values at different sphere volumes and time deviations as a consequence of the erroneous entry of application time or time discrepancies between applicator and PET/CT scanner. The curves illustrate the SUVmax value fluctuations at time deviation.

SUVmax values in different applied activities

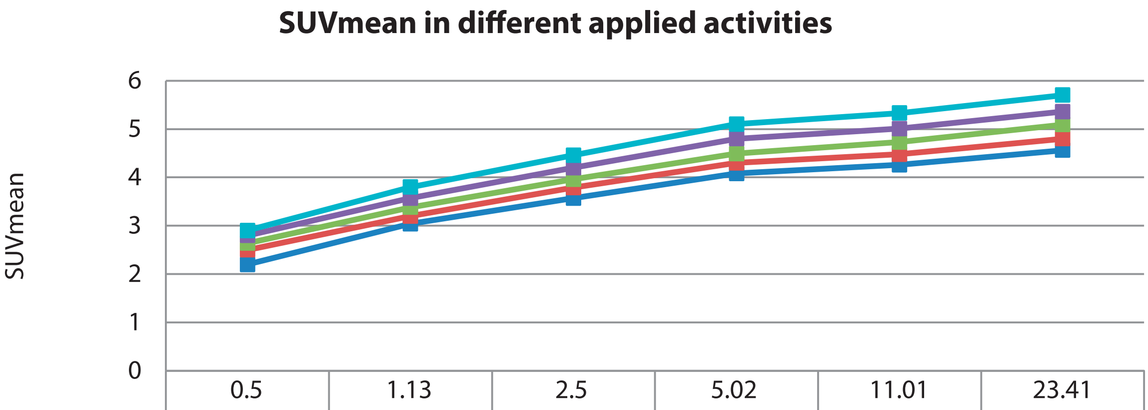


	0.5	1.13	2.5	5.02	11.01	23.41
60 MBq	2.67	4.49	6.07	6.05	5.75	5.59
57 MBq	2.81	4.74	6.39	6.37	6.06	5.88
54 MBq	2.97	4.99	6.74	6.72	6.39	6.21
51 MBq	3.14	5.29	7.14	7.12	6.77	6.57
48 MBq	3.34	5.62	7.58	7.57	7.19	6.98

Image 7: SUVmax values of different sphere volumes and different radiopharmaceutical activities. The curves illustrate the SUVmax value fluctuations at different radiopharmaceutical activities.

synchronisation on a PET/CT scanner and time on the activity/dose meter (calibrator) or read-out computer. RP is prepared for a patient and defined for a specific time unit, which is usually not entirely the same as the actual application time. It is therefore necessary to use the right corrections of physical decay of RP. This means that the RP activity for application must be defined on the basis of RP preparation and application, and the time when PET/CT imaging begins. The obtained analysis results confirm the impact of time on SUV. An error can be the result of erroneous time synchronisation between PET/CT and dose meter (calibrator) or a consequence of erroneous time entry in the imaging protocol. The collected results match the results of other studies (3, 12, 13, 19).

The net activity/dose of prepared RP that is administered to a patient must be measured precisely and applied in whole. It must be ensured that the remaining activity after the RP application in the injector is minimised to 1%. The remaining activity in the injector can be measured after use. It is lower than 3% of the defined dose in most cases (95%). It is necessary to know the exact net activity/dose prepared for a patient. In 5% of all cases, the remaining activity in the injector accounts for 10% (19). This is mostly due to a very high specific RP activity (RP activity on a total amount or mass MBq/ml), i.e. soon after production). To avoid this, the empty volume in the injector and the application process must be taken into account. The aforementioned problems can arise when RP is prepared and



	0.5	1.13	2.5	5.02	11.01	23.41
60 MBq	2.2	3.04	3.57	4.08	4.26	4.56
57 MBq	2.5	3.2	3.79	4.3	4.48	4.8
54 MBq	2.64	3.38	3.96	4.49	4.73	5.09
51 MBq	2.8	3.57	4.2	4.8	5.01	5.36
48 MBq	2.9	3.8	4.46	5.1	5.33	5.7

Image 8: SUVmean values of different sphere volumes and different radiopharmaceutical activities. The curves illustrate the SUVmean value fluctuations at different radiopharmaceutical activities.

applied manually. Using an automatic applicator can eliminate these issues in most cases. If RP is applied paravenously, the quantitative assessment of SUV is not objective. It is, however, still possible and a visual assessment of the PET/CT image is facilitated. The performed analysis confirmed that an incomplete application or inappropriately prepared activity can have a significant impact on the quantitative value of SUVmax and SUVmean, and matched the results published by other authors (3, 19).

PET/CT work includes doctors, medical physicists, registered nurses and graduate radiographers. Radiographers are responsible for a correctly performed examination, which also includes the correct entry of data in imaging protocol (RP applied activity, RP application time, patient's weight and height) and RP application.

Radiographers regularly conduct routine tests (daily and monthly quality control tests (QC)) on a PET/CT machine and applicator, and annual tests together with medical physicists.

CONCLUSION

Quantitative assessment of SUVmax and SUVmean is an important tool in oncology imaging assessment. The analyses showed that parameters, which include incorrect time between the RP application and imaging time, incomplete application or incorrectly measured RP activity as well as incorrect or incorrectly entered body weight of the patient into imaging protocol, can have a significant impact and alter the quantitative assessment of SUVmax and SUVmean. Since a radiographer bears a great responsibility when performing imaging, they must be aware of potential errors that can lead to an incorrect quantitative assessment of SUVmax and SUVmean in the PET/CT examination.

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Radiološki inženirji v prvi bojni liniji

Med pandemijo COVID-19 radiološki inženirji neprekinjeno zagotavljamo visoko kvalitetno slikovno diagnostiko in izvajamo radioterapijo, ob zagotavljanju varnosti bolnikov in samih sebe.

Radiographers on the Frontline

During the COVID-19 pandemic, radiographers continue to provide high quality diagnostic imaging services and deliver cancer treatments, while ensuring the safety of the patients and ourselves.

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