Current Problems in Diagnostic Radiology ▮ (2018) ▮▮▮–▮▮▮

Current Problems in Diagnostic Radiology

journal homepage: www.cpdrjournal.com

Top 100 Cited articles on Radiation Exposure in Medical Imaging: A Bibliometric Analysis

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Background: Bibliometric analyses by highest number of citations can help researchers and funding agencies in determining the most influential articles in a field. The main objective of this analysis was to identify the top 100 cited articles addressing radiation exposure from medical imaging and assess their characteristics.

Methods: Relevant articles were extracted from the Scopus database after a systematic search by researchers using an iteratively defined Boolean search string. Subsequently, exclusion criteria were applied. A list of top 100 articles was prepared, and articles were ranked according to the citations they had received. No time restriction was applied. Descriptive statistics of the data were compiled.

Results: The top-cited articles were published from 1970-2013, with the most articles published in 2009 and 2010 (12 articles in each year). The citations ranged from 107-1888 with a median of 272. Manuscripts from our top-cited list originated from 20 different countries, with contributions made by 158 authors and 160 organizations. Eighty-eight percent of studies evaluated patient-related radiation exposure, 7% health care workers, and 5% both or were not specified. Thirty-two percent of studies examined adult populations, 14% pediatric, and 54% included both populations or did not specify. Seventy-two percent of studies were dedicated to Computed Tomography, 8% to radiography/fluoroscopy, 9% to interventional procedures, 4% to nuclear medicine, and 7% to a combination of 2 or more modalities.

Conclusion: The top 100 cited articles in medical imaging related to radiation exposure are diverse, originating from many countries with numerous contributing authors. The most common topics covered involve CT and adult patients. The recent peak in the most-highly cited articles (2010) suggests that increased attention has been devoted to this field in recent years. Based on these results, it would appear that research on radiation exposure in medical imaging is poised to continue expanding.

Introduction

Since the discovery of the x-ray in 1895,[1] the use of ionizing radiation in diagnostic and therapeutic medical procedures has proliferated, with numerous benefits but also consequences. The central deleterious effect is that patients as well as medical staff are exposed to radiation. Some adverse effects of radiation, such as skin erythema and cataracts, only occur above a certain threshold.[2] These are rare as the medical community is diligent to ensure that no patient or staff exceeds these thresholds. Other effects of radiation are dose dependent, such as genetic mutations, deformities, and cancer.[3,4] The risk of these effects increases with each subsequent dose of radiation a person receives, and therefore it is very important that one understands how much radiation exposure may be encountered from each of the different diagnostic and interventional imaging modalities employed.

It is now estimated that the amount of radiation certain individual patients have received from diagnostic imaging approaches the dose of radiation that Japanese survivors of the atomic bomb received.[5] It was estimated that 2500 deaths in the United States over a one-year period were attributed to Computed Tomography (CT) examinations alone.[6] Increasing volume of research is being conducted on minimizing radiation dose during medical imaging.[7,8] The hazards of radiation exposure are increasingly publicized, and there has been a strong desire to limit nontherapeutic medical radiation exposure. Regulatory bodies have published guidelines in an attempt to protect people from excess ionizing radiation and its consequences.[9] This is a popular area for research, with various studies focusing on reducing dose, protecting patients, or investigating how to accurately estimate cumulative patient dose.[10–14]

In this study, we conducted a bibliometric analysis of the literature focused on the dose and impact of radiation to patients and medical professionals. Citation frequency is a type of bibliometric analysis which centers on examining those publications

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https://doi.org/10.1067/j.cpradiol.2018.03.005
0363-0188/

TABLE 1
Top 100 articles listed by number of citations

	Authors	Title	Year	Cited by
1	Brenner, D.J., Elliston, C.D., Hall, E.J., Berdon, W.E.	Estimated risks of radiation-induced fatal cancer from pediatric CT	2001	1888
2	Pearce, M.S., Salotti, J.A., Little, M.P., McHugh, K., Lee, C., Kim, K.P., Howe, N.L., Ronckers, C.M., Rajaraman, P., Craft, A.W., Parker, L., De González, A.B.	Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumors: A retrospective cohort study	2012	1215
3	Smith-Bindman, R., Lipson, J., Marcus, R., Kim, K.-P., Mahesh, M., Gould, R., Berrington De González, A., Miglioretti, D.L.	Radiation dose associated with common computed tomography examinations and the associated lifetime attributable risk of cancer	2009	1140
4	Berrington De González, A., Mahesh, M., Kim, K.-P., Mettler, F., Land, C.	Projected cancer risks from computed tomographic scans performed in the United States in 2007	2009	1032
5	Einstein, A.J., Henzlova, M.J., Rajagopalan, S.	Estimating risk of cancer associated with radiation exposure from 64-slice computed tomography coronary angiography	2007	1024
6	Fazel, R., Krumholz, H.M., Wang, Y., Ross, J.S., Chen, J., Ting, H.H., Shah, N.D., Nasir, K., Einstein, A.J., Nallamothu, B.K.	Exposure to low-dose ionizing radiation from medical imaging procedures	2009	809
7	Hausleiter, J., Meyer, T., Hermann, F., Hadamitzky, M., Krebs, M., Gerber, T. C., McCollough, C.,Martinoff, S., Kastrati, A., Schömig, A., Achenbach, S.	Estimated radiation dose associated with cardiac CT angiography	2009	696
8	Hausleiter, J., Meyer, T., Hadamitzky, M., Huber, E., Zankl, M., Martinoff, S., Kastrati, A., Schömig, A.	Radiation dose estimates from cardiac multislice computed tomography in daily practice: Impact of different scanning protocols on effective dose estimates	2006	577
9	Jakobs, T.F., Becker, C.R., Ohnesorge, B., Flohr, T., Suess, C., Schoepf, U.J., Reiser, M.F.	Multislice helical CT of the heart with retrospective ECG gating: Reduction of radiation exposure by ECG-controlled tube current modulation	2002	521
10	Hara, A.K., Paden, R.G., Silva, A.C., Kujak, J.L., Lawder, H.J., Pavlicek, W.	Iterative reconstruction technique for reducing body radiation dose at CT: Feasibility study	2009	478
11	Sodickson, A., Baeyens, P.F., Andriole, K.P., Prevedello, L.M., Nawfel, R.D., Hanson, R., Khorasani, R.	Recurrent CT, cumulative radiation exposure, and associated radiation-induced cancer risks from CT of adults	2009	477
12	Brenner, D.J., Elliston, C.D.	Estimated radiation on risks potentially associated with full-body CT screening	2004	456
13	Earls, J.P., Berman, E.L., Urban, B.A., Curry, C.A., Lane, J.L., Jennings, R.S., McCulloch, C.C., Hsieh, J., Londt, J.H.	Prospectively gated transverse coronary CT angiography versus retrospectively gated helical technique: Improved image quality and reduced radiation dose	2008	436
14	Lee, C.I., Haims, A.H., Monico, E.P., Brink, J.A., Forman, H.P.	Diagnostic CT scans: assessment of patient, physician, and radiologist awareness of radiation dose and possible risks	2004	431
15	Mettler Jr., F.A., Bhargavan, M., Faulkner, K., Gilley, D.B., Gray, J.E., Ibbott, G.S., Lipoti, J.A., Mahesh, M., McCrohan, J.L., Stabin, M.G., Thomadsen, B.R., Yoshizumi, T.T.	Radiologic and nuclear medicine studies in the United States and worldwide: Frequency, radiation dose, and comparison with other radiation sources - 1950-2007	2009	384
16	Miglioretti, D.L., Johnson, E., Williams, A., Greenlee, R.T., Weinmann, S., Solberg, L.I., Feigelson,H.S., Roblin, D., Flynn, M.J., Vanneman, N., Smith-Bindman, R.	The use of computed tomography in pediatrics and the associated radiation exposure and estimated cancer risk	2013	359
17	Boone, J.M., Nelson, T.R., Lindfors, K.K., Seibert, J.A.	Dedicated breast CT: Radiation dose and image quality evaluation	2001	358
18	Hunold, P., Vogt, F.M., Schmermund, A., Debatin, J.F., Kerkhoff, G., Budde, T., Erbel, R., Ewen, K., Barkhausen, J.	Radiation exposure during cardiac CT: Effective doses at multidetector row CT and electron-beam CT	2003	357
19	Marin, D., Nelson, R.C., Schindera, S.T., Richard, S., Youngblood, R.S., Yoshizumi, T.T., Samei, E.	Low-tube-voltage, high-tube-current multidetector abdominal CT: Improved image quality and decreased radiation dose with adaptive statistical iterative reconstruction algorithm—Initial clinical experience	2010	337
20	Brody, A.S., Frush, D.P., Huda, W., Brent, R.L., DiPietro, M.A., Applegate, K.E., Cassady, C.I., Cohen, H., Wood, B.P., Wyly, J.B., Stolic, A.	Radiation risk to children from computed tomography	2007	329
21	Smith-Bindman, R., Miglioretti, D.L., Johnson, E., Lee, C., Feigelson, H.S., Flynn, M., Greenlee, R.T., Kruger, R.L., Hornbrook, M.C., Roblin, D., Solberg, L.I., Vanneman, N., Weinmann, S., Williams, A.E.	Use of diagnostic imaging studies and associated radiation exposure for patients enrolled in large integrated health care systems, 1996-2010	2012	316
22	Shuman, W.P., Branch, K.R., May, J.M., Mitsumori, L.M., Lockhart, D.W., Dubinsky, T.J., Warren, B.H., Caldwell, J.H.	Prospective versus retrospective ECG gating for 64-detector CT of the coronary arteries: Comparison of image quality and patient radiation dose	2008	316
23	Maryanski, M.J., Schulz, R.J., Ibbott, G.S., Gatenby, J.C., Xie, J., Horton, D., Gore, J.C.	Magnetic resonance imaging of radiation dose distributions using a polymer-gel dosimeter	1994	316
24	Gore, J.C., Kang, Y.S.	Measurement of radiation dose distributions by nuclear magnetic resonance (NMR) imaging	1984	299
25	Brix, G., Lechel, U., Glatting, G., Ziegler, S.I., M̈nzing, W., Müller, S.P., Beyer, T.	Radiation exposure of patients undergoing whole-body dual-modality 18F-FDG PET/CT examinations	2005	285
26	Brenner, D.J.	Radiation risks potentially associated with low-dose CT screening of adult smokers for lung cancer	2004	282
27	Prakash, P., Kalra, M.K., Kambadakone, A.K., Pien, H., Hsieh, J., Blake, M.A., Sahani, D.V.	Reducing abdominal CT radiation dose with adaptive statistical iterative reconstruction technique	2010	267
28	Nakayama, Y., Awai, K., Funama, Y., Hatemura, M., Imuta, M., Nakaura, T., Ryu, D., Morishita, S., Sultana, S., Sato, N., Yamashita, Y.	Abdominal CT with low tube voltage: Preliminary observations about radiation dose, contrast enhancement, image quality, and noise	2005	263
29	Hirai, N., Horiguchi, J., Fujioka, C., Kiguchi, M., Yamamoto, H., Matsuura, N., Kitagawa, T., Teragawa, H., Kohno, N., Ito, K.	Prospective vs retrospective ECG-gated 64-detector coronary CT angiography: Assessment of image quality, stenosis, and radiation dose	2008	257
30	Dewey, M., Zimmermann, E., Deissenrieder, F., Laule, M., Dübel, H.-P., Schlattmann, P., Knebel, F., Rutsch, W., Hamm, B.	Noninvasive coronary angiography by 320-row computed tomography with lower radiation exposure and maintained diagnostic accuracy: Comparison of results with cardiac catheterization in a head-to-head pilot investigation	2009	240
31	Vañó, E., González, L., Guibelalde, E., Fernández, J.M., Ten, J.I.	Radiation exposure to medical staff in interventional and cardiac radiology	1998	235
32	Shadley, J.D., Afzal, V., Wolff, S.	Characterization of the adaptive response to ionizing radiation induced by low doses of x-rays to human lymphocytes	1987	231

TABLE 1 (*continued*)

	Authors	Title	Year	Cited by
33	Fong, P.M., Keil, D.C., Does, M.D., Gore, J.C.	Polymer gels for magnetic resonance imaging of radiation dose distributions at normal room atmosphere	2001	230
34	Coles, D.R., Smail, M.A., Negus, I.S., Wilde, P., Oberhoff, M., Karsch, K.R., Baumbach, A.	Comparison of radiation doses from multislice computed tomography coronary angiography and conventional diagnostic angiography	2006	227
35	Winer-Muram, H.T., Boone, J.M., Brown, H.L., Jennings, S.G., Mabie, W.C., Lombardo, G.T.	Pulmonary embolism in pregnant patients: Fetal radiation dose with helical CT	2002	227
36	Stolzmann, P., Leschka, S., Scheffel, H., Krauss, T., Desbiolles, L., Plass, A., Genoni, M., Flohr, T.G., Wildermuth, S., Marincek, B., Alkadhi, H.	Dual-source CT in step-and-shoot mode: Noninvasive coronary angiography with low radiation dose	2008	220
37	Leipsic, J., LaBounty, T.M., Heilbron, B., Min, J.K., Mancini, G.B.J., Lin, F.Y., Taylor, C., Dunning, A., Earls, J.P.	Estimated radiation dose reduction using adaptive statistical iterative reconstruction in coronary CT angiography: The ERASIR study	2010	219
38	Heyer, C.M., Mohr, P.S., Lemburg, S.P., Peters, S.A., Nicolas, V.	Image quality and radiation exposure at pulmonary CT angiography with 100- or 120-kVp protocol: Prospective randomized study	2007	219
39	Islam, M.K., Purdie, T.G., Norrlinger, B.D., Alasti, H., Moseley, D.J., Sharpe, M.B., Siewerdsen, J.H., Jaffray, D.A.	Patient dose from kilovoltage cone beam computed tomography imaging in radiation therapy	2006	218
40	Schulze, D., Heiland, M., Thurmann, H., Adam, G.	Research: Radiation exposure during midfacial imaging using 4- and 16-slice computed tomography, cone beam computed tomography systems and conventional radiography	2004	215
41	Miller, D.L., Balter, S., Cole, P.E., Lu, H.T., Schueler, B.A., Geisinger, M., Berenstein, A., Albert, R., Georgia, J.D., Noonan, P.T., Cardella, J.F., St. George, J., Russell, E.J., Malisch, T.W., Vogelzang, R.L., Miller III, G.L., Anderson, J.	Radiation doses in interventional radiology procedures: The RAD-IR study part I: Overall measures of dose	2003	211
42	Stewart, A., Kneale, G.W.	Radiation dose effects in relation to obstetric x-rays and childhood	1970	210
43	Leschka, S., Stolzmann, P., Schmid, F.T., Scheffel, H., Stinn, B., Marincek, B., Alkadhi, H., Wildermuth, S.	Low kilovoltage cardiac dual-source CT: Attenuation, noise, and radiation dose	2008	208
44	Singh, S., Kalra, M.K., Gilman, M.D., Hsieh, J., Pien, H.H., Digumarthy, S.R., Shepard, J.-A.O.	Adaptive statistical iterative reconstruction technique for radiation dose reduction in chest CT: A pilot study	2011	204
45	Siegel, M.J., Schmidt, B., Bradley, D., Suess, C., Hildebolt, C.	Radiation dose and image quality in pediatric CT: Effect of technical factors and phantom size and shape	2004	200
46	Shadley, J.D., Wolff, S.	Very low doses of x-rays can cause human lymphocytes to become less susceptible to ionizing radiation	1987	198
47	Moscariello, A., Takx, R.A.P., Schoepf, U.J., Renker, M., Zwerner, P.L., O′Brien, T.X., Allmendinger, T., Vogt, S., Schmidt, B., Savino, G., Fink, C., Bonomo, L., Henzler, T.	Coronary CT angiography: Image quality, diagnostic accuracy, and potential for radiation dose reduction using a novel iterative image reconstruction technique-comparison with traditional filtered back projection	2011	190
48	Raff, G.L., Chinnaiyan, K.M., Share, D.A., Goraya, T.Y., Kazerooni, E.A., Moscucci, M., Gentry, R.E., Abidov, A.	Radiation dose from cardiac computed tomography before and after implementation of radiation dose-reduction techniques	2009	188
49	Huang, B., Law, M.W.-M., Khong, P.-L.	Whole-body PET/CT scanning: Estimation of radiation dose and cancer risk	2009	188
50	Huda, W., Atherton, J.V., Ware, D.E., Cumming, W.A.	An approach for the estimation of effective radiation dose at CT in pediatric patients	1997	182
51	Hurwitz, L.M., Reiman, R.E., Yoshizumi, T.T., Goodman, P.C., Toncheva, G., Nguyen, G., Lowry, C.	Radiation dose from contemporary cardiothoracic multidetector CT protocols with an anthropomorphic female phantom: Implications for cancer induction	2007	180
52	Silverman, S.G., Tuncali, K., Adams, D.F., Nawfel, R.D., Zou, K.H., Judy, P.F.	CT fluoroscopy-guided abdominal interventions: Techniques, results, and radiation exposure	1999	175
53	Stolzmann, P., Scheffel, H., Schertler, T., Frauenfelder, T., Leschka, S., Husmann, L., Flohr, T.G., Marincek, B., Kaufmann, P.A., Alkadhi, H.	Radiation dose estimates in dual-source computed tomography coronary angiography	2008	171
54	Wintersperger, B., Jakobs, T., Herzog, P., Schaller, S., Nikolaou, K., Suess, C., Weber, C., Reiser, M., Becker, C.	Aortoiliac multidetector-row CT angiography with low kV settings: Improved vessel enhancement and simultaneous reduction of radiation dose	2005	168
55	Mehlman, C.T., DiPasquale, T.G.	Radiation exposure to the orthopaedic surgical team during fluoroscopy: "How far away is far enough?"	1997	168
56	Miller, D.L., Balter, S., Cole, P.E., Lu, H.T., Berenstein, A., Albert, R., Schueler, B.A., Georgia, J.D., Noonan, P.T., Russell, E.J., Malisch, T.W., Vogelzang, R. L., Geisinger, M., Cardella, J.F., St. George, J., Miller III, G.L., Anderson, J.	Radiation doses in interventional radiology procedures: The RAD-IR study. Part II: Skin dose	2003	166
57	Chodick, G., Bekiroglu, N., Hauptmann, M., Alexander, B.H., Freedman, D. M., Doody, M.M., Cheung, L.C., Simon, S.L., Weinstock, R.M., Bouville, A., Sigurdson, A.J.	Risk of cataract after exposure to low doses of ionizing radiation: A 20-year prospective cohort study among US radiologic technologists	2008	164
58	Silva, M.A.G., Wolf, U., Heinicke, F., Bumann, A., Visser, H., Hirsch, E.	Cone-beam computed tomography for routine orthodontic treatment planning: A radiation dose evaluation	2008	164
59	Prakash, P., Kalra, M.K., Digumarthy, S.R., Hsieh, J., Pien, H., Singh, S., Gilman, M.D., Shepard, J.-A.O.	Radiation dose reduction with chest computed tomography using adaptive statistical iterative reconstruction technique: Initial experience	2010	163
60	Trabold, T., Buchgeister, M., Küttner, A., Heuschmid, M., Kopp, A.F., Schröder, S., Claussen, C.D.	Estimation of radiation exposure in 16-detector row computed tomography of the heart with retrospective ECG-gating	2003	161
61	Abada, H.T., Larchez, C., Daoud, B., Sigal-Cinqualbre, A., Paul, J.-F.	MDCT of the coronary arteries: Feasibility of low-dose CT with ECG-pulsed tube current modulation to reduce radiation dose	2006	160
62	Howe, G.R., McLaughlin, J.	Breast cancer mortality between 1950 and 1987 after exposure to fractionated moderate-dose-rate ionizing radiation in the canadian fluoroscopy cohort study and a comparison with breast cancer mortality in the atomic bomb survivors study	1996	160
63	Katsura, M., Matsuda, I., Akahane, M., Sato, J., Akai, H., Yasaka, K., Kunimatsu, A., Ohtomo, K.	Model-based iterative reconstruction technique for radiation dose reduction in chest CT: Comparison with the adaptive statistical iterative reconstruction technique	2012	153

TABLE 1 (*continued*)

	Authors	Title	Year	Cited by
64	Funama, Y., Awai, K., Nakayama, Y., Kakei, K., Nagasue, N., Shimamura, M., Sato, N., Sultana, S., Morishita, S., Yamashita, Y.	Radiation dose reduction without degradation of low-contrast detectability at abdominal multisection CT with a low tube voltage technique: Phantom study	2005	153
65	Van Gelder, R.E., Venema, H.W., Serlie, I.W.O., Nio, C.Y., Determann, R.M., Tipker, C.A., Vos, F.M., Glas, A.S., Bartelsman, J.F.W., Bossuyt, P.M.M., Laméris, J.S., Stoker, J.	CT colonography at different radiation dose levels: Feasibility of dose reduction	2002	152
66	Flicek, K.T., Hara, A.K., Silva, A.C., Wu, Q., Peter, M.B., Johnson, C.D.	Reducing the radiation dose for CT colonography using adaptive statistical iterative reconstruction: A pilot study	2010	149
67	Hausleiter, J., Martinoff, S., Hadamitzky, M., Martuscelli, E., Pschierer, I., Feuchtner, G.M., Cataln-Sanz, P., Czermak, B., Meyer, T.S., Hein, F., Bischoff, B., Kuse, M., Schmig, A., Achenbach, S.	Image quality and radiation exposure with a low tube voltage protocol for coronary CT angiography: results of the PROTECTION II trial	2010	147
68	Hendrick, R.E.	Radiation doses and cancer risks from breast imaging studies	2010	146
69	Huda, W., Vance, A.	Patient radiation doses from adult and pediatric CT	2007	145
70	Paulson, E.K., Sheafor, D.H., Enterline, D.S., McAdams, H.P., Yoshizumi, T.T.	CT fluoroscopy-guided interventional procedures: Techniques and radiation dose to radiologists	2001	144
71	Bischoff, B., Hein, F., Meyer, T., Hadamitzky, M., Martinoff, S., Schömig, A., Hausleiter, J.	Impact of a reduced tube voltage on CT angiography and radiation dose. Results of the PROTECTION I study	2009	143
72	Sankaranarayanan, K., Duyn, A.v., Loos, M.J., Natarajan, A.T.	Adaptive response of human lymphocytes to low-level radiation from radioisotopes or X-rays	1989	143
73	Maruyama, T., Takada, M., Hasuike, T., Yoshikawa, A., Namimatsu, E., Yoshizumi, T.	Radiation dose reduction and coronary assessability of prospective electrocardiogram-gated computed tomography coronary angiography. Comparison with retrospective electrocardiogram-gated helical scan	2008	142
74	McParland, B.J.	A study of patient radiation doses in interventional radiological procedures	1998	137
75	Frush, D.P., Slack, C.C., Hollingsworth, C.L., Bisset, G.S., Donnelly, L.F., Hsieh, J., Lavin-Wensell, T., Mayo, J.R.	Computer-simulated radiation dose reduction for abdominal multidetector CT of pediatric patients	2002	134
76	Mayo, J.R., Hartman, T.E., Kyung Soo Lee, Primack, S.L., Vedal, S., Muller, N.L.	CT of the chest: Minimal tube current required for good image quality with the least radiation dose	1995	134
77	Alkadhi, H., Stolzmann, P., Desbiolles, L., Baumueller, S., Goetti, R., Plass, A., Scheffel, H., Feuchtner, G., Falk, V., Marincek, B., Leschka, S.	Low-dose, 128-slice, dual-source CT coronary angiography: Accuracy and radiation dose of the high-pitch and the step-and-shoot mode	2010	132
78	Chang, S.M., Nabi, F., Xu, J., Raza, U., Mahmarian, J.J.	Normal stress-only vs standard stress/rest myocardial perfusion imaging. similar patient mortality with reduced radiation exposure	2010	131
79	Deschênes, S., Charron, G., Beaudoin, G., Labelle, H., Dubois, J., Miron, M.-C., Parent, S.	Diagnostic imaging of spinal deformities: Reducing patients radiation dose with a new slot-scanning X-ray imager	2010	129
80	Madani, A., De Maertelaer, V., Zanen, J., Gevenois, P.A.	Pulmonary emphysema: Radiation dose and section thickness at multidetector CT quantification—comparison with macroscopic and microscopic morphometry	2007	129
81	Yu, L., Li, H., Fletcher, J.G., McCollough, C.H.	Automatic selection of tube potential for radiation dose reduction in CT: A general strategy	2010	128
82	Ravenel, J.G., Scalzetti, E.M., Huda, W., Garrisi, W.	Radiation exposure and image quality in chest CT examinations	2001	128
83	Zankl, M., Veit, R., Williams, G., Schneider, K., Fendel, H., Petoussi, N., Drexler, G.	The construction of computer tomographic phantoms and their application in radiology and radiation protection	1988	127
84	Katz, S.I., Saluja, S., Brink, J.A., Forman, H.P.	Radiation dose associated with unenhanced CT for suspected renal colic: Impact of repetitive studies	2006	126
85	Ware, D.E., Huda, W., Mergo, P.J., Litwiller, A.L.	Radiation effective doses to patients undergoing abdominal CT examinations	1999	126
86	Fricke, B.L., Donnelly, L.F., Frush, D.P., Yoshizumi, T., Varchena, V., Poe, S.A., Lucaya, J.	In-plane bismuth breast shields for pediatric CT: Effects on radiation dose and image quality using experimental and clinical data	2003	122
87	Nawfel, R.D., Judy, P.F., Schleipman, A.R., Silverman, S.G.	Patient radiation dose at CT urography and conventional urography	2004	121
88	Einstein, A.J., Elliston, C.D., Arai, A.E., Chen, M.Y., Mather, R., Pearson, G.D. N., Delapaz, R.L., Nickoloff, E., Dutta, A., Brenner, D.J.	Radiation dose from single-heartbeat coronary CT angiography performed with a 320-detector row volume scanner	2010	120
89	Heneghan, J.P., McGuire, K.A., Leder, R.A., DeLong, D.M., Yoshizumi, T., Nelson, R.C.	Helical CT for nephrolithiasis and ureterolithiasis: Comparison of conventional and reduced radiation-dose techniques	2003	118
90	Slomczykowski, M., Roberto, M., Schneeberger, P., Ozdoba, C., Vock, P.	Radiation dose for pedicle screw insertion: Fluoroscopic method vs computer-assisted surgery	1999	118
91	Kluner, C., Hein, P.A., Gratta, O., Hein, E., Hamm, B., Romano, V., Rogalla, P.	Does ultra-low-dose CT with a radiation dose equivalent to that of KUB suffice to detect renal and ureteral calculi?	2006	116
92	Cohnen, M., Kemper, J., Möbes, O., Pawelzik, J., Mödder, U.	Radiation dose in dental radiology	2002	116
93	Kan, M.W.K., Leung, L.H.T., Wong, W., Lam, N.	Radiation dose from cone beam computed tomography for image-guided radiation therapy	2008	113
94	Lange, H.W., Von Boetticher, H.	Randomized comparison of operator radiation exposure during coronary angiography and intervention by radial or femoral approach	2006	113
95	Hamberg, L.M., Rhea, J.T., Hunter, G.J., Thrall, J.H.	Multi-detector row CT: Radiation dose characteristics	2003	113
96	Griffey, R.T., Sodickson, A.	Cumulative radiation exposure and cancer risk estimates in emergency department patients undergoing repeat or multiple CT	2009	111
97	Kalra, M.K., Woisetschläger, M., Dahlström, N., Singh, S., Lindblom, M., Choy, G., Quick, P., Schmidt, B., Sedlmair, M., Blake, M.A., Persson, A.	Radiation dose reduction with sinogram affirmed iterative reconstruction technique for abdominal computed tomography	2012	110
98	Doran, S.J., Koerkamp, K.K., Bero, M.A., Jenneson, P., Morton, E.J., Gilboy, W.B.	A CCD-based optical CT scanner for high-resolution 3D imaging of radiation dose distributions: Equipment specifications, optical simulations and preliminary results	2001	110
99	Howe, G.R.	Lung cancer mortality between 1950 and 1987 after exposure to fractionated moderate-dose-rate ionizing radiation in the Canadian fluoroscopy cohort study and a comparison with lung cancer mortality in the atomic bomb survivors study	1995	110

TABLE 1 (*continued*)

	Authors	Title	Year	Cited by
100	Kato, R., Katada, K., Anno, H., Suzuki, S., Ida, Y., Koga, S.	Radiation dosimetry at CT fluoroscopy: Physician's hand dose and development of needle holders	1996	107
			Total	27261
			Mean	273

which have been most-referenced by other researchers. Citation frequency serves as a proxy for influence and secondarily for quality of medical publications; looking at the most-cited manuscripts in a field allows for the evaluation of contributions by specific authors, organizations, and countries.[15] This type of analysis can show burgeoning trends, evaluate the progression of research patterns over time, highlight authors or centers of excellence, and provide information for researchers and editors.[16-18]

Although bibliometric analyses have been published in multiple fields of medicine, including many aspects of radiology,[19-22] our literature search did not reveal a bibliometric analysis on radiation exposure from medical imaging. With this study, the main goal is to elucidate which prior publications have been the most impactful in this area so that other researchers can then use these results to conduct further studies. A secondary goal was to determine which aspects of radiation research require further attention from investigators and regulatory bodies. This would serve to encourage future research in these areas of need, which would benefit this field of research as a whole.

Materials and Methods

To conduct the present study, a search was carried out in October of 2017 using the SCOPUS database with the intention of retrieving the top-cited articles related to ionizing radiation exposure via medical imaging. Although different databases may present different numbers of citations counts for the same articles, SCOPUS is the database which has been used in most prior bibliometrics publications; therefore, we decided to keep the method consistent. Scopus has also been shown to be equal, if not superior to, other well-known databases such as Google Scholar and Web of Science.[23-24]

No specific year parameters were chosen. We wanted SCOPUS to search as far back in time and as recently as possible. To obtain broad yet relatively focused results, the following search was conducted using common Boolean search parameters. These specific terms were chosen by 2 practicing radiologists familiar with bibliometric analyses. This search string was subsequently vetted through verification against common literature terms in the field and iteratively refined by cross-checking reference lists of the highly cited papers.

(TITLE (radiation OR radioactive) AND TITLE (expos* OR harm* OR dose OR level OR protect* OR damag* OR risk* OR consequence) AND TITLE (radiolog* OR imaging OR x-ray OR CT OR "computed tomography" OR angiography OR pet OR "PET/CT" OR "positron emission tomography" OR fluoro* OR "nuclear medicine" OR "V/Q" OR "ventilation perfusion" OR "interventional radiology" OR "gamma camera" OR MUGA OR MIBI))

This specific search returned 5640 results, from the years 1970 through to 2013, which were ranked by citation frequency in the Scopus Database. We then systematically reviewed the publications starting with highest cited publication and applied the following exclusion criteria: studies conducted on animals or nonliving matter, studies concerned with treatment doses of radiation (as opposed to diagnostic or interventional), those which were published in a language other than English, and those which were not a primary research article published in a peer-reviewed journal. The authors processed the top 170 cited publications, and after applying these criteria, were left with 134 publications, of which the top 100 were selected and listed in descending order of number of citations.

Once the final list of the top 100 cited articles was created, the following analyses were performed: range and average number of citations, countries of origin, number of publications by author, year of publication, affiliation, journal source, and proportions of

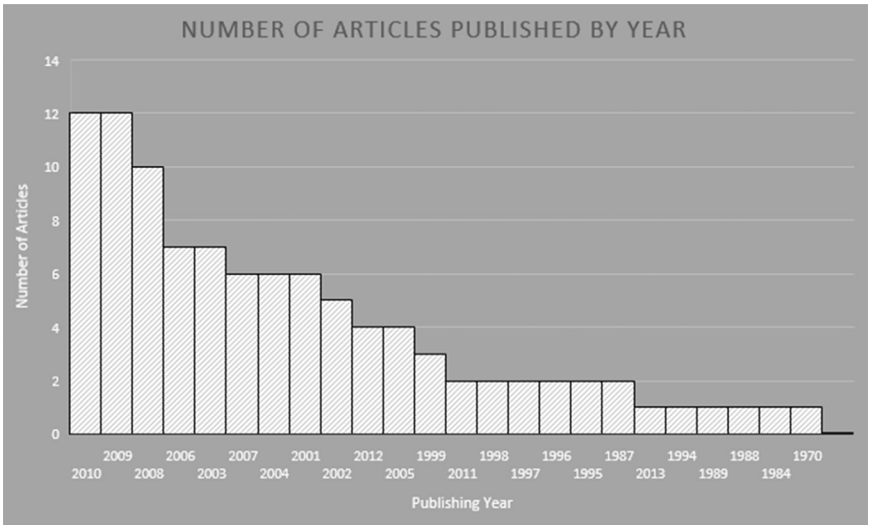

FIG 1. Number of articles published by year.

TABLE 2
Number of articles published per journal that published at least 2 articles

Journal name	Number of articles
Radiology	32
American Journal of Roentgenology	12
European Radiology	7
Physics in Medicine and Biology	4
JAMA Journal of the American Medical Association	3
Journal of Computer Assisted Tomography	3
Journal of the American College of Cardiology	3
Radiation Research	3
Archives of Internal Medicine	2
British Journal of Radiology	2
Circulation	2
Jacc Cardiovascular Imaging	2
Journal of Vascular and Interventional Radiology	2
Lancet	2
Medical Physics	2
Spine	2
American Journal of Epidemiology	1
American Journal of Orthodontics and Dentofacial Orthopedics	1
Catheterization and Cardiovascular Interventions	1
Dentomaxillofacial Radiology	1
Heart	1
International Journal of Radiation Oncology Biology Physics	1
Investigative Radiology	1
JAMA Pediatrics	1
Journal of Nuclear Medicine	1
Journal of Orthopaedic Trauma	1
Journal of the American Medical Association	1
Mutagenesis	1
Mutation Research Fundamental and Molecular Mechanisms of Mutagenesis	1
New England Journal of Medicine	1
Pediatrics	1
Radiation and Environmental Biophysics	1
Rofo Fortschritte Auf Dem Gebiet Der Rontgenstrahlen Und Der Bildgebenden Verfahren	1

*Also making contributions were the following journals: American Journal of Epidemiology, American Journal of Orthodontics and Dentofacial Orthopedics, Catheterization and Cardiovascular Interventions, Dentomaxillofacial, Radiology, Heart, International Journal of Radiation Oncology Biology Physics, Investigative Radiology, JAMA, Pediatrics, Journal of Nuclear Medicine, Journal of Orthopaedic Trauma, Journal of the American Medical, Association, Mutagenesis, Mutation Research Fundamental and Molecular Mechanisms of Mutagenesis, New England Journal of Medicine, Pediatrics, Radiation and Environmental Biophysics, and Rofo Fortschritte Auf Dem Gebiet Der Rontgenstrahlen Und Der Bildgebenden Verfahren

the following: adult and pediatric patients, patients and health care workers, and imaging modalities.

Results

The top 100 cited articles ranked by total number of citations are listed in Table 1. The lowest cited article in the top 100 was cited 107 times and the highest cited article 1888 times. The mean number of citations was 272.

These articles were published from 1970 through 2013. The years 2009 and 2010 contained the most articles out of the top 100, with 12 each. The highest cited article was published in 2001 and the lowest one in 1996. Figure 1 displays the number of articles per year that composed the top 100.

These articles were published in a total of 32 journals. The top 3 publishing journals were *Radiology,*[32] *American Journal of Roentgenology,*[12] and *European Journal of Radiology.*[7] Table 2 shows the list of journals which have published at least 2 of the most frequently cited articles in this field. The other contributing journals (which published 1 article each) are listed below the table.

A total of 160 organizations have contributed to research in the top 100 articles in this field. The one with the most contributions was the National Cancer Institute with 7. Table 3 provides a complete list of contributing organizations.

In terms of countries, 20 countries contributed. There was 1 article in which the country of origin was undetermined. The United States contributed greater than half of the publications with 58. Table 4 lists all the countries of origin.

A total of 158 authors have made contributions in this list of top 100 articles. Huda, W. and Hsieh, J. were the authors contributing the most publications, with 5 each. The complete list of authors and their total number of publications can be seen in Table 5.

Eighty-eight percent of studies were dedicated to patient-related radiation exposure, 7% to health care workers, and 5% were not specified. These proportions of subject matter are displayed graphically in Figure 2.

Thirty-two percent of studies were dedicated to adult populations ($>$ 18 years of age), 14% to pediatric populations (18 years of age and younger), and 54% did not specify (Fig 3).

Seventy-two percent of studies were dedicated to diagnostic Computed Tomography, 8% to radiography /fluoroscopy, 9% to interventional procedures, 4% to nuclear medicine, and 7% to a combination of 2 or more of these modalities (Fig 4).

Discussion

The most commonly cited article was titled “Estimated risks of radiation-induced fatal cancer from pediatric CT.” In fact, the top 4 cited articles all focused on cancer risk. This is an important and clinically relevant topic with wide reaching implications; therefore, it makes sense why many other researchers remain interested in using this data and citing it in their publications. It could also be that these are papers with results that fit well into a variety of

TABLE 3
Contributing organizations listed by number of contributions

Number of articles	Organizations
7	National Cancer Institute
6	Duke University School of Medicine, Harvard Medical School, Yale University School of Medicine, University of California, San Francisco, and Massachusetts General Hospital
5	Mayo Clinic, State University of New York Upstate Medical University, Siemens AG, and Columbia University in the City of New York
4	Klinikum rechts der Isa, Brigham and Women's Hospital, UniversitatsSpital Zurich, Ludwig-Maximilians-Universitat Munchen, and University Hospital Zurich, Institut fur Diagnostische Radiologie
3	Deutsches Herzzentrum Munchen, Food and Drug Administration, VA Medical Center, University of Washington, Seattle, New York Presbyterian Hospital, Columbia University, Medical Center, Group Health Research Institute, and GE Healthcare, United States
2	Fairfax Radiological Consultants, Trinity Clinic, Klinikum der Universitat Munchen, Kyung, Hee University, Yale University, Walter Reed National Military Medical Center, National Institutes of Health, Bethesda, Uniformed Services University of the Health Sciences, Northwestern University, University of Florida College of Medicine, Universitats Klinikum Essen und Medizinische Fakultat, The University of British Columbia, UT Southwestern Medical School, Yale-New Haven Hospital, Kaiser Permanente Center for Health Research, University of Toronto, Hahnemann University Hospital, Kumamoto University, Cleveland Clinic Foundation, Drexel University College of Medicine, Helmholtz Center Munich German Research Center for Environmental Health, University Michigan Ann Arbor, Charite - Universitatsmedizin Berlin, UT Southwestern Medical Center, Mayo Clinic Scottsdale-Phoenix, Arizona, University of Illinois at Chicago, Beth Israel Medical Center, Marshfield Clinic, Universitatsklinik, Erlangen und Medizinische Fakultat, Northwestern Memorial Hospital, Henry Ford Health System, Siemens USA, Philips Healthcare Nederland
1	Information Management Services, Kawasaki Hospital, Laboratory Center Bremen Abteilung für Medizinische Strahlenhygiene und Dosimetrie, Center for Health Research, Institute of Radiology, Center for Health Research, M. E. Miller Inst. for Biomechanics, Nicolaus Copernicus Hospital, Division of Medical Intelligence and Informatics, Centro Médico de Asturias, NHS, Institute of Radiology, Michigan Heart P.C., Computerized Imaging Reference Systems Inc CIRS, Lenox Hill Hospital, Departments of Cardiology, Cardiovascular Center, Computed Tomography, Institute for Health Research, Krankenhaus Landshut-Achdorf, DIQUAD, Toshiba American Medical Systems, Siemens Medical Corporation, Northern Institute of Cancer Research, Dutch Childhood Oncology Group - Longterm Effects after Childhood Cancer DOCG, LATER, The Johns Hopkins Ciccarone Preventive Cardiology Center, Université libre de Bruxelles ULB, Humboldt-Universitat zu Berlin, The Mount Sinai Medical Center Emory University, The Johns Hopkins School of Medicine, Academic Medical Centre, University of Amsterdam, Mayo Clinic in Jacksonville, Florida, Emory University School of Medicine, University of Amsterdam, New Jersey Department of Environmental Protection, UC Davis Medical Center, Universitatsklinikum Heidelberg, Ohio State University, Boston Medical Center, Vanderbilt University, Duke University Health System, Universitatsklinikum Hamburg-Eppendorf und Medizinische Fakultat, Johns Hopkins University, National Heart, Lung, and Blood Institute, Ruhr-Universitat Bochum, CHU Sainte-Justine - Le centre hospitalier universitaire mere-enfant, Newcastle University, United Kingdom, Edward Mallinckrodt Institute of Radiology, The University of Hong Kong, University of Michigan Health System, Johann Wolfgang Goethe Universitat Frankfurt am Main, University Hospital Maastricht, National Health Service Weill Cornell Medical College, Universitat Leipzig, Ontario Cancer Institute University of Toronto, Hospital de La Santa Creu I Sant Pau, Centre Hospitalier de L'Universite de Montreal, University of Colorado Health Sciences Center, University of Innsbruck Washington University in St. Louis, Universitat Ulm, Université de Mons, UniversitatsSpital Bern, Columbia University, College of Physicians and Surgeons, King Fahd National Guard Hospital, Vancouver Hospital and Health Sciences Center, Vancouver, Icahn School of Medicine at Mount Sinai, Berufsgenossenschaftliches Universitatsklinikum Bergmannsheil gGmbH, Princess Margaret Hospital Hong Kong, HealthPartners, University of Florida, Gesundheit Nord Klinikum Links Der Weser, UC Davis, University of Florida Health Science Center, Waterford Regional Hospital Ireland, Methodist Hospital Houston, University of Texas MD. Anderson Cancer Center, The Netherlands Cancer Institute, St. Paul's Hospital, Dalhousie University, Barnes-Jewish Hospital at Washington University Medical Center, Universitat Heidelberg, Universitat Tubingen, University of Cincinnati College of Medicine, Kaiser Permanente, Rhode Island Hospital, Kumamoto University Hospital, Technische Universitat Munchen, Leiden University, William Beaumont Hospital, University of Twente, HealthPartners Research Foundation, University of Surrey, GE Global Research, Hospital Notre-Dame, Centre Chirurgical Marie Lannelongue, University of Miami Leonard M. Miller School of Medicine, University of Toronto Faculty of Medicine, Indiana University School of, Medicine Indianapolis, UCL, Universitatsklinikum Tubingen Medizinische Fakultat

TABLE 4
List of countries by number of articles published

Country/territory	Number of articles
United States	58
Germany	23
Canada	6
Japan	6
Netherlands	6
Switzerland	6
United Kingdom	5
Spain	3
South Korea	3
Italy	2
Hong Kong	2
Austria	1
Belgium	1
Brazil	1
France	1
Ireland	1
Poland	1
Saudi Arabia	1
Sweden	1
Turkey	1

different research topics, most notably different publications on cancer, which has no doubt been a heavily researched topic dating back many years.

Examining the list of top 100 cited articles in this field of radiation, it is obvious that "radiation dose" is the most common topic. This topic is subdivided in several ways by these top 100 articles. For example, some looked at certain imaging modalities only, such as CT, radiography, intraprocedural fluoroscopy, or nuclear medicine studies. Aside from cancer risk, which was the theme of the top 4 cited articles, radiation exposure made up the majority of the topics in the top 100; therefore, we can more confidently extrapolate that this topic has been most frequently studied, and conceivably the most impactful in this field of research. In fact, if we look at the 24 articles published more recently, in years 2009 and 2010 which were the years with most publications, we found this trend evolving. Twenty-three out of these 24 recent publications had topics related to radiation dose. In fact, almost all of these 23 propose some new method of dose reduction. Also, half of these 23 recent publications are already in the top 50 on the citations list. Therefore, one could draw the conclusion that radiation dose made up the bulk of research in this field over its lifespan. However, one could also say that more

TABLE 5
List of authors by number of publications

Author name	Number of publications
Hsieh, J.	5
Huda, W.	5
Alkadhi, H.	4
Brenner, D.J.	4
Hadamitzky, M.	4
Hausleiter, J.	4
Kalra, M.K.	4
Leschka, S.	4
Marincek, B.	4
Martinoff, S.	4
Scheffel, H.	4
Stolzmann, P.	4
Yoshizumi, T.T.	6
Einstein, A.J.	3
Elliston, C.D.	3
Frush, D.P.	3
Gore, J.C.	3
Kim, K.P.	3
Mahesh, M.	3
Meyer, T.	3
Miglioretti, D.L.	3
Nawfel, R.D.	3
Schmidt, B.	3
Schömig, A.	3
Singh, S.	3
Smith-Bindman, R.	3
Suess, C.	3
Achenbach, S.	2
Albert, R.	2
Anderson, J.	2
Awai, K.	2
Balter, S.	2
Berenstein, A.	2
Berrington De González, A.	2
Bhargavan, M.	2
Bischoff, B.	2
Blake, M.A.	2
Boone, J.M.	2
Brink, J.A.	2
Cardella, J.F.	2
Cole, P.E.	2
Desbiolles, L.	2
Digumarthy, S.R.	2
Donnelly, L.F.	2
Earls, J.P.	2
Feigelson, H.S.	2
Flohr, T.G.	2
Forman, H.P.	2
Funama, Y.	2
Geisinger, M.	2
Georgia, J.D.	2
Gilman, M.D.	2
Greenlee, R.T.	2
Hamm, B.	2
Hara, A.K.	2
Hein, F.	2
Howe, G.R.	2
Ibbott, G.S.	2
Johnson, E.	2
Judy, P.F.	2
Kastrati, A.	2
Lee, C.	2
Lu, H.T.	2
Malisch, T.W.	2
Mayo, J.R.	2
Miller, D.L.	2
Miller, G.L.	2
Morishita, S.	2
Nakayama, Y.	2
Nelson, R.C.	2
Noonan, P.T.	2
Pien, H.	2
Plass, A.	2
Prakash, P.	2
Roblin, D.	2

TABLE 5 (*continued*)

Author name	Number of publications
Russell, E.J.	2
Sato, N.	2
Schoepf, U.J.	2
Schueler, B.A.	2
Shadley, J.D.	2
Shepard, J.A.O.	2
Silva, A.C.	2
Silverman, S.G.	2
Sodickson, A.	2
Solberg, L.I.	2
St. George, J.	2
Sultana, S.	2
Vanneman, N.	2
Vogelzang, R.L.	2
Ware, D.E.	2
Weinmann, S.	2
Wildermuth, S.	2
Wolff, S.	2
Yamashita, Y.	2
Abada, H.T.	1
Abidov, A.	1
Adam, G.	1
Adams, D.F.	1
Afzal, V.	1
Akahane, M.	1
Akai, H.	1
Alasti, H.	1
Alexander, B.H.	1
Allmendinger, T.	1
Andriole, K.P.	1
Anno, H.	1
Applegate, K.E.	1
Arai, A.E.	1
Atherton, J.V.	1
Baeyens, P.F.	1
Barkhausen, J.	1
Bartelsman, J.F.W.	1
Baumbach, A.	1
Baumueller, S.	1
Beaudoin, G.	1
Becker, C.	2
Bekiroglu, N.	1
Berdon, W.E.	1
Berman, E.L.	1
Bero, M.A.	1
Beyer, T.	1
Bisset, G.S.	1
Bonomo, L.	1
Bossuyt, P.M.M.	1
Bouville, A.	1
Bradley, D.	1
Branch, K.R.	1
Brent, R.L.	1
Brix, G.	1
Brody, A.S.	1
Brown, H.L.	1
Buchgeister, M.	1
Budde, T.	1
Bumann, A.	1
Caldwell, J.H.	1
Cassady, C.I.	1
Cataln-Sanz, P.	1
Chang, S.M.	1
Charron, G.	1
Chen, J.	1
Chen, M.Y.	1
Cheung, L.C.	1
Chinnaiyan, K.M.	1
Chodick, G.	1
Choy, G.	1
Claussen, C.D.	1
Cohen, H.	1
Cohnen, M.	1
Coles, D.R.	1
Craft, A.W.	1
Cumming, W.A.	1

TABLE 5 (*continued*)

Author name	Number of publications
Curry, C.A.	1
Czermak, B.	1
Dahlström, N.	1
Daoud, B.	1
De González, A.B.	1
De Maertelaer, V.	1
DeLong, D.M.	1

recently, the focus has switched to including dose reduction strategies when measuring radiation exposure, and that these studies have been garnering more attention. This could be because there is more utility in a publication that proposes some sort of feasible intervention with a potential health benefits related to dose reduction.

Other researchers decided to focus on specific populations such as children, fetuses, or medical imaging technologists. Figure 2 demonstrates that 88% of studies focused on patients. Patients certainly seem to be the population of greatest interest in this field, much more so than health care professionals. Also, there were more than twice as many studies dedicated to adults (32%) compared to children (14%). Interestingly, however, the top 2 cited articles in this field were pediatric studies. Even though it is known that radiation can have more severe consequences for children than for adults, this may be because adults are a larger population and that they are generally imaged more frequently than children, probably because there is an awareness of this risk.

In the field of bibliometrics, articles usually gain more citations with increasing time, which can be explained by the Matthew effect of cumulative advantage. This is a well-known principle in sociology which essentially states that "the rich get richer and the poor get poorer."[25] In the research community, this would translate to: publications with more citations are thought to be superior, hence when looking for publications to cite in future studies, these ones will continue to be preferentially selected, and only gain more citations with time. Therefore, a very interesting finding in our study is that all the articles in the top 20 were published after 2001, and 24 of the top 100 were from the years 2009 and 2010. In other words, some of the most-cited studies were published relatively recently within the previous 10 years, contrary to what would be expected from the Matthew effect with older articles, supposedly having the opportunity to gain more citations with time. Moreover, the proportion of studies focusing

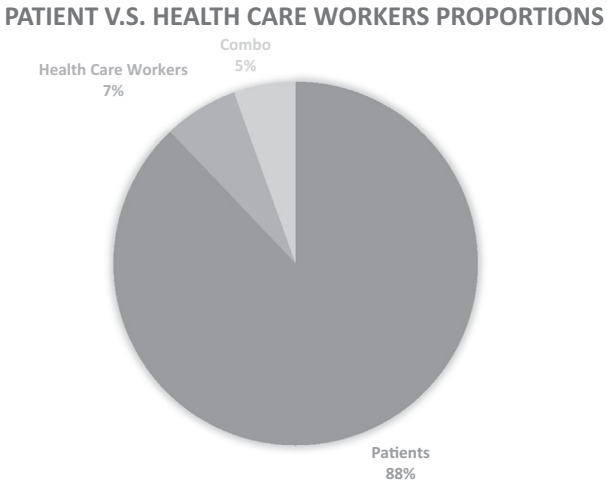

FIG 2. Proportions of studies dedicated to patients vs employees.

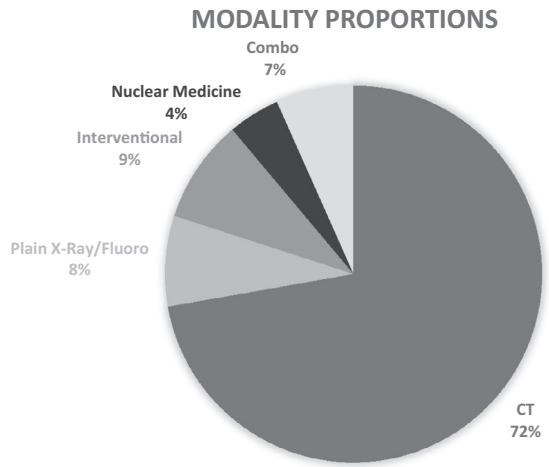

FIG 3. Proportions of studies dedicated to different imaging modalities.

solely on CT radiation doses is 72%; this likely reflects the magnitude of cumulative patient radiation dose which originates from CT due to its frequent use and centrality in medical imaging in more recent years. This suggests that this field of research is currently experiencing a renaissance, since newer publications are receiving more attention and going against the principle known as the Matthew effect. The issue of radiation exposure from diagnostic imaging is becoming more frequently covered in mass media and recognized in the public. Also, this supports the rapid growth and utilization of CT as a diagnostic tool. Therefore, there has been a spike in research during the 21st century, which is supported by the data seen in this analysis. The proportion of 72% of studies focusing on CT also supports this notion that CT is on the rise and a leading topic in this field of research. Interestingly, when looking at all studies that focused on CT scans, 23 of 55 were dedicated solely to cardiac imaging. This statistic also suggests that cardiac imaging is a popular area of research within the field of CT. All in all, this is a progressive field of research that is evolving with time and always producing new research content.

Another interesting statistical phenomenon that is demonstrated in our research is the "Pareto Distribution." This is a power law probability distribution which assumes that the majority of wealth is held by a small proportion of the population.[26] This phenomenon is demonstrated in our research by the fact that nearly 50% of the total number of publications come from the top 20 publications. This relates to Bradford's law, which is a bibliometric law explaining that a small number of publications make up a large percentage of influential research in a given field.[27]

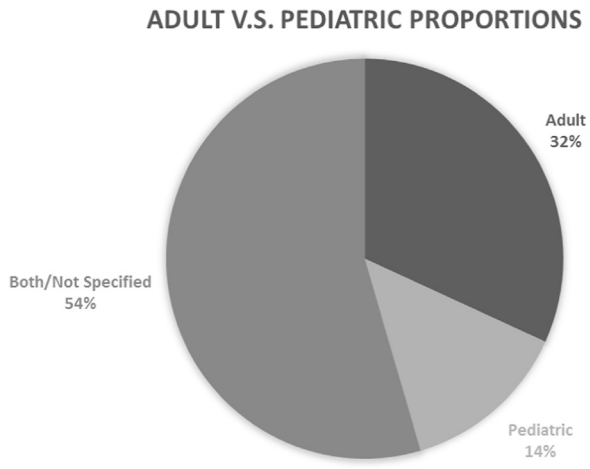

FIG 4. Proportions of studies dedicated to adult vs pediatric populations.

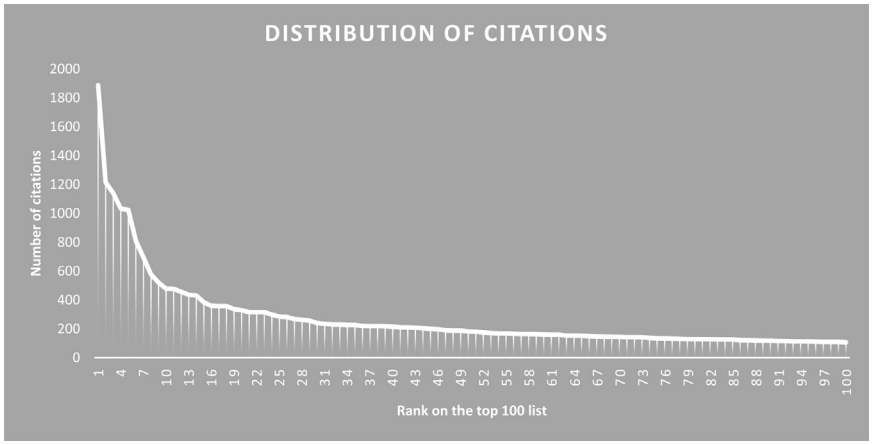

FIG 5. Distribution of citations in the top 100 cited articles.

Mathematically this can be modeled as an exponential decrease in the number of citations as we move down our top 100 list (Fig 5). However, as explained above, this field of research is rapidly expanding and evolving, with new topics and new technology coming to the forefront and more recent articles garnering the most attention. This speaks to the fact that this field of research constantly is looking for new data. If we use what is known about the Pareto distribution, we can assume that if a bibliometric analysis was conducted on this topic in the future, there would be many articles published after today's date that would make the top 100, and probably the top 20. Also, the newer articles would continue to climb to top of the list and they would probably have exponentially more citations than the publications coming after them.

Knowing how much radiation people are being exposed to is important, primarily for the reason that it should drive further research or action to be taken to limit such radiation exposure. Fortunately, several of the articles published looked at other aspects in this field. For example, quite a few recent publications went on to suggest further improvements which could be made to reduce the amount of radiation exposure or how to better protect people from radiation. Some studies decided to look at better ways to measure the amount of radiation. Other publications decided to research the cellular and genetic effects that have been caused by radiation exposure. Although it is encouraging that these topics were covered by some publications, the majority still focused solely on dose. It would be ideal if there were more publications focused solely on these other important topics. Therefore, there are certainly opportunities for such dedicated studies in the future for any interested researchers.

Only one publication of the top 100 investigated employee and public awareness of the amount of radiation exposure and its risk. Considering that patients are the main population being exposed to radiation from medical imaging procedures, it would be beneficial to know their understanding of the risks of radiation exposure. Hospital staff also experience exposure to ionizing radiation, and investigating their understanding of the risks of exposure may be an area for further study. Finally, it would certainly be beneficial to study physicians' attitudes toward these topics as they are the gatekeepers to how many diagnostic and interventional procedures are performed.

One topic that was not included in these top 100 articles was radiation exposure to people outside of the medical setting. For example, exposure to x-rays during whole-body scanning during airport screening, or occupational exposures of other jobs which employ radiation techniques. This was intentional, based on the search criteria that we selected, since we wanted to be able to specifically assess research conducted on radiation exposure in hospitals to patients and staff. However, this would certainly be an interesting opportunity for a separate bibliometric analysis.

Our goals of this study may seem paradoxical to some—determine which articles have been most influential and determine which topics need more research. These two actually go hand in hand. Without knowing which topics are most heavily studied, we cannot determine which topics have been underexamined in the literature and therefore are in need of more attention. Since it is easier to see what is present than to recognize what is absent, we decided to make elucidating the more studied and most influential topics in this field the main goal of our study. However, our secondary goal of suggesting which aspects of radiation exposure need more attention, is an equally important (if not more important) outcome. It is likely that regardless of this study, the most popular topics in this field will continue to garner more attention and still be influential in the research community moving forward. However, without such a study, some of the lesser-studied topics may not become recognized as areas of need. We hope that our work will encourage research on the less frequently studied topics so that this becomes a well-rounded field of research, which includes results from many different topics and perspectives.

Although it seems like a broad range of topics in this field of research have been covered, and there are many publications with many citations, there is still much work to be done in this field. The reason we can draw this conclusion is because compared to some other bibliometric analyses, the number of total citations in the top 100 is significantly less than in some other fields of research, for example the fields of stroke, lymph node imaging, and thrombolytics.[28-36] These are unquestionably very important topics in medicine; however, we would argue that radiation exposure deserves the same amount of attention by the research community. The fact that this field currently has fewer citations than several other fields could be because it has come to attention recently. We have mentioned that it is growing rapidly and therefore we predict that in the future the number of citations of publications in radiation exposure will come to equal those in other important aspects of medicine.

Conclusion

Overall, many different important aspects of radiation exposure related to medical imaging have been covered by the research community, including contributions from many different authors, organizations, and countries. CT scans and adult patients seem to

be the most common imaging modality and population studied in the top 100 articles. The attention paid specifically to cardiac imaging identifies this as a current "hot topic" in this field and certainly would make a great subject for prospective researchers. We have also seen the trend shift toward proposing methods of dose reduction, rather than the classic research topic of solely measuring radiation dose. Those wishing to publish in this field would be wise to try to implement these types of methods. There remain areas of need in this field of research such as physicians' opinions on medical radiation exposure and the patients' knowledge of the potential risks. Finally, the number of citations in this field of research does not yet match that of some other important health-related research fields. However, medical radiation exposure is a rapidly growing subject which should continue to expand and evolve in the near future.

Disclosures

Dr. Khosa is the recipient of the Canadian Association of Radiologists/Canadian Radiological Foundation Leadership Scholarship (2017) and the Vancouver Coastal Health Leadership Award (2017). No financial disclosures or conflict of interest on behalf of the authors. There was no commercial funding for this study.

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