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Ultraviolet exposure from indoor tanning devices: a systematic review

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Summary

Use of indoor tanning devices increases the risk of cutaneous melanoma and nonmelanoma skin cancer. Indoor tanning devices have become important sources of ultraviolet (UV) exposure, both UVB and UVA. This systematic review assessed UV measurements performed in indoor tanning devices related to irradiance level, wavelength distribution and similarities to natural sun. The study was performed in accordance with the MOOSE and PRISMA guidelines. We searched PubMed, Embase and Web of Science from inception to May 2015, and also examined the reference lists of the retrieved studies. Eighteen studies were included. Twelve studies examined the erythema-weighted UV irradiances of indoor tanning devices, 11 studies examined UVB and 13 studies studied UVA. Compliance with irradiance limits was reported in nine studies. Erythema-weighted irradiances were highest in the most recent studies. Most studies had mean values higher than from natural sun and with large variations between devices. All studies except two had mean unweighted UVB irradiances lower than from natural summer sun (at latitudes from 37°S to 35°N), while mean unweighted UVA irradiances were, with one exception, substantially higher than from natural sun. The high values of UVA exposure from modern tanning devices are alarming in light of the increased focus on UVA irradiance as a carcinogen, and as UVA exposure confers little protection against subsequent UV exposure.

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What's already known about this topic?

- The ultraviolet (UV) irradiance from indoor tanning devices is supposedly similar to that of tropical sun.
- It is not known whether the intensity and wavelength distributions are similar, and whether these have changed over time.

What does this study add?

- Erythema-weighted UV from indoor tanning devices is generally higher than from natural sun, with large variations between devices.
- UVA irradiance from tanning devices is much higher than from natural sun.

Indoor tanning increases the risk of cutaneous melanoma, nonmelanoma skin cancer,[1–3] skin ageing and immediate effects such as sunburn, phototoxic and photoallergic reactions, and eye damage.[4,5] In spite of being classified as carcinogenic to humans,[6] indoor tanning devices are commonly used, particularly during youth,[7–12] and starting at an increasingly younger ages.[13]

Radiation within the whole ultraviolet (UV) spectrum is associated with skin mutagenesis and carcinogenesis.[6,14,15] Indoor tanning devices are important sources of UVB

(280–315 nm) and UVA (315–400 nm) exposure. As opposed to UVB, UVA does not increase melanin production and contributes little or nothing to skin thickening and protection against subsequent UV exposure.[16,17]

Exposure from indoor tanning devices is limited or guided by technical standards and recommendations.[18–23] Irradiance limits are now binding in Europe.[19] However, several studies have found low compliance with such requirements.[24–35]

Knowledge of intensities and wavelength distributions from indoor tanning devices is needed to study the health effects of such exposure. UV irradiance from these devices has been measured in some countries,[25–34,36–43] but it is not known whether there are differences across countries and over time. We therefore conducted a systematic review of the literature on UV irradiance from indoor tanning devices, including UVA, UVB, erythema-weighted UV irradiance (an indication of the sunburn power of the radiation), UV index (UVI) and compliance with irradiance limits. We also evaluated potential differences from natural sun.

Methods

Search strategy and data extraction

This systematic review was carried out according to the MOOSE and PRISMA guidelines.[44–46] We searched PubMed, Embase (OVID) and Web of Science from inception to May 2015 for the following search terms: indoor tanning device, artificial tanning device, indoor tanning appliance, artificial tanning appliance, sunbed or solarium; combined with ultraviolet or UV, irradiance, radiation, emission, emit or output; and these terms were combined with and without measurement. There were no language restrictions. Furthermore, we examined the reference lists of the included studies and of relevant reports and systematic reviews. We included all studies presenting UV irradiance measurements from indoor tanning devices for cosmetic purposes. Studies without any information regarding the type of sunlamp and tanning device, and studies without criteria for the selection of devices were excluded.

All identified studies were reviewed by one of the authors (L.T.N.N.), and the following information was extracted from each study: country and area where the study was conducted; number of tanning devices included; time period for the measurements; type of selection criteria for tanning devices and facilities; type of measurement instrument and measurement method; mean erythema-weighted UVA, UVB and total UV irradiances; mean UVI (i.e. the total erythema-weighted UV irradiance multiplied by 40 $m^2\ W^{-1}$);[47] mean unweighted UVB and UVA irradiances; and SDs, 95% confidence intervals (CIs) and minimum and maximum values. Erythema-weighted UV is given as the unweighted UV irradiance weighted according to the reference action spectrum for UV-induced erythema (sunburn) in white human skin valid for the UV wavelength region 250–400 nm.[48] We contacted the authors of seven studies[25,27–29,31,33,38] to obtain additional results; the four most recent studies provided detailed measurement data for their devices.[25,27–29]

Indoor tanning devices

Indoor tanning devices (sunbed, shower/stand-up cabinet, portable facial tanner or a tanning chair) have lamps emitting UV radiation, as the sun does, but with a different ratio of UVB to UVA and more intense total UV. The radiation source can be either fluorescent low-pressure lamps or high-pressure lamps, which have quite different UV spectra.[25,27,29,32] Furthermore, sunbeds may have different lamps in the bench, canopy (the part of a sunbed above the body) and facial area.

Irradiance limits according to international standards and national regulations

Irradiance limits apply to varying degree across countries and time. Table 1 summarizes the limits for the relevant period.[49–56] Voluntary guidelines for indoor tanning devices are provided by an international technical standard prepared by the International Electrotechnical Commission.[18] Tanning devices are now classified into UV types (1–5) according to their erythema-weighted UVB and UVA irradiances, and with an upper limit ($0{\cdot}7\ W\ m^{-2}$). Since 2010, a more restrictive binding limit ($0{\cdot}3\ W\ m^{-2}$) has applied for all devices in Europe,[19,51] after the European Commission[56] recommended restricting indoor tanning emission to that of natural tropical sun ($0{\cdot}3\ Wm^{-2}$; UVI = 12).

Some European countries allow only UV type 3 devices, as this was the only UV type with both UVB and UVA radiation restrictions from 1989 to 2010,[51,52] with a maximum total UV dose of $0{\cdot}3\ W\ m^{-2}$. The very high irradiance limit in the Australian/New Zealand standard ($1{\cdot}5\ W\ m^{-2}$; UVI = 60)[20,54] was binding only in South Australia.[57] It was reduced in 2008 to $0{\cdot}9\ W\ m^{-2}$, UVI = 36.[20] By January 2015 commercial solaria were banned in most Australian jurisdictions,[53] as in Brazil since 2009.[55] In the U.S.A., regulations include no irradiance limits, but have a requirement on the ratio of irradiance in the region 200–280 to 280–320 nm.[22,58] As in the Australian regulations, mandatory limitations apply on exposure (i.e. irradiance multiplied by exposure time).[20–23]

The technical standards use UVB and UVA wavelength regions of 250–320 and 320–400 nm, respectively, which differ from the regions for unweighted UVB and UVA of 280–315 and 315–400 nm, respectively. Dividing UVB and UVA at 315 nm as opposed to 320 nm matters, as unweighted UV from tanning lamps increases rapidly around 315–320 nm. Therefore, UVB irradiance will be significantly higher using the wider 280–320-nm region compared with 280–315 nm, as done in some studies.[25,27,29,36,39,41] Choosing 250 or 280 nm as the starting wavelength does not matter, as very little UV is allowed from tanning devices below 280 nm[18] and little is emitted.[25,27,32,36,38,39,43] Choosing 315 or 320 nm as the starting wavelength for UVA is ignored in this review, as most unweighted UVA irradiance from tanning lamps is emitted at longer wavelengths.[25,27–29,32,36,38,39,43]

Table 1 Ultraviolet (UV) irradiance and UV index (UVI): limits for indoor tanning devices according to international standards and regulations and values for natural sun for the relevant periods in this review

	Erythema-weighted UV (Wm^{-2})[a]				Unweighted UV (Wm^{-2})			
	UVB (250–320 nm)	UVA (320–400 nm)	Total UV (250–400 nm)	UVI[b]	UVB (280–320 nm)	UVA (320–400 nm)	UVB (280–315 nm)	UVA (315–400 nm)
Standards								
International standard[18,49,50]								
All devices, since 2004[18,49,c]			0·7	28				
Additional requirement for UV type 3 devices, since 1989[50]	< 0·15	< 0·15	0·3	12				
European standard[19,51,52]								
All devices, since 2010[51]			0·3	12				
Additional requirement for UV type 3 devices, since 1989[52,d]	< 0·15	< 0·15	0·3	12				
Australian[e]/New Zealand standard								
All devices, since 2008[20]			0·9	36				
All devices, 2002–2008[54]			1.5	60				
Regulations								
Norway, 1983–1992[32,f]	< 0·19	< 0·15						200
Australia, 1983–2001[43,g]								200
U.S.A.[22,h]			No limits					
Brazil, since 2009[55]			Total ban					
Natural sun								
Crete, 35°N[32]	0·224	0·042	0·27	11			2·0	61
Melbourne, 37°S[29]				11	3·6	58		
Tropical sun, 23°S to 23°N[56]			0·3	12				

[a]Weighted according to the erythema action spectrum.[48] [b]UVI is the total erythema-weighted UV irradiance multiplied by 40 m^2 W^{-1}.[47] [c]An upper limit of 1 Wm^{-2} was introduced in 2004,[49] where UV was weighted according to the nonmelanoma skin cancer action spectrum. This corresponds to the present limit of 0·7 Wm^{-2} weighted with the erythema action spectrum.[18] [d]Conflicting national requirements had to be withdrawn within a maximum of 3 years after publication in 1989.[50] [e]By January 2015, most Australian jurisdictions had a total ban on commercial tanning devices.[53] [f]The Norwegian regulations with erythema-weighted UVB and UVA converted from the original unweighted UVA and American Conference of Governmental Industrial Hygienists-weighted UVB.[32] [g]The Australian regulations permit < 0·1% of total UV for 280–300 nm and < 1·0% of total UV for 300–315 nm.[43] [h]US Food and Drug Administration regulations.[22]

Irradiance from natural sun

UV irradiance from natural sun is included for comparison with UV from indoor tanning devices in Table 1. Data for natural sun at 35°N (Crete, Greece) were obtained from Nilsen *et al.*,[30] where UV was estimated for a clear summer day at noon (when the sun's intensity is at its maximum), and using the regions 280–315 and 315–400 nm. Data for 37°S (Melbourne, Australia) are from Gies *et al.*,[29] using the regions 280–320 and 320–400 nm. Erythema-weighted UV data for tropical sun are from the Scientific Committee on Consumer Products.[56] The tropics include latitudes on both sides of the Equator (23°S to 23°N) where the sun is directly overhead at least once a year.

Statistical analysis

For publications without information on 95% CI, SD or minimum or maximum values, these were calculated from the published irradiances for each device,[36,41–43] after receiving the data files[25,27,29] or on consulting our own files.[30,32] For three studies,[31,38,39] we estimated mean irradiances for all devices based on the published data, and for two studies we calculated 95% CIs from reported means and SDs.[26,28] Furthermore, minimum and/or maximum values were read from the figures in four publications.[28,31,37,40] Table S1 (see Supporting Information) presents all extracted and calculated values (n, mean, SD, 95% CI, minimum and maximum) for the included studies. For studies including measurements in several body positions,[30–32,36,38] only the maximum values are included as required by the international standard.[18] For two studies the maximum of body and facial measurements could not be determined, and only the canopy[37] and bench[40] values are included in the results (Table S1 includes the values for the facial position). The Spearman correlation coefficient, r_{sp}, was calculated for the European studies between mean erythema-weighted UV and time of measurement (or year of publication if not specified), and between mean UVA and time of measurement. Nilsen *et al.* included data from inspection (measurements in tanning facilities) and from type testing of tanning models before sale/use (approval data) in their 2008 study.[32] Only inspection data were included in the calculation of r_{sp}. For unweighted UVB we present results for both the 280–320-nm and 280–315-nm regions, where relevant.

Results

Study selection and characteristics

We identified 24 studies during the search (Fig. 1). Six studies were excluded due to lack of information regarding the type of tanning device, radiation source or how the devices were selected.[59–64] The 18 included studies (Table 2) were published in 1986–2015 and included 2895 tanning devices. Thirteen studies were from Europe, two from Australia and three from the U.S.A.

Erythema-weighted ultraviolet irradiance and ultraviolet index

Twelve studies reported erythema-weighted UV or UVI measured in indoor tanning devices, and the minimum-to-maximum ranges were wide for many studies (Fig. 2). The most recent studies in Europe[25–28] and Australia[29] found the highest mean erythema-weighted UV. There is a positive correlation between the mean erythema-weighted UV and time of measurement for the European tanning devices (r_{sp} = 0·75). The vertical stippled lines in Figure 2 show the current European (for all devices since 2010 and for UV type 3 devices since 1989) and Australian (since 2008) limits from Table 1. Most European studies[25–28,30,32,33,36] had mean irradiances above the limit. The mean irradiances of the Norwegian approval data[32] were below the limit, as it was compulsory for approval (Table 1). Even though the mean UV irradiance of the Australian study was highest,[29] it was below the voluntary, but very high, Australian limit. All mean values were below the international standard limit of 0·7 Wm^{-2} (UVI = 28). Finally, most mean erythema-weighted UV levels and UVIs were higher than from natural sun in the tropics, 0·3 Wm^{-2} and 12, respectively (Table 1, Fig. 2), and thereby were also above the European limit (0·3 Wm^{-2}).

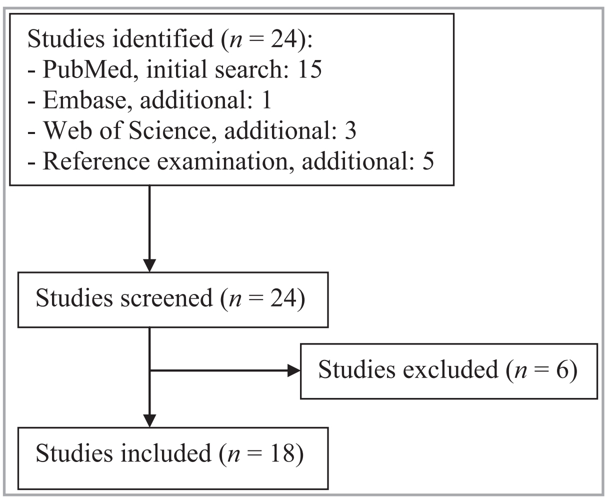

Fig 1. Flowchart of the study selection process.

Unweighted ultraviolet B irradiance

Eleven studies reported unweighted UVB: six within the 280–320-nm region (upper part of Fig. 3)[25,27,29,36,39,41] and six within the conventional 280–315-nm region (lower part of Fig. 3).[29,30,37,38,40,43] Gies *et al.* provided UVB values within both regions in their 2011 study,[29] and except for Khazova *et al.*[25] they reported the highest mean UVB of all studies. Furthermore, these two studies reported the only mean irradiances higher than typical UVB from natural sun (Crete for 280–315 nm and Melbourne for 280–320 nm; Table 1).

Unweighted ultraviolet A irradiance

Thirteen studies reported unweighted UVA (Fig. 4). The highest mean UVA was found in a recent study from Italy by Facta *et al.*[27] There was a positive correlation between the mean UVA and time of measurement in the European studies (r_{sp} = 0·93). The vertical line at 60 Wm^{-2} indicates typical UVA from natural sun [61 Wm^{-2} in Crete (315–400 nm) and 58 Wm^{-2} in Melbourne (320–400 nm); Table 1], and the mean UVA was higher than this in all studies except for the oldest study, by Gies *et al.*[43]

Erythema-weighted ultraviolet irradiance and compliance with standards and regulations

Nine of the studies[25–33] in Figure 2 also presented compliance with irradiance limits for the measured devices (Table S2; see Supporting Information). Compliance with the European limit of 0·3 Wm^{-2} or the UV type 3 requirements was low in all studies (10–42% and 10–59%, respectively). High compliance was found with the very high limit in the Australian study.[29]

Discussion

This is to our knowledge the first systematic review of UV measurements from indoor tanning devices. Mean UVA irradiances were much higher than from natural sun, while UVB irradiances were lower, except in two studies. The range from minimum to maximum was wide in many studies. The erythema-weighted UV was generally higher than for natural sun, and European studies relating measurements to irradiance limits found low compliance.

This systematic review was carried out according to the MOOSE and PRISMA guidelines.[44–46] Some studies may be limited by selection bias, as not all studies included all or a random selection of available tanning devices and facilities.[36,39] We used only English search terms, which might have excluded studies in other languages, although we did not

Table 2 Characteristics of the studies on ultraviolet irradiance from indoor tanning devices included in the systematic review

Study	Country and area	Data collection	No. of devices	Tanning devices and facilities	Type of measurement instrument	Measurement method[a]
Europe						
Petri 2015[26]	Greece	2013–2014	40	All devices (sunbeds and stand-up units) in all facilities agreed to participate: 23 premises	Broadband meter	European standard[b]
Khazova 2015[25]	England: three areas in South East England, three local areas in Northern Ireland, two local areas in Scotland	2011–2013	188	All devices (sunbeds and stand-up units) in all facilities within chosen districts	Diode-array spectroradiometer	European standard[a]
Facta 2013[27]	Italy: Piedmont (northwest)	2010–2011	96	All types of devices (chairs, sunbeds, stand-up units), in tanning salons and beauty parlours	Double-monochromator spectroradiometer	European standard[a]
Tierney 2012[28]	England: North, Midlands, South West and London	2010–2011	402	All types of devices (sunbeds, stand-up units, high-pressure units) in the chosen districts and in all kinds of facilities	Diode-array spectroradiometer	[c,d]
Cloke 2010[31]	South East Wales: Vale of Glamorgan, Rhondda Cynon Taf and Merthyr Tydfil	2008–2009	65	Sunbeds and stand-up units in all facilities within chosen districts	Diode-array spectroradiometer	[c,e,f]
Nilsen 2011[30]	Norway: six districts around the country	2008	194	All devices, in randomly selected facilities	Diode-array spectroradiometer	European standard[a]
Oliver 2007[33]	Scotland: Dundee and Perth and Kinross Council	2004–2005	133	All devices (sunbeds and stand-up units) in all facilities within chosen districts	Diode-array spectroradiometer	[c,d]
Nilsen 2008[32]						
Inspection 2003	Norway: selected counties in eastern, central and northern parts	2003	307	All devices in all facilities within the chosen districts	Broadband meter	European standard[a]
Inspection 1998–1999	Norway: coastal municipalities from central to western and southern parts	1998–1999	1034	All devices in all facilities within the chosen districts	Double-monochromator spectroradiometer and broadband meter	European standard[a]
Approval 1993–2005	Norway	1993–2005	217	All types of tanning devices approved for sale, lease or use in Norway	Double-monochromator spectroradiometer	European standard[a]
Approval 1983–1992		1983–1992	229			
Gerber 2002[36]	Switzerland		9	Selected sunbeds from main Swiss manufacturers	Double-monochromator spectroradiometer	None[b,e,g]
McGinley 1998[37]	Scotland: central Scotland	1997	100	Sunbeds in commercial use, in all facilities	Double-monochromator spectroradiometer	None[h]
Moseley 1998[38]	Scotland: Perth and Kinross Council		37	All devices in all facilities	Double-monochromator spectroradiometer	[b,c]
Wright 1996[40]	England: Bradford		50	In various types of facilities	Broadband meter	None
Bowker 1987[42]	England: Oxford	1982	17	All devices, in all facilities	Broadband meter	None

Table 2 (continued)

Study	Country and area	Data collection	No. of devices	Tanning devices and facilities	Type of measurement instrument	Measurement method[a]
Australia						
Gies 2011[29]	Australia: Sydney and Melbourne	2008	20	Selected devices (sunbeds and stand-up units) in cooperation with tanning industry representatives, in selected, large facilities	Double-monochromator spectroradiometer	[c,d]
Gies 1986[43]	Australia		15	Selection of sunbeds	Single-monochromator spectroradiometer	None[i]
U.S.A.						
Hornung 2003[34]	U.S.A.: North Carolina	1999	171	All devices in 62 invited tanning facilities	Broadband meter	None[e,f]
Miller 1998[39]	U.S.A.		2	Commonly used devices	Double-monochromator spectroradiometer	[c]
Bruyneel-Rapp 1988[41]	U.S.A.: Arkansas		14	All facilities within a major city of Arkansas	Broadband meter	None

[a]The International and European standards, IEC/EN 60335-2-27,[18,19] include requirements for the measurement procedure: the irradiance must stabilize before measuring, the benches and canopies are to be measured separately by covering up the opposite part, measurements are to be performed at a given exposure distance [at the surface of the benches, 30 cm up from the acrylics of the bench for the canopies, and 20/30 cm (IEC/EN) up from the bench when measuring facial lamps], and the maximum irradiance shall be recorded. [b]The collecting optics were 25 cm above the acrylic surface for sunbed canopy measurements. [c]Not specified that measurements are according to IEC/EN 60 335-2-27,[18,19] but still following the general principles of the standard. [d]The collecting optics were 20 cm above the acrylic surface for sunbed canopy measurements. [e]No information regarding covering up the opposite part of the device during measurement. [f]The instrument was placed on the acrylics of the benches. [g]No information regarding ageing of sunlamps. [h]Collecting optics positioned 20 cm below the upper surface of the sunbed. [i]Measurements performed at the surface of the acrylics.

Study; country; measurement period	*n*	Erythema-weighted UV (Wm^{-2}) Mean (95% CI)	Min–Max	UVI[a]
Europe				
Petri 2015;[26] Greece; 2013–2014	40	0·54 (0·44–0·64)	0·09–1·13	**22**
Khazova 2015;[25] England; 2011–2013	188	0·61 (0·57–0·65)	0·07–1·50	**24**
Facta 2013;[27] Italy; 2010–2011	96	0·51 (0·47–0·56)	0·15–1·20	**20**
Tierney 2012;[28] England; 2010–2011	402	0·56 (0·54–0·58)	0·10–1·32	**22**
Cloke 2010;[31,b] Wales; 2008–2009	65	0·17 (0·16–0·18)	0·08–0·28	7
Nilsen 2011;[30] Norway; 2008	194	0·34 (0·33–0·35)	0·17–0·83	**14**
Oliver 2007;[33] Scotland; 2004–2005	133	0·41	0·02–0·93	**16**
Nilsen 2008;[32] Norway; 2003	307	0·30 (0·30–0·31)	0·16–0·58	12
Norway; 1998–1999	1034	0·36 (0·35–0·36)	0·14–0·58	**14**
Approval;[c] Norway; 1993–2005	217	0·24 (0·23–0·24)	0·02–0·33	9
Approval;[c] Norway; 1983–1992	229	0·15 (0·14–0·15)	0·04–0·33	6
Gerber 2002;[36] Switzerland	9	0·32 (0·23–0·40)	0·17–0·51	**13**
Moseley 1998;[38] Scotland	37	0·16	0·03–0·34	6
Australia				
Gies 2011;[29] Victoria; 2008	20	0·63 (0·52–0·74)	0·25–1·22	**25**
U.S.A.				
Miller 1998[39]	2	0·44	0·22–0·66	**18**

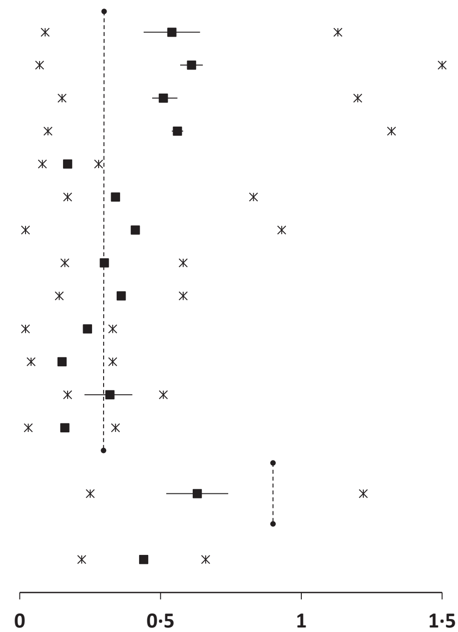

Fig 2. Mean erythema-weighted ultraviolet (UV) irradiances (squares) with 95% confidence intervals (CIs; horizontal lines), minimum and maximum values (stars) and mean UV index (UVI). The vertical stippled lines show the European (0·3 Wm^{-2}, UVI = 12) and Australian (0·9 Wm^{-2}, UVI = 36) irradiance limits. UVIs higher than for tropical sun (UVI = 12) are in bold numbers. The measurement period is given if reported. [a]UVI is the total erythema-weighted UV irradiance multiplied by 40 m^2 W^{-1}.[47] For most studies it is calculated from the erythema-weighted UV irradiance. [b]Maximum reading in each tanning device, excluding facial measurements. [c]Approval data: data from type testing of tanning models before being allowed for sale/use in Norway.[32]

restrict the searches to only English written publications. We included only published studies, as it was hard to identify unpublished work. National authorities may perform UV measurements as part of their regular inspections, as in a European project aiming to harmonize inspection of indoor tanning devices across Europe.[35] Including such measurements would add more countries to this review, but could also make it more biased. Such inspections may be initiated by skin burn reports, possibly due to very high UV.

Another possible limitation is the quality of the measurements. Use of a double-monochromator spectroradiometer gives the lowest measurement uncertainty and thereby the best quality,[65] and this was used in about half of the studies (Table 2).[27,29,32,36–39] Broadband meters, used in six studies,[26,32,34,40–42] are suitable for field measurements as they are portable and easy to use. However, such instruments have higher measurement uncertainties than the double-monochromator spectroradiometers, due mainly to a possible mismatch between the detector spectral responsivity function and the ideal spectral weighting function.[32,66] With careful correction procedures, the results can still be satisfactory.[32] Single-monochromator spectroradiometers, used in six studies,[25,28,30,31,33,43] may be affected by significant stray light contribution.[67] Again, uncertainty can be reduced by careful calibration and correction procedures.[25,28,30,33,67]

Another limitation related to measurements is the measurement method. Four studies[25,27,30,32] used standardized procedures from the International and European standards,[18,19] with measurements performed at a specified distance and with the other part of the device covered up (Table 2). Measurements further away from the lamps, as was the case for many studies,[26,28,29,31,33,34,36–38] expectedly give lower UV irradiances. Furthermore, when the other part of a tanning device is not covered during measurement, as may be the case in three studies,[31,34,36] reflectance from it will contribute and give too high UV irradiance. McGinley *et al.*[37] found a correction factor of 0·82–0·83 when a person was lying in the sunbed compared with a totally uncovered bench.

The included studies have reported confidence intervals or SDs only to a limited degree. This is one reason why we did not perform a meta-analysis. The voluntary international standard[18] has been widely adopted, but common radiation limits throughout time and countries do not exist. Due to the large variation in regulations and irradiance limits across the world, studies from different regions are not combinable in a meta-analysis. Moreover, the number of countries with UV measurement studies was generally low, and only one or two studies have been published within some regions. This limits the estimation of correlation coefficients for time trends and the generalizability of the results. Within Europe, the region

Study; country; measurement period	n	Unweighted UVB irradiance (Wm^{-2}) Mean (95% CI)	Min–Max
Wavelength region 280-320 nm			
Europe			
Khazova 2015;[25] England; 2011–2013	188	8·1 (7·5–8·8)	0·9–22·6
Facta 2013;[27] Italy; 2010–2011	96	3·3 (2·6–4·0)	0·03–19·9
Gerber 2002;[36] Switzerland	9	2·4 (1·4–3·4)	0·1–4·3
Australia			
Gies 2011;[29] Victoria; 2008	20	4·6 (3·2–5·9)	0·4–12·2
U.S.A.			
Miller 1998[39]	2	3·4	0·02–6·8
Bruyneel-Rapp 1988;[41] Arkansas	14	0·2 (0·1–0·3)	0·05–0·38
Wavelength region 280-315 nm			
Europe			
Nilsen 2011;[30] Norway; 2008	194	1·9 (1·8–1·9)	0·5–4·1
Moseley 1998;[38] Scotland	37	1·1	0·04–3·8
McGinley 1998;[37,a] Scotland; 1997	89	0·75	0·2–2·8
Wright 1996;[40,b] England	50	0·2	0·01–0·8
Australia			
Gies 2011;[29] Victoria; 2008	20	2·7 (1·9–3·4)	0·4–6·9
Gies 1986;[43] Victoria	15	0·06 (0·02–0·05)	0·003–0·1

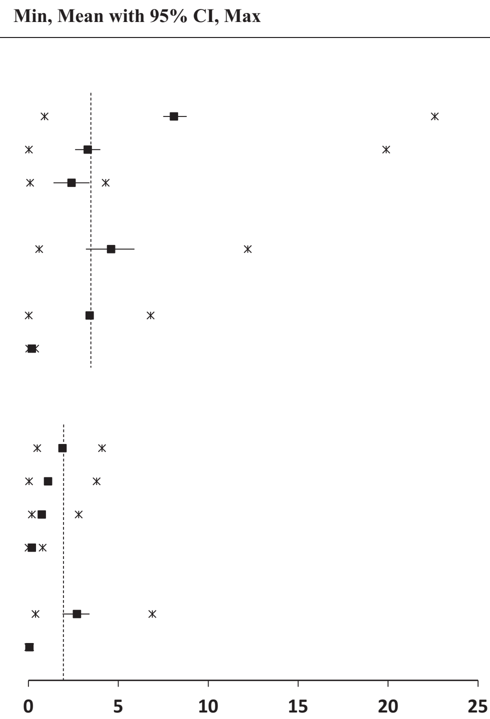

Fig 3. Mean unweighted ultraviolet (UV)B irradiances (squares) with 95% confidence intervals (CIs; horizontal lines) and minimum and maximum values (stars). The studies are grouped based on the UVB wavelength region used, 280–320 nm or 280–315 nm. The vertical lines are the unweighted UVB values from natural sun (280–320 nm, 3·6 Wm^{-2} for Melbourne; 280–315 nm, 2·0 Wm^{-2} for Crete). The measurement period is given if reported. [a]Only canopies. [b]Only benches.

Study; country; measurement period	n	Unweighted UVA irradiance (Wm^{-2}) Mean (95% CI)	Min–Max
Europe			
Khazova 2015;[25] England; 2011–2013	188	396 (375–417)	67–961
Facta 2013;[27,a] Italy; 2010–2011	96	719 (641–796)	209–1940
Nilsen 2011;[30,b] Norway; 2008	194	287 (268–306)	149–1193
Gerber 2002;[36,a] Switzerland	9	351 (240–461)	165–538
Moseley 1998;[38,b] Scotland	37	214	48–399
McGinley 1998;[37,c] Scotland; 1997	89	130	54–295
Wright 1996;[40,d] England	50	135	65–190
Bowker 1987;[42,b] England ; 1982	17	100 (64–136)	7·4–316
Australia			
Gies 2011;[29,a] Victoria; 2008	20	247 (208–286)	98–438
Gies, 1986;[43,b] Victoria	15	11 (8·3–13·6)	5·7–22
U.S.A.			
Hornung 2003;[34] North Carolina; 1999	136	192	18–674
Miller 1998[39,a]	2	465	310–620
Bruyneel-Rapp 1988;[41,a] Arkansas	14	119 (92–145)	50–180

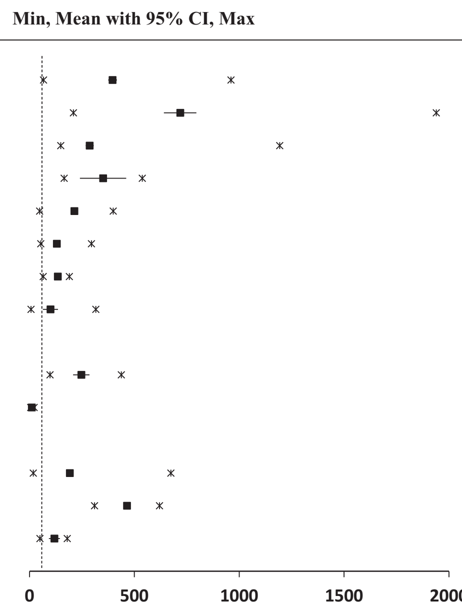

Fig 4. Mean unweighted ultraviolet (UV)A irradiances (squares) with 95% confidence intervals (CIs; horizontal lines) and minimum and maximum values (stars). The vertical line is the unweighted UVA value from natural sun in Crete and Melbourne (averaged as 60 Wm^{-2}). The measurement period is given if reported. [a]UVA wavelength region 320–400 nm. [b]UVA wavelength region 315–400 nm. [c]Only canopies. [d]Only benches.

with the most studies, the measurements span over a long period (1983–2014). Altogether, displaying the available mean irradiances with 95% CIs and the range from minimum to maximum gave a good picture of UV from tanning devices across studies and over the years.

Studies relating measurements to irradiance limits found that the limits were exceeded to a large extent in Europe. Exceeding the limits may easily cause erythema, as the exposure time schedules are based on expected UV levels that will be within the limits. This can be illustrated by the Norwegian approval data,[32] with mean erythema-weighted UV within the limit, as is compulsory for approval. However, when the tanning devices were measured in the tanning facilities, the irradiances were higher (Fig. 2). Norway is the only country with advance approval of tanning devices. The sunburn risk is further raised due to the large variation in UV across tanning devices (Figs 2–4). A factor of three difference was found by Nilsen *et al.*[68] between the weakest and the strongest devices in the same facility. Large variation within the same device was found by Khazova *et al.*,[25] Gies *et al.*[29] and Gerber *et al.*[36] Altogether, inspections and inspection studies are important in order to achieve compliance with the irradiance limits given by safety standards and regulations. However, as stated by Autier *et al.*,[69] regulation does not turn a carcinogenic agent into a healthy one.

The radiation or exposure time limitations given by the international standards and regulations are set for safety reasons and to avoid known negative health effects, such as erythema, but with little emphasis on whether harmful effects are caused by UVB or UVA radiation.[56] Vogel *et al.*[70] found increased risk of melanoma also for those who had tanned indoors without burning. Historically, only UVB was considered harmful.[4] The high, and increasing, values of UVA exposure from modern tanning devices are alarming in light of the increased focus on UVA as a carcinogen.[6,15] The mean UVB irradiances of the reviewed studies (Fig. 3) were 0·2·3 times that from natural sun in Crete or Melbourne, whereas mean UVA irradiances (Fig. 4) were 1·7–12 times higher, except in the study of Gies *et al.* from 1986.[43]

In conclusion, most UV measurement studies have been performed in Europe. Erythema-weighted UV from modern tanning devices was high and generally higher than from natural sun, and with large variations between devices. Compliance with irradiance limits was low in Europe, whereas it was high in Australia because of their very high limit. International regulations have focused on minimizing erythema, with little emphasis on whether harmful effects are caused by UVB or UVA. We show that modern tanning devices emit large amounts of UVA, at levels higher than from natural sun and with increasing amounts over time in Europe.

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Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's website:

Table S1. Ultraviolet irradiance from indoor tanning devices in the studies included in the systematic review.

Table S2. Compliance with standards from studies on indoor tanning devices included in the systematic review.

