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Biological effects of indoor sunlight in rural dwelling houses

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Abstract—The biological effects of indoor sunlight in dwelling houses was studied in the southern part of Anhui Province, China. It was revealed that: (1) The indoor UV intensity correlated positively to the outdoor UV with a regression coefficient of 2.51 $\mu W/cm^2$; (2) For a south-facing house with three hour exposure per day to sunlight around the winter solstice, the deactivation rate of indoor sunlight for Staphylococcus albus, Streptococcus viridans and Streptococcus hemolyticus was 95.9%, 80.0% and 51.9%, respectively. The rate was twice as high as that for a north-facing house; (3) Among all the mice infected by Salmonella typhimurium, 70% of those receiving 3h exposure keep alive for seven days after infection, while the mice in the control group (without exposure) all died; (4) In dogs receiving 3h exposure, rachitic signs occurred much later and without deformity of limbs, the epiphyseal cartilage's tongue was shorter and its length was negatively correlated with sunlight intensity (for ulna $r=-0.63$, for tibia $r=-0.71$). It is suggested that daily exposure to sunlight at noon around the winter solstice should be longer than three hours and this must be considered when new houses are designed.

Keywords: biological effect; deactivation of bacteria; immunological effect; antirachitic effect; sunlight.

1 Introduction

Residential insolation has been proved to be one of the essential environmental factors for human life, and its effect on residential sanitation and the health of residents also has been much discussed (Senn, 1980; WHO, 1979; Loomis, 1970; Wang, 1956; Yang, 1981; Zheng, 1981). In winter, adequate exposure to sunlight in residences is of particular importance to infant's growth. However, the intensity of sunlight in dwelling houses varies greatly with climate zone, the season and the direction of the building, and so do its biological effects. In response to the requirement for a practicable sanitary criterion of residential insolation in the climate zone III_B (round E. Long. 115 and N. Lat. 31) to meet the needs of flourishing development of dwelling-house construction, a cooperative research group was organized to conduct a systematic investigation. The present study is a part of this work, which is still under way.

2 Methods and research items (Hu, 1983)

2.1 Experimental field

A single-storey farm house with three rooms adjoined was rented from a local resident in

the rural areas of Dangtu County, Anhui Province (belonging to the hot climate zone III_B; Yang, 1981). The house faces south, by 4°6′ to east, and without other buildings in front of it. After the occupiers moved out, the house was thoroughly sterilized and a new wall was built in the middle room to creat a light - tight chamber for keeping experimental animals. The two adjoining rooms were used for the animals to be exposed to indoor sunlight. The light penetrating area of each adjoining room was 1.38 m^2 and the area ratio of window to ground was 1:9.8. Platforms were set upside and outside of two rooms at a height of 1.2m and a distance of 0.5m from the window. The indoor ones were used for displaying experimental animals and samples, while the outdoor ones for displaying samples when measuring UV intensity.

2.2 **Determination of ultraviolet radiation intensity**

Samples prepared by ammonium molybdate method (Tokegawa, 1936) were displayed in pairs to sunlight on the indoor and outdoor platforms for 1h, 2h and 3h, respectively. To avoid possible influence of testing order or on the way to laboratory, each sample was stored in a light tight box, which was uncovered during exposure and covered immediately after exposure. And then the UV intensity could be worked out.

2.3 **Determination of deactivation efficiency of bacteria by indoor sunlight**

Certain amount of S. albus, S. viridans or S. hemolytium dilutions was smeared on the surfaces of different - medium - containing dishes. Each kind of the specimens was divided into three groups at random to be displayed on the indoor platform for 1h, 2h, and 3h, and then cultured at 37°C for 24 hours. The deactivation efficiency was analyzed.

2.4 **Determination of immunological efficiency of indoor sunlight**

One day before the experiment, 40 healthy male mice with a body weight of 20—22g were exposed to sunlight for two hours. The mice were infected by subcutaneous injection of suspension of Salmonella typhimurium at the nape. The infected mice were randomly divided into four groups to receive 1h, 2h, or 3h exposure to indoor sunlight daily for a week, with the control group receiving no exposure. All the mice were kept in the light - tight chamber with the same living conditions to observe their recovery.

2.5 **Observation of the antirachitic efficiency of indoor sunlight**

Sixteen weanling dogs of the same breed, weighing about 2 kg, were obtained from the local residents. The dogs were divided by body weight into four groups, and then one dog from each group was placed randomly in one of the four experimental groups for receiving different exposure. All the dogs were fed on ordinary food and kept in the same chamber with a temperature of 11°C ± 5°C and a relative humidity of 78.4% ± 9.4%, but without detectable UV. The concentrations of serum Ca and P and the activity of alkaline phosphatase were measured before and after the experiment. The dogs were examined by X - ray regularly and observed daily for signs of rachitis. At the end of the experiment they were sacrificed. Using routine microtomy and hematoxylin - eosin staining the thickness of the epiphyseal cartilage and the length of its tongue were measured with a micrometer under a microscope.

The exposure time for all animals and bacteria was scheduled at 10—11 (1h), 10—12 (2h) and 10—13 (3h) o'clock for each related group. The antirachitic experiment was started from

December 28, 1984, and continued for 58 days.

3 Results and analysis

3.1 UV intensity of sunlight inside and outside houses around the winter solstice

The indoor and outdoor UV intensities (Table 1 and Table 2) were analyzed by linear correlation and linear regression ($r=0.76$, $b=2.51\ \mu W/cm^2$, $P<0.01$). The filterable rate of UV through a single layer of window glass varied with the house orientation and weather conditions. With 3h exposure, in the south-facing house it was 33.9% on fine days and 31.3% on cloudy days around the Winter Solstice, while in the north-facing house it was 9.3% on fine days. The indoor UV intensity in the south-facing house was 3.5 times that in the north-facing house.

Table 1 Intensity of sunlight inside and outside the south-facing houses around the winter solstice

	Number of detection points	$X \pm SD, \mu W/cm^2$		
		1h(10am−11am)	2h(10am−12am)	3h (10am−13pm)
Indoor	45	167.2±24.2	392.6±20.1	622.2±26.1
Outdoor	45	504.2±23.8	1128.5±16.4	1827.9±19.3

Table 2 Intensity of UV light measured at different conditions around the winter solstice

	South-facing						North-facing		
	Fine days			Cloudy days			Fine days		
	1h	2h	3h	1h	2h	3h	1h	2h	3h
Indoor	139.2	354.0	622.2	53.4	160.2	267.0	53.4	106.8	170.5
Outdoor filter	536.4	1158.6	1834.2	214.8	583.0	851.2	851.2	1158.6	1834.2
rate, %	25.9	30.5	33.9	24.8	27.4	31.3	9.1	9.2	9.3

Note: No measurable UV light during cloudy days for the north-facing house.

3.2 Deactivation rate of indoor sunlight for bacteria around the winter solstice

The deactivation rate of sunlight varied significantly with bacterium, house orientation and exposure time. Examined by X^2 test, the difference was significant ($P<0.05$). Even at the same experimental point and for equal exposure time, different kind of bacteria responded to sunlight variously ($P<0.01$). It was found that in the south-facing house 3h exposure brought about the highest deactivation rate (for S. albus−95.9%, S. viridand−80.8% and S. hemilyticus−51.9%) and in the north-facing house, because of lack of direct sunlight, the deactivation rate (for S. albus−52.3%, S. viridand−48.5% and S. hemolyticus−26.0%) was obviously lower than that in the south-facing one. Whatever the house orientation may be, the deactivation rate increased with the rise of sunlight intensity and/or the prolongation of exposure time (Table 3).

3.3 Immunological effect of indoor sunlight on mice

In the seven days, experimental period, 63% of mice in the exposure-receiving groups remained alive, while the mice in the control group all died (Table 4). With the survival rates examined by X^2 test, the difference was of great significance ($P<0.01$), which suggests that the immunity of mice to S. typhimurium is enhanced with the increase of exposure to sunlight.

Table 3 Comparison of deactivation effect of sunlight on different kinds of bacteria in different facing houses

House facing	Exposure time, h	Deactivation rate, %		
		Staphylococcus albus	Streptococcus viridans	Streptococcus hemolyticus
South	1	74.5	63.2	19.2
	2	90.8	73.0	49.5
	3	95.5	80.8	51.9
North	1	12.4	36.3	1.4
	2	38.5	46.7	10.6
	3	52.3	48.5	26.0

Table 4 Immunological effect of sunlight on mice survcial counted on the seventh day after infection

Groups	Exposure mice, h	Number of experimental mice	Number of surviving mice	Survival rate, %
Control	0	10	0	0
Experimental	1	10	6	60
	2	10	6	60
	3	10	7	70

3.4 Antirachitic effect of indoor sunlight on dogs

During the 58 days, experimental period, it was fine in 39 days, rainy in 15 days and cloudy in 4 days. Influenced by the weather, the designed exposure time for all the dogs has not been reached.

The relationship between exposure time and the receiving UV light intensity in dogs (Table 5).

Table 5 The relationship between exposure time and the receiving UV light intensity in dogs

Groups	Average expos. days	Average exposure hours daily, h	Indoor UV received by dogs daily, $\mu W/cm^2$
0 h	0	0	0
1 h	26	0.7	94.2
2 h	25	1.4	263.3
3 h	37	2.2	441.7

3.4.1 Rachiticus signs and hemogram of dogs

The average rectal temperature of the dogs was 37.8°C (ranging from 35 to 39.5°C) and the heart rate was 108/min(ranging from 80 to 156/min). Both the temperature and the heart rate were on the low side of normal. At the end of the experiment the body weight of dogs was by 127g and 241g reduced in the control and 1h groups, and by 5g and 201g increased in the 2h and 3h groups.

The average time from the outset of the experiment to the appearance of rachiticus symptoms in dogs (Table 6).

The ranges of hemogram indices of dogs were as follows: (1) erythrocytes—345×10^4—$855\times10^4/mm^3$; (2) leukocytes—5300—33150/mm^3; (3) hemoglobin—46%—78%; (4) neutrocytes—49%—78%; and (5) lymphocytes—20%—50%. Except that the percentage of lymphocytes was slightly higher, the rest were on the low side of normal (Shi, 1977; Table 7).

Table 6 The average time from the outset of the experiment to the appearance of rachiticus symptoms in dogs (days)

Groups	Time for symptom appearance (day)			Deformity of limbs (dog)
	Poor appetite	Diarrhea	Unsteady standing	
0 h	32	4	14	3/4
1 h	13	13	32	1/4
2 h	19	22	37	1/4
3 h	34	33	48	0/4

Table 7 Serological indices in dogs before and after experiment

		Ca, mg/dL		P, mg/dL		AP*, king unit		Ca × P
		Mean value	Range	Mean value	Range	Mean value	Range	
Before ex—	0	8.0	7.0—8.8	7.7	5.7—11.0	10.0	2.13—14.30	61.9
periment	1	7.9	6.6—8.8	7.8	5.9—11.5	12.5	2.92—28.75	62.4
	2	7.6	6.4—8.8	5.8	2.7—8.0	10.5	1.27—19.66	44.1
	3	7.1	6.3—8.0	7.3	5.2—11.0	20.3	2.11—48.30	51.8
After ex—	0	6.2	6.0—6.6	4.7	2.9—6.3	42.6	7.40—80.5	29.1
periment	1	6.8	6.0 7.7	4.5	2.9—6.0	38.8	30.41—47.47	30.6
	2	5.5	4.4—6.0	2.6	1.6—4.5	35.9	25.20—47.80	14.3
	3	5.5	4.5—6.6	3.8	2.4—5.0	55.9	28.27—83.62	20.9

* AP = alkaline phosphatase

As compared with the control group, the rachiticus signs of dogs in the 3h group started to appear much later ($P<0.05$) and there was no deformity of dogs' limbs ($P<0.01$). The severity of riches was negatively correlated to the length of exposure and the intensity of sunlight.

3.4.2 Biochemical test of serum

Before the experiment, the serum Ca, P and alkaline phosphatase were normal, and the product of Ca and P was larger than 40 mg/dL. After the experiment, the serum Ca was slightly decreased, the serum P obviously reduced and the product of Ca and P less than 30 mg/dL. The activity of serum alkaline phosphatase was greatly increased and was higher than 30 King units. The discrepancy of the product of Ca and P before and after the experiment is remarkably significant ($P<0.01$) and the diagnosis of richests in these dogs can be made (Beijing, 1977).

3.4.3 Roentgenography

Before the experiment no abnormality of bones was found in any of the dogs. After the experiment, osteoporisis and widened epiphysis were found by different degree in the dogs' limb.

3.4.4 Pathomorphological examination of bones

The average thickness of epiphyseal cartilage of the rib, ulna and tibia was 0.32 mm, 0.55 mm and 0.50 mm in the control group and was 0.22 mm, 0.39 mm and 0.45 mm in the 3h group. The difference between groups for the same bone was not significant ($P>0.05$). The length of epiphyseal cartilage's tongue (Table 8, Fig. 1, Fig. 2) was negatively correlated to the intensity of sunlight.

By correlation coefficient analysis it was revealed that for ulna $r_{min}=-0.52$ ($P<0.05$); $r_{max}=-0.63$ ($P<0.05$) and for tibia $r_{min}=-0.53$ ($P<0.05$); $r_{max}=-0.71$ ($P<0.01$). Apparently, any increase of sunlight intensity will bring about corresponding decrease of the length of the epiphyseal cartilage's tongue.

Table 8 Change of average length of the epiphyseal cartilage's tongue in dogs receiving different exposure per day

Intensity of indoor UV,	Ulna			Tibia		
$\mu w/cm^2$	Mean value	Range	High value	Mean value	Range	High value
0	0.30	0.23—0.38	0.60	0.37	0.32—0.41	0.71
94.2	0.29	0.25—0.32	0.43	0.20	0.15--0.25	0.44
236.1	0.20	0.18—0.22	0.32	0.19	0.14—0.24	0.32
441.7	0.18	0.14—0.21	0.26	0.17	0.13—0.19	0.26

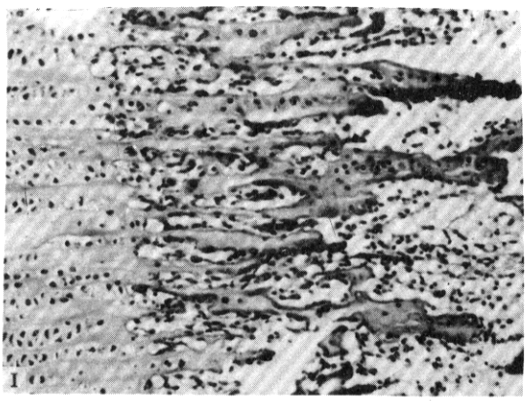

Fig. 1 Control group—dog 4
The epiphyseal cartilage's tongue of the upper tibia extending to the trunk of the bone; the most long—0.8mm; the general—0.4—0.5mm H. E. 33X

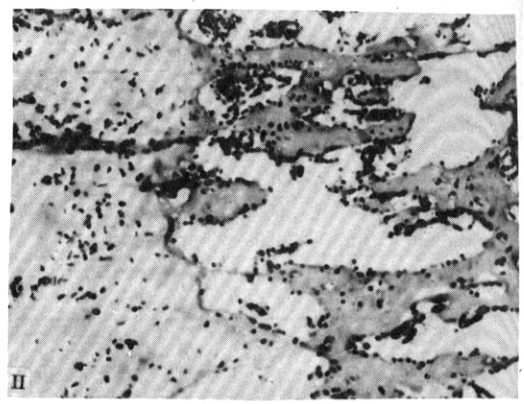

Fig. 2 Three-hour group—dog 1
The epiphyseal cartilage's tongue of the upper tibia extending to the trunk of the bone; the most long—0.25mm; the general—0.05—0.10mm H. E. 33 X

4 Discussion

4.1 Adequate insolation in dwelling-houses is important for enhancing the occupiers health and the residential sanitary level (Hu, 1983). In the flourishing development of dwelling-house construction, it is necessary to set a stipulation of sunshine time during designing dwelling-houses in order to increase the healthful effect of sunlight. Although this problem has been much discussed both abroad and at home, there is still no a complete sanitary criterion of sunshine time practicable for the hot climate zone in our country (Yang, 1981). The present study focus on deactivative or germicidal, immunological and antirachitic effects of filterable sunlight on subjects receiving different exposure (Hu, 1983). Results suggest that in winter, no less than three hours of sunshine time are needed to cause a good biological effects, this is in agreement with the previous data in the literature (Senn, 1980; WHO, 1979; Loomis, 1970; Wang, 1956; Yang, 1981; Zheng, 1981). However, most of the reported studies were carried out in laboratories or outdoor and on one single item (Loomis, 1970; Wang, 1956; Yang, 1981). Based on our field experiment and comprehensive analysis of indoor sunlight effect, the exposure time here suggested seems to be more reliable and practicable.

4.2 To ensure the reliability of the data obtained from field test, the principles of control, balance, randomization and repetition were well followed when this study was designed (Hu,

1983). It has been proved that the filterable sunlight had the wavelength longer than 310 nm (Yang, 1981; Strother, 1979) and theoretically, the insolation effect results from a comprehensive effect of long-wave length UV, short-wave length infrared rays and visible light. The purpose of this study is to determine the intensity of UV, which plays a major biological effect (Hu, 1983). We have measured the intensity of UV light both inside and outside of the house by using of a modified ammonium molybdate method. Obviously the accuracy of this method is not high enoughlike using of modern devices, but it is sensitive and steady. Owing to its simplicity and practicability this method is suitable to be used in our country, and now it is still considered to be a standard method for the measurement of UV intensity.

4.3 Thc recommendation of "no less than 3h exposure at noon daily around the Winter Solstice" is based on the following facts: (1) The deactivation effect of sunlight is exercised through the plasmosin-clotting action of long-wave UV and the heat effect of infrared rays. Comparison of the results in groups with different exposure time suggested that the highest deactivation rate for all kinds of bacteria was caused by 3h exposure. (2) of the mice receiving 3h exposure daily, 70% remained alive on the seventh day of experiment, while those receiving no exposure totally died. This indicated that the discrepancy of survival rate results mainly from the deference of exposure time, since the living conditions for all mice were the same. And it seemed that long-term small intensity exposure might cause a better effect than short-term one. Under the sunlight, the ergosterol and 7-dehydrocholesterol in the subcutaneous tissue were turned into vitamin D_2 and D_3, which helped the body to absorb Ca and P. And thus the antirachitic effect was excised. The experimental dogs, because of lack of outdoor action, all suffered from rickets in different degree, but those in thc 3h group developed relatively better and had milder symptoms as well as shorter epiphyseal cartilage's tongue.

Based on the present study we have demonstrated in many ways that at least 3h sunlight exposure per day in winter is necessary for a new designing house.

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