GRENZ RAYS

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In the 28 years since the original report on grenz rays was published a great deal of experience with this technic has been amassed. It is surprising that, in spite of some excellent therapeutic results which have been reported, and in spite of the inviting nature of the theoretical considerations upon which the modality is based, it has not been taken up to any extent by American dermatologists until quite recently. Very little fundamental investigative work with it has been done in this country. Misconceptions are still rife, and the subject remains highly controversial. Since there is ample evidence to put an understanding of the role of grenz rays in superficial radiotherapy on a sound basis, it appears worth while to attempt to set forth briefly some of the pertinent data, and thus to permit for ultimate detailed evaluation of the modality.

PHYSICAL CONSIDERATIONS

The grenz rays were described by Bucky (1) in 1923. As defined by him (2) and accepted by others (3–30), they are x-rays of 1–4 Angstroms (Å), averaging 2 Å, produced in tubes whose windows will permit the emergence of such soft rays in practical, usable amounts. The original grenz-ray tubes had windows of Lindemann glass (1, 17), a mixture of lithium and beryllium borates. Later ones used inverted "bubble" windows (31, 32) of pyrex glass, while today's tubes have windows of metallic beryllium.

These windows make the very long wavelengths available. The hardness of the shorter wavelengths is limited by the impressed peak kilovoltage (KVP), in accordance (26, 29) with the formula $\lambda_{min} = 12.354/KV$. In the original Lindemann-window tubes, the hardest beam in the grenz-ray range was produced (2, 4, 8, 29) at from 8–12 KVP. In today's beryllium-window tubes, radiation of this quality is obtained (33, 34) at about 14–15 KVP.

It must be emphasized that radiations generated at higher voltages, and of qualities above half-value layer (HVL) 0.035 mm. Al, are not to be confused with grenz rays. They are soft x-rays, but the difference between them and grenz rays can be seen readily by reference to the absorption curves of Ebbehøj (15) in Figure 1. Since back-scatter is negligible (35, 26) in this range, these curves are equivalent to depth-dose curves, and they show at a glance how rapidly the depth-dosage increases with rise in quality. Even the step from medium (curve #4) to hard (curve #5) grenz rays, representing an increase from about 12 to about 14 KVP, doubles the dose at 3 mm., the maximal thickness (36, 37) of normal skin. With increase in voltage beyond the grenz-ray range, the depth-dosage climbs quickly, and effects become possible which could not be produced by more superficial radiations. It was for that reason that Bucky established the upper limit of the grenz-ray range at HVL 0.036 mm. Al, and it was for that reason that, at a meeting of the Council for the Study of

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Grenz-Ray Therapy on March 17, 1950, the upper limit of the grenz-ray range was set at HVL 0.035 mm. Al.

Grenz rays are absorbed quite strongly in air, so that they do not obey the inverse-square law. Intensities calculated by the inverse-square law are always higher than the observed intensities. Attention was directed to this early by Glasser (2, 4) and Mutscheller (38). Detailed studies on air absorption have been done recently by Day and Taylor (39) at the National Bureau of Standards and by Jennings (40) in England. Day and Taylor, working with constant potential at a minimum distance of 119 cm., found that rays generated at 7.5 KV

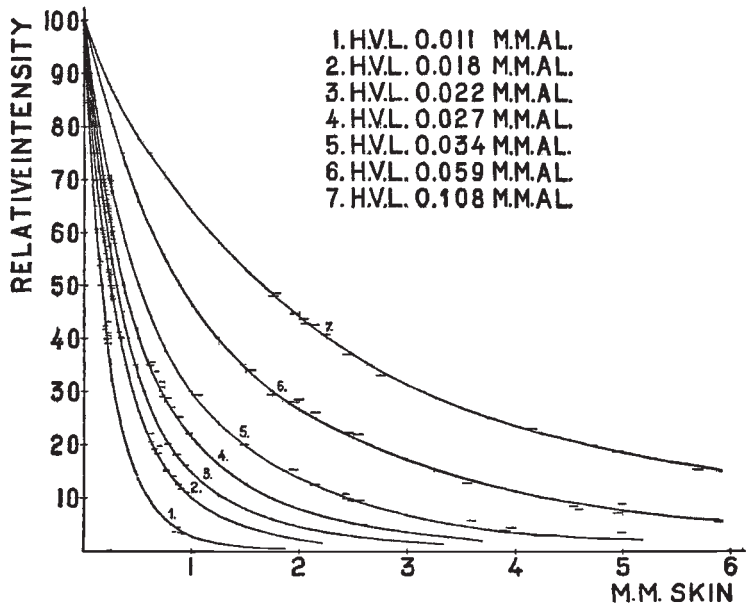

FIG. 1. Absorption curves for grenz rays and soft x-rays. After Ebbehøj, E.

were already filtered down to a homogeneous beam at that distance. Jennings's data show that, for a 10 KVP unfiltered beam, increase in focus-skin distance (FSD) from 10 to 20 cm. reduced the intensity to 78 % of that calculated by the inverse-square law. Similarly, air absorption caused by increase in FSD from 10 to 30 cm. reduced intensity to 65 %, while increase from 10 to 50 cm. reduced it to 44 % of that calculated by the inverse-square law. This was in addition to the absorption of very soft rays in the 7 cm. or so of air included in the original 10 cm. For unfiltered 20 KVP rays, air absorption reduced the intensities correspondingly to 88 % at 20 cm., 78 % at 30 cm., and 61 % at 50 cm.; while for unfiltered 30 KVP rays the corresponding figures were 90 % at 20 cm., 82 % at 30 cm., and 68 % at 50 cm. These figures show the high absorption of the longer wavelengths in air.

With today's tubes, air absorption of grenz rays thus limits practicable FSDs to a maximum of 20–25 cm., for at greater distances the drop in intensity causes

too great increase in treatment time. The diameters of effective treatment fields are about ¾ of the FSD, so that the largest usable fields are about 15–18 cm. in diameter.

BIOPHYSICAL CONSIDERATIONS

Grenz rays therefore offer a means of delivering effective dosage (2, 18, 22–25, 27, 41, 42) to the skin with a minimum of danger (vide infra) to it or to the organs and structures in and beneath it. These rays are absorbed relatively superficially, as the curves in Figure 1 show.

Bucky postulated (2) differences in biologic action between grenz rays and x-rays. He stated that there were differences in erythema, pigmentation, histologic changes, biologic effect on the skin, and biologic effect on the total organism. This thesis was supported (43, 44) by some contemporaries, disputed (45, 46, 47) by others. It still remains a moot point, though some recent biophysical work has indicated a wavelength dependence of biologic effect. Spear (48) and Catcheside and Lea (49) used chromosome-breaks in pollen grains of Tradescantia bracteata as a biologic indicator to show the amount of ionization required to produce breaks. Lea (50) made detailed calculations showing that the average ion density of secondary electrons is almost constant for rays produced at from 30 to 180 KV. Gray (51) determined the mean linear ion density for the range from 1000 to 3 KV, and Catcheside and Lea (49) showed that the coefficient of chromosome-breakage in their experiments was highest at 4.1 Å, falling off through 1.5 A to 0.15 Å. In the light of this work, it appears that the low energy of grenz-ray photoelectrons may produce effects differing, at least in degree, from those of higher energy x-ray secondary electrons.

RANGE OF THERAPEUTIC EFFECTIVENESS

Low depth doses limit or block the effectiveness of grenz rays in the treatment of many deep dermatoses. Tinea capitis, cystic acne (53, 22, 24), the tumor stage (52, 53, 18, 22, 27) of mycosis fungoides, and epithelioma of more than 1–2 mm. in depth (54, 55) call for more penetrating radiation. However, Sagher has reported (56, 57) surprising results from experimental irradiation of lepromatous infiltrates, and regards grenz rays as the treatment of choice (58, 59) in cutaneous leishmaniasis.

This limitation becomes an asset in the treatment of superficial dermatoses, making possible the use of high surface dosage with little fear of the consequences of high depth-dosage. Even such chronic recurrent dermatoses as psoriasis (60, 20, 23), neurodermatitis (61, 62, 63), and some types of localized pruritus (64, 10, 65) can be treated safely and with repeated courses, without great concern for the sequelae which the cumulative effects of more penetrating radiations in excessive aggregate dosage might produce.

SEQUELAE

As ionizing radiations, grenz rays can cause injury to the skin, though only superficial damage has been reported following their use. Superficial atrophy

and telangiectasia may occur (8, 12, 22, 56, 66–71) after either very large doses of soft rays (HVL 0.016–0.022 mm. Al) or smaller doses of hard rays (HVL 0.030–0.035 mm. Al). The dose which is required (8, 66, 67, 68, 12, 72, 29) to accomplish such damage, though, is far beyond the range of the usual therapeutic doses. Sequelae have been reported resulting from larger doses, i.e. thousands of r rather than from smaller doses, i.e. hundreds of r. The first two cases of superficial atrophy and telangiectasia were reported by Bucky (2, pp. 97, 98), and most workers with the technic have seen such injuries.

Erythema is frequently produced by intensive grenz ray therapy, but is not a contraindication to further treatment. It appears earlier (22, 73–78) than does x-ray erythema, usually lasts (75, 76, 22) from a few days up to four weeks, and, like x-ray erythema, may show (2, 76, 79, 14, 78, 22) the wave-like fluctuations in intensity described (80) by Miescher. When erythema has occurred, treatment can be resumed when necessary after the erythema has subsided.

There has been much discussion about the "erythema dose" of grenz rays. It appears impossible to set a figure here, because of the marked variation in response with quality. The range is about 250–400 r. In any individual, it will require (81, 76, 79, 82, 78, 18) a smaller dose of hard than of soft grenz rays to produce an erythema. It appears preferable (83, 73, 76) to avoid the concept entirely, and to discuss grenz ray dosage only in terms of roentgens and quality until a biologic indicator independent of wavelength is devised.

This paradox in the biologic action of grenz rays, in that the erythema dose of hard rays is smaller than that of soft rays, is probably explainable on the basis that the hard beam contains a greater percentage of rays capable of reaching and affecting the superficial vascular plexus.

Pigmentation occurs more frequently following grenz rays administered in routine dosage, and is usually somewhat more intense (84) than that produced by x-rays or ultraviolet radiation. Most of the pigmentation produced with ordinary dosage disappears within the first few weeks after termination of therapy.

However, striking differences exist between the sequelae of overdosage of grenz rays and those produced by overdosage of x-rays. For the hardest of the grenz rays (Figure 1, curve #5), the dose at 3 mm. depth is 7 % of the dose in air at the surface. To deliver an epilating dose of 350 r to the hair bulbs would thus require a surface dose of 5000 r. In actual experience, even temporary epilation in the human has been reported (85, 86) only twice, to the author's knowledge, and many observers (6, 8, 87, 88, 72, 22, 27, 29) have called attention to the safety of the hair, including the eye lashes, under grenz-ray therapy. Though superficial atrophy and telangiectasia are seen, records of instances of sclerosis, permanent dryness, permanent epilation, wrinkling, and other sequelae of intermediate depth have not been found. Of perhaps far greater importance, though, is the fact that a review (104) of the world literature on grenz rays, done recently by Sagher of Jerusalem and the author, failed to locate any report of a keratosis, indolent ulcer, or epithelioma resultant upon the use of these rays. This confirms the findings of other (18, 19, 20, 24, 27, 29), earlier reviews.

TABLE 1

GRENZ RAYS	X-RAYS
Wavelengths 1–4 Å, averaging 2 Å. Voltage range 6–15 KVP. HVL 0.012 mm. to 0.035 mm. Al. Soft rays up to HVL 0.020–0.022 mm. Al (curves 2, 3). Medium rays HVL 0.022–0.028 mm. Al (curves 3, 4). Hard rays HVL 0.030–0.035 mm. Al (curve 5)	Wavelengths 0.12–1 Å. Voltage range from 15–20 KVP up, conventionally 50–100 KVP for dermatologists. HVL 0.050 mm. to 1 mm. Al (inherent filter only)
Air absorption very high, thus limiting greater and more practicable FSDs*. With today's tubes, FSD limited to maximum of about 20–25 cm.	Air absorption negligible, with conventional tubes. Quite high for unfiltered beams from beryllium-window tubes. FSD up to 50 cm. practicable
Field diameters up to 15–19 cm.	Field diameter about 75% of FSD, for shock-proof units
Absorbed almost completely in first 3 mm. of tissue. Back-scatter not yet detected, may be non-existent. Depth-dose falls off rapidly, is insignificant beyond 3 mm.	Penetrating power rises rapidly with voltage. Back-scatter increases with voltage, with increase in area of field, and with increase in volume of tissue, adding still more to depth-dose
Exit dose negligible on ears, digits, palms, and nose. Virtually non-existent elsewhere	Exit dose quite appreciable, especially above 60 KVP. Must be taken into consideration in thin areas
Erythema occurs not infrequently, does not contraindicate further treatment. May show wave-like fluctuations of Miescher	Erythema, when produced, usually contraindicates further treatment in benign disease. Shows Miescher's waves
Erythema dose varies widely with quality. Smaller for hard rays than for soft	Erythema dose usually critical. Greater for hard rays than for soft
Superficial atrophy and telangiectasia occur infrequently, only after very high dosage. Deeper sequelae not reported. No record of keratosis, ulcer, epithelioma, or leukemia found	Sequelae of any depth or degree may be produced, if large enough doses are given. May range in severity up to metastasizing carcinoma. Leukemia is a hazard to the operator if necessary precautions are not taken
Can be used safely over radiosensitive deep organs. No apparent danger of cataract, sterilization, or inhibition of bony growth centers	When given in large doses, radiosensitive deep organs in danger. Sterilization, cataract and inhibition of bony growth centers in children can be produced by excessive dosage

* Focus—skin distance.

Radiosensitive deep organs and structures, such as the eye, the testes, and the bony growth centers of children, seem to be safe from the grenz rays (8, 87, 89, 72, 22, 27, 29) because of the low depth doses. This has been emphasized par-

ticularly in the treatment of such conditions as epithelioma of the lids, pruritus scroti, and dermatoses (90, 87, 91) in children.

Protection, in the conventional sense, is not needed for patient, operator, or workers in adjacent rooms. Absorption of grenz rays in air is so great that adequate distance protects the operator, and lack of scatter in the grenz ray range protects everything outside of the direct beam.

For ready reference, the major differences between grenz rays and x-rays are listed in Table 1.

COMMENT

A perusal of the literature will show that there has always been a remarkable amount of controversy about grenz rays. Historically, this may have been a projection of the much earlier misconception (2, pp. 2–5) about "dangerous soft" and "ineffective hard" x-rays, ultimately shown to be a question of dosage rather than a quality effect.

When Bucky reported his early experiences with the grenz ray portion of the roentgen spectrum, a controversy arose concerning his over-enthusiastic statement that only a small, harmless percentage of grenz rays reached the basal layer of human skin and his claim that grenz rays were different from x-rays. Martenstein (92) ingeniously showed that recognizable radiographs of guinea-pig chests could be made with grenz rays, and claimed that his experiment proved that grenz rays were no different from other x-rays. It should be mentioned that only a fraction of a roentgen ray was required to expose a dental x-ray film. The work of Day and Taylor (39) shows that the minimum wavelengths of grenz rays penetrate at least 120 cm. of air. Some absorption work (93, 94) was also adduced to prove that penetration into the cutis did occur. The dispute was furthered by a set of erroneous absorption curves for 30, 60, and 100 KV x-rays, and by the inferences drawn from them, in Bucky's book (2, pp. 59, 16–19). These curves, calculated erroneously from Compton's tables, demonstrate the inherent pitfalls of inductive reasoning in comparison with the experimental method. Corrected curves for 100 and 25 KV have since been published (95) by Bucky.

Another, and perhaps more serious, disagreement arose over Bucky's equally over-enthusiastic claim (2, p. 111) that radiation sequelae were not produced by grenz rays. To a man accustomed to the post-irradiation catastrophes of 1897–1915, the superficial late effects of grenz ray overdosage probably did not deserve to be called sequelae. However, the statement was taken literally, and American dermatologists, apparently forgetting that Bucky himself had reported (2, pp. 97–98) the first two cases of atrophy and telangiectasis caused by grenz rays, demonstrated several cases (96–100) themselves, and apparently concluded that this discredited the technic.

These controversies are quite understandable in perspective. MacKee's fundamental work had only recently placed radiotherapy of the skin on a sound, safe basis, and the physical measurement of x-ray dosage was just beginning. Actual measurement of depth-dosage was new, and the international r, proposed in

1927, was not accepted officially as the unit of x-ray dosage (103) until 1937. Also, hyperbole is ever vulnerable to the danger of being taken literally. It is scarcely surprising that Bucky's emphatic claims aroused opposition among his contemporaries.

It is a little more difficult to assess the misconceptions and misunderstandings which still persist concerning grenz rays. It appears probable that the early controversies blocked objective evaluation of the technic by the teachers of the day. Today, most of the medical men in this country who have heard of the modality at all know it only as a technic which is impracticable and useless. Errors and misconceptions are still being perpetuated.

In his evaluation of grenz rays (8) for the Council on Physical Medicine of the AMA in 1931, MacKee said, "In general, it is doubtful whether any skin disease . . . can be cured with grenz rays that cannot be cured with x-rays of shorter wavelengths or with beta rays of radium." This statement has been repeated many times and in many places, most recently in the last edition (29) of his book.

So far as can be ascertained, the statement is entirely true; it also seems to be beside the point. Except for nevus flammeus, keratosis follicularis, and a few other uncommon dermatoses, no record or claim had been found concerning skin diseases which could be treated effectively with grenz rays, but not with x-rays or beta rays. How to evaluate this fact is somewhat of a problem, for the rationale of therapy with the long wavelengths is not based on increased range of effectiveness, but on safety. All that seems really to matter is that grenz rays provide equal therapeutic effectiveness with substantial increase in safety. It is difficult to see the validity of any other comparison.

In March, 1950, there was presented (105) before a dermatological society meeting a case of "Dermatitis Due to Grenz Rays." The patient had been working, at a distance of 45 cm., with unfiltered 25 KV radiations from a beryllium-window tube. He was represented as having been hypersensitive to the sun's rays since early childhood. One discussant stated: ". . . the beam of grenz rays . . . is the same as that of x-rays and produces the same type of damage." Another said, "One of the strong contentions of the proponents of grenz ray therapy is that these rays do no harm."

It appears important to correct such misconceptions. Since the upper limit of the grenz-ray range does not extend above 14–15 KVP, this radiodermatitis was not produced by grenz rays, but by soft x-rays. It is evident, as previously mentioned, that the softer components of the 25 KV beam, i.e., the grenz rays would have been filtered out by the air at 45 cm.

The world experience shows that the damage resultant upon overdosage with grenz rays does not approach in magnitude or severity that which may follow overdosage with x-rays of conventional wavelengths. As exemplified by Bucky's original report of atrophy and telangiectasia, the proponents of grenz ray therapy do not contend that these rays can do no harm. They accept the fact that any agent potent enough to do good is also potent enough to do harm, and recognize the great advantage of grenz rays to reside in the fact that they can

be used, not with complete safety, but with safety far greater than that afforded by x-rays of conventional quality.

CONCLUSIONS

1. Grenz rays are x-rays of 1–4 Å, produced in thin-windowed tubes at 6–15 KVP.
2. They are absorbed strongly in air, and are absorbed almost completely in the first 3 mm. of tissue.
3. Their margin of safety is greater than that of conventional x-rays.
4. They are inadequate for the treatment of disease at depths of more than 2 to 3 mm.
5. They are capable of causing superficial damage to the skin, but are not yet reported to have caused an instance of keratosis, chronic ulcer, or epithelioma.
6. The modality is in need of further detailed evaluation.

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