Title
Changes in Rabbit Brain Specific Gravity After High Doses of X-Irradiation

Authors
Leith, John T
Gaugl, John F

Publication Date
2023-09-06

CHANGES IN RABBIT BRAIN SPECIFIC GRAVITY AFTER HIGH DOSES OF X-IRRADIATION[1]

John T. Leith

Donner Laboratory of Medical Physics
and Lawrence Berkeley Laboratory
University of California, Berkeley, California

and John F. Gaugl[2]

Department of Physiology, University of California
Berkeley, California

DISCLAIMER

Running Title: Brain Specific Gravity after X-irradiation...

Address for Proofs: John T. Leith
Lawrence Berkeley Laboratory, Bldg. 10
University of California
Berkeley, California 94720

Changes in specific gravity of different areas of rabbit brain have been studied after exposure to 10 Krads of x-rays to the head only. A triphasic change in brain specific gravity was found; i.e., a decrease from 0 to 1.5 hours after irradiation, followed by a short-lived rise to approximately pre-irradiation values at two hours post-irradiation, and then a developing second decrease to 6 hours after irradiation. The initial decrease and short-lived increase in brain specific gravity appear to be primarily due to disturbances in circulatory relationships of the central nervous system, while the second decrease is due to a developing defect in brain permeability as indicated by increased protein levels in the aqueous humour and cerebrospinal fluid, and by a developing brain edema.

1. Introduction

The fluid economy of the mammalian central nervous system is strictly controlled (Davson, 1969). However, high doses of ionizing radiation appear to have the capacity to induce significant disturbances in the maintenance of this economy, the exact mechanism through which these disturbances are effected being still controversial. Pertinent to this controversy, in 1957, Gerstner and Kent reported a biphasic change in rabbit brain specific gravity after x-ray doses sufficient to produce the so-called "acute central nervous system syndrome". Specifically, they noted a transient increase in brain specific gravity (0 to 3 hours after 9 Kr), followed by a decreasing brain specific gravity from 3 to 12 hours after irradiation. These data suggest the possibility of

acute phasic changes in brain permeability or perfusion mechanisms as evidenced by changes in brain specific gravity. It was our intention to reinvestigage and further define this phenomenon.

2. Materials and Methods

2.1. Animals and irradiation procedure

Animals were New Zealand White rabbits, of both sexes, obtained from the ABC Caviary and Rabbitry, Bethesda, Maryland and the Horton Breeding Laboratories, Los Gatos, California. Animals weighed between 1 and 2 kilogrammes. X-irradiations of the head only were performed with a Phillips Constant Potential Deep Therapy x-ray unit, operated at 250 kVp and 15 mA. The remainder of the body was not shielded. The inherent filtration was 1.1 mm Al and added filtration of 0.5 mm Al was used. The FSD was maintained in all experiments at 20 cm. Measurements from a Victoreen R-meter and lithium fluoride discs placed at the midbrain level of a rabbit skull frozen in liquid nitrogen, indicated a midbrain dose-rate of 1000 rads per minute. The total administered dose was 10 Krads, and animals were restrained and unanesthetized. The field size was approximately 121 cm^2.

2.2. Brain specific gravity (S.G.) measurements

The technique of Nelson, Mantz, and Maxwell (1971) was used to measure brain specific gravity. Two solutions of carbon tetrachloride (S.G. 1.5992 as determined using a plummet) and benzene (S.G. 0.8760) were prepared, such that solution A had a specific gravity of 1.0000 and solution B had a specific gravity of 1.0600. The heavier of the two mixtures (solution B) was placed into a 250 ml graduated cylinder and the lighter

mixture (solution A) was then carefully layered on top to provide a final unmixed volume of 250 ml. The gradient was prepared by mixing the solutions with a metal wire coiled at one end. Mixing was begun at the junction of the two solutions and gradually extended from the junction in either direction until a relatively linear gradient was obtained.

After mixing, the column was calibrated with 13 standards of potassium sulfate of varying S.G. (range 1.0000 to 1.0556). The amounts of K_2SO_4 needed to make a desired S.G. may be found in the Handbook of Physics and Chemistry (1969). The position of the standards and tissue samples (medulla, cerebral cortex, superior colliculus, cerebral white matter, olfactory bulb, cerebellar cortex, anterior thalamus, and pituitary) were determined one minute after being placed in the column. As it is virtually impossible to obtain a completely linear S.G. gradient after mixing the column, calibration values were routinely fitted to a third-order least-square polynomial equation, describing the particular gradient, and experimental tissue S.G. values were determined from the equation. The time between sacrifice of the animal and placement of the tissue sample in the S.G. column was less than five minutes.

2.3. Determination of brain relative vascularity

In this procedure, the method of Nair, Palm, and Roth (1960) was used. Animals were anesthetized (sodium pentobarbital, 35 mg/kg, intraperitoneally) and 10 μCi of human radio-iodinated serum albumin (Abbott) were injected into the femoral vein. At the end of 15 minutes, one ml of blood was withdrawn from the femoral artery, and the animal was killed by immersion into liquid nitrogen (-195°C). The animal was transferred to a refrigerated room (0-2°C), allowed to remain there for one hour, and then

the brain was removed and various areas were dissected. The areas assayed for radioactivity were cerebral white matter, medulla, thalamus, cerebral cortex, superior colliculus, and cerebellar cortex. Tissue samples were homogenized in 1 ml of NCS solubilizer (Amersham) and diluted to 10 ml with Bray's liquid scintillation counting solution. Then, 5 ml of this homogenate were counted for radioactivity in a Nuclear Chicago Mark II liquid scintillation counter. The remaining 5 ml of homogenate was dried to constant weight, and relative vascularities were determined as the number of counts/mg of dry tissue to the number of counts/ml of blood.

2.4. Other physiological measurements

In anesthetized animals, arterial blood pressures were made from cannulas placed in the femoral artery at the junction of the thoracic aorta. Pressures were measured by a Sensotec micro-strain guage attached to a d.c. channel of a Grass Model 7 polygraph. Pressure calibrations were obtained using a mercury manometer.

Cerebral blood flow was measured using an electromagnetic flow probe placed unilaterally around the internal carotid artery in conjunction with an electromagnetic flow-meter (Carolina Medical Electronics). Zero flow determinations were made by vessel occlusion proximal to the transducer. Cerebral arterial blood flow was expressed as its mean at any time, this value being obtained by an integrating circuit in the flow-meter.

Protein concentrations of aqueous humour from the anterior chamber of the eye and from cerebrospinal fluid were measured using the technique of Lowry, Rosebrough, Farr, and Randall (1951). Cerebrospinal fluid was obtained from the cisterna magna using a capillary pipette.

3. Results

The data on the specific gravities of selected brain areas are presented in table 1. Immediately after irradiation (0.5 and 1.0 hours), there is a decreased S.G. in all 7 main cerebral areas. However, at the 1.5 hour time period after irradiation, the S.G. values have again all increased. These changes are, however, not statistically different from pre-irradiation values. At 2 hours and later after irradiation, brain specific gravity values again begin to decrease.

Interestingly, the S.G. of pituitary presents a different picture from the other brain areas. The pituitary S.G. increases steadily to about 2.0 to 2.5 hours after irradiation, being significantly greater than pre-irradiation values during this time interval. After 2.5 hours post-irradiation, pituitary specific gravity begins to decrease, returning to approximately pre-irradiation levels by 6 hours after irradiation.

The values for the aqueous humour specific gravities (table 2) continually increase until 1.5 hours after exposure, and then begin to decrease toward pre-irradiation levels. The aqueous humour specific gravity is significantly greater ($P<0.05$, analysis of variance) than pre-irradiation values from 1.0 - 3.5 hours after irradiation. The blood specific values also begin to increase after irradiation, being greater than pre-irradiation values until 4.0 hours after irradiation, when blood values then begin to decline toward pre-irradiation levels. However, at no time after irradiation are blood specific gravity changes significantly different than pre-irradiation values.

The average brain specific gravity (mean of the seven brain areas sampled) is also presented in table 2. The averaged brain specific

gravity shows an initial decline followed by a return to pre-irradiation values at about 1.5 hours after exposure and then a decline, with values being significantly less than pre-irradiation values from 3.5 to 6.0 hours after irradiation ($P<0.05$, analysis of variance).

In table 3 are presented the relative vascularity values for the brain areas measured, together with their corresponding relative densities as computed from their specific gravities. There is a positive correlation between the relative vascularity and specific gravities of the individual areas. Analysis of the correlation produced a correlation coefficient of 0.99, which is significant at the 0.01 level of probability.

In Figure 1 are presented the values obtained for the aqueous humour and cerebrospinal fluid protein values after irradiation. Our control values compare well with values listed by Davson (1960). It may be seen that protein levels begin increasing dramatically at about 1.0 hours after irradiation, reaching a level of about 200 mg/100 ml, approximately 10 times the normal values, at 4 hours after irradiation. At 6 hours after irradiation, protein concentrations in both aqueous humour and cerebrospinal fluid have decreased from their previous highs.

In Figure 2 are presented the average values for the arterial blood pressure and cerebral blood flow after irradiation. Both parameters show an initial decline at about 1 hour after exposure, followed by a short-lived increase to approximately pre-irradiation levels, and then a second slower decline. The variation in the data does not permit estimation of the changes occurring in cerbrovascular resistance.

4. Discussion

Our data on the specific gravity changes of individual brain areas do not support Gerstner and Kent's data (1957) on the specific gravity changes of entire rabbit brain. Their original data are presented in Table 4. They found a biphasic change in brain specific gravity after irradiation. Total brain specific gravity was significantly higher ($P<0.05$, analysis of variance) than that found in mock-irradiated animals at 2 hours after irradiation. At 6 hours and later after irradiation, there is a developing edema as evidenced by a decreasing brain specific gravity which is significantly lower ($P<0.05$, analysis of variance) at 12 hours after irradiation than values from mock-irradiated control animals. However, they also showed a similar biphasic change in the specific gravity of blood (Table 4), raising the question of whether the changes in brain specific were primary or secondary effects of radiation; e.g., could the "dehydration" phase be systemically produced, as by diuresis?

In the present work a significant dehydration phase of brain specific gravity was not found, although there was a short-lived recovery in the brain specific gravity at two hours after irradiation. Our data are in agreement however, on the longer changes in brain specific gravity, in that there is a developing brain edema as shown by a decreasing brain specific gravity.

The changes in arterial blood pressure, cerebral blood flow, and the correlation between brain specific gravity and relative vascularity values for the brain areas studied all suggest that the initial early decrease and short-lived increase in brain specific gravity seen here are primarily reflections of changes in the blood content of these brain areas.

Since the specific gravity of blood is greater than that of brain, a decrease in brain specific gravity may be interpreted as a decreased blood volume, and conversely an increased brain specific gravity may be interpreted as an increased blood volume. Also, the longer decline in brain specific gravity to 6 hours after irradiation is probably mainly due to a defect in brain permeability, as shown by the increased protein levels in aqueous humour and cerebrospinal fluid. This increase in protein levels is significantly greater than in control rabbits by one hour after irradiation, and reaches a plateau at about two hours after irradiation. Still, the phases of changes in brain blood content and protein leakage are not well enough separated to definitively state that two distinctly different phenomena are occurring. With regard to the finding of increased protein concentrations in aqueous humour and cerebrospinal fluid, it is of interest that Wykoff and Short (1969) have shown increased protein levels in cerebrospinal fluid of burro, 8 hours after only 100 rads of whole-body neutron exposure.

The pituitary presents a different picture than the other brain areas with regard to specific gravity changes. The reason for the steady increase in pituitary specific gravity to about 2.5 hours after irradiation is unclear, although it may represent some sort of pooling of blood in the brain at the pituitary level after irradiation, irrespective of the decreasing cerebral blood flow. The gland is highly vascular, which partly accounts for its high control specific gravity (1.0512), which is, in fact, higher than that of our measured value for blood. In addition, measurements of the water content of the pituitary indicated that it is about 98% fluid compared to 75 - 85% for other brain areas.

Our data on changes in arterial pressure and cerebral blood flow agree quite well with data of Chapman and Young (1968) who found similar changes in the monkey after 2500 R of gamma rays, although their exposure was not limited to the head only. Still, an acute decrease (10 minutes after irradiation) in arterial pressure and cerebral blood flow were found, with a short-lived recovery in these parameters at about 30 minutes after irradiation, followed by a slow decrease in arterial pressure and cerebral blood flow.

Brooks, Gerstner, and Smith (1956) and Kundel (1966) have also reported immediate declines in blood pressure after supralethal doses of x- and gamma rays. In both studies there was subsequent partial recovery and then a slower secondary decline.

The slight recovery in the aortic blood pressure pattern seen at 1.5 - 2 hours after irradiation may be due to the presence of epileptiform seizures, as in non-anesthetized animals seizures were commonly seen beginning at about 45 minutes after irradiation and increased in severity to about 2 hours after irradiation. This phasic change in specific gravity from 0.5 - 2 hours after irradiation correlates extremely well in time with an acute increase in rabbit brain temperature after comparable x-ray doses (Leith and Levy 1970).

Some of the differences between the present specific gravity data and Gerstner and Kent's original data may be due to the size of the animals. The water content of rabbit brain is age-dependent (Graves and Himwich, 1955), and our animals weighed 1 - 2 kilogrammes while Gerstner and Kent's animals weighed 2 - 3 kilogrammes. As our animals were younger, they may also have been more susceptible to the irradiation.

Still, one has the problem of explaining the initial "dehydration"

(i.e. increased brain specific gravity) shown by Gerstner and Kent (1957). Their whole brain specific gravity of 1.0362 is significantly lower ($P<0.05$) than our averaged brain specific gravity of 1.0391, and is lower than that found in any of the individual brain areas measured. Also, their blood specific gravity of 1.0502 is higher than that found in our animals (i.e. 1.0487), difference significant at the 0.05 level of probability). The differences in brain specific gravity may be explained if Gerstner and Kent's brain specific gravity measurements were biased by an unknown contribution from rabbit brain cerebrospinal fluid. As rabbit brain contains about 1.8 ml of cerebrospinal fluid normally (Pollay and Davson 1963), this amount could easily reduce the average whole brain specific gravity to 1.0362. Similarly, it is possible then, that the initial "dehydration" observed by Gerstner and Kent (1957) is simply a reflection of a changing cerebrospinal fluid content in the brain.

In summary, changes in the specific gravity and cerebrovascular parameters of rabbit brain have been described after doses of radiation sufficient to produce the acute mammalian central nervous system syndrome.

FOOTNOTES

[1]Research supported jointly by the United States Atomic Energy Commission and by the National Aeronautics and Space Administration.

[2]Present Address: Texas College of Osteopathic Medicine, Fort Worth, Texas.

REFERENCES

Brooks, P.M., Gerstner, H.B., and Smith, S.A., 1956, Am. J. Physiol., 186, 532.

Chapman, P.H., and Young, R.J., 1969, Radiat. Res., 35, 68.

Davson, H., 1960, A Textbook of General Physiology, Little, Brown, and Co., Boston, Mass. (2nd ed.) pp. 359.

Davson, H., 1969, Handbook of Neurochemistry, Vol. II, Plenum Press, New York, pp. 23.

Gerstner, H.B., and Kent, S.P., 1957, Radiat. Res., 6, 626.

Graves, J., and Himwich, H.E., 1955, Am. J. Physiol., 180, 205.

Kundel, H.L., 1966, Radiat. Res., 27, 406.

Leith, J.T., and Levy, C.K., 1970, Int. J. Radiat. Biol., 18, 291.

Lowry, O.H., Rosebrough, N.J., Farr, A.L., and Randall, R.J., 1951, J. Biol. Chem., 193, 265.

Nair, V., Palm, D., and Roth, L.J., 1960, Nature, 188, 497.

Nelson, S.R., Mantz, M.L., and Maxwell, J.A., 1971, J. Appl. Physiol., 30, 268.

Pollay, M., and Davson, H., 1963, Brain, 86, 137.

Weast, R.C., Editor, 1969, Handbook of Chemistry and Physics (50th ed.), Cleveland, Ohio, Chemical Rubber Co., pp. D-197.

Wykoff, M.H., and Short, C.E., 1969, Am. J. Vet. Res., 30, 73.

RÉSUMÉ

Des changements de la gravité spécifique de diverses zones du cerveau du lapin ont été étudiés après exposition à 10 krad de rayons X à la tête exclusivement. On a trouvé un changement triphasé de la gravité spécifique du cerveau; c'est-à-dire, une diminution à partir de l'heure zéro jusqu'à une heure et demie après l'irradiation, suivie d'une augmentation de courte durée, deux heures après l'irradiation, aux valeurs d'avant l'irradiation plus ou moins, et puis une deuxième diminution en développement jusqu'à six heures après l'irradiation. La diminution initiale et l'augmentation de courte durée de la gravité spécifique du cerveau semblent être dues principalement à des troubles des relations circulatoires du systeme nerveux central; tandis que la deuxième diminution est due aussi à une anomalie en développement de la perméabilité de la barrière hématо-encéphalique, comme l'indiquent les teneurs augmentés des protides dans l'humeur aqueuse et dans le liquide céphalo-rachidien, et l'oedème du cerveau en développement.

ZUSAMMENFASSUNG

Wechsel des spezifischen Gewichts verschiedener Fläche des Gehirns des Kaninchens sind nach Aussetzung an 10 kRad Röntgenstrahles nur auf dem kpf studiert worden. Ein dreiphasiges Wechsel des spezifischen Gewichts des Gehirns wurde gefunden; das ist, eine Abnahme von 0-1,5 Uhr nach Bestrahlung; dann folgte ein kurzlebiges Aufsteigen ungefähr auf den Werten vor Bestrahlung 2 Urhren nach Bestrahlung, und nächst eine zweite entwickelnd Abnahme bis 6 Uhren nach Bestrahlung. Die anfängliche Abnahme und die kurzlebige Aufsteigen des spezifischen Gewichts des Gehirns

scheiner hauptsächlich die folge von Störungen in der zirkulatorischen Beziehungen des Zentralnervensystems; während die zweite Abnahme auch die Folge von einem entwickelnden Mangel der Durchdringbarkeit der Blut-Gehirn Schranke ist, wie die zugenommenen Höhen des Proteins im Kammerwasser und in der Cerebrospinalflüssigkeit, und das enwickelnde Gehirnödem anzeigen.

TABLE 1

SPECIFIC GRAVITIES OF IRRADIATED TISSUES

Time after Irradiation (hours)	Olfactory Bulb	Cerebral White Matter	Medulla	Anterior Thalamus	Cerebral Cortex	Superior Colliculus	Cerebellar Cortex	Pituitary
0	1.0362 (0.0014)[1]	1.0357 (0.0021)	1.0383 (0.0019)	1.0391 (0.0017)	1.0401 (0.0015)	1.0402 (0.0009)	1.0424 (0.0012)	1.0511 (0.0017)
0.5	1.0359 (0.0018)	1.0369 (0.0022)	1.0376 (0.0018)	1.0383 (0.0012)	1.0399 (0.011)	1.0399 (0.0011)	1.0419 (0.0014)	1.0512 (0.0014)
1.0	1.0362 (0.0015)	1.0373 (0.0014)	1.0374 (0.0014)	1.0381 (0.0020)	1.0396 (0.0016)	1.0397 (0.0011)	1.0418 (0.0015)	1.0518 (0.0017)
1.5	1.0365 (0.0009)	1.0374 (0.0018)	1.0383 (0.0014)	1.0388 (0.0020)	1.0406 (0.0018)	1.0400 (0.0010)	1.0424 (0.0008)	1.0524 (0.0014)
2.0	1.0357 (0.0016)	1.0366 (0.0020)	1.0379 (0.0012)	1.0385 (0.0015)	1.0401 (0.0014)	1.0396 (0.0018)	1.0416 (0.0013)	1.0531* (0.0016)
2.5	1.0359 (0.0014)	1.0366 (0.0015)	1.0382 (0.0015)	1.0375 (0.0016)	1.0398 (0.0014)	1.0390 (0.0013)	1.0403* (0.0014)	1.0530* (0.0016)
3.0	1.0357 (0.0014)	1.0360 (0.0019)	1.0371 (0.0018)	1.0368* (0.0015)	1.0395 (0.0015)	1.0386* (0.0014)	1.0401* (0.0013)	1.0518 (0.0020)
3.5	1.0356 (0.0016)	1.0362 (0.0021)	1.0372 (0.0019)	1.0365* (0.0016)	1.0396 (0.0013)	1.0382* (0.0010)	1.0390* (0.0014)	1.0514 (0.0018)
4.0	1.0359 (0.0017)	1.0364 (0.0014)	1.0374 (0.0015)	1.0362* (0.0017	1.0398 (0.0015)	1.0382* (0.0012)	1.0378* (0.0015)	1.0511 (0.0015)
6.0	1.0355 (0.0012)	1.0359 (0.0020)	1.0368 (0.0020)	1.0360* (0.0014)	1.0392 (0.0009)	1.0378* (0.0014)	1.0375* (0.0016)	1.0509 (0.0021)

[1] Values in parentheses indicate the standard deviation of the mean value of 10 determinations.

* Indicates Specific Gravity values significantly different ($P<0.05$) from pre-irradiation values.

TABLE 2

SPECIFIC GRAVITIES OF IRRADIATED TISSUES

Time after Irradiation (hours)	Aqueous Humour	Blood	Entire Brain[1]
0	1.0071 (0.0018)	1.0487 (0.0020)	1.0391 (0.0017)
0.5	1.0088 (0.0020)	1.0504 (0.0024)	1.0385 (0.0019)
1.0	1.0114* (0.0021)	1.0493 (0.0022)	1.0387 (0.0019)
1.5	1.0136* (0.0018)	1.0504 (0.0025)	1.0391 (0.0020)
2.0	1.0121* (0.0018)	1.0502 (0.0019)	1.0386 (0.0020)
2.5	1.0097* (0.0022)	1.0493 (0.0021)	1.0382 (0.0016)
3.0	1.0091* (0.0018)	1.0498 (0.0020)	1.0377 (0.0017)
3.5	1.0090* (0.0017)	1.0495 (0.0022)	1.0375* (0.0015)
4.0	1.0080 (0.0019)	1.0487 (0.0018)	1.0374* (0.0014)
6.0	1.0070 (0.0015)	1.0481 (0.0022)	1.0369* (0.0013)

[1] The value for entire brain is obtained from the average value of the individual brain areas studied.

[2] Values in parentheses indicate the standard deviation of the mean value obtained from measurements on 10 animals.

* Indicates values significantly different from pre-irradiation values at the 0.05 level of probability.

TABLE 3

RELATIVE BLOOD CONTENT OF DIFFERENT AREAS OF THE RABBIT BRAIN

Area	Relative Blood Content[1]	Relative Specific Gravity[2]
Cerebral White Matter	1.00 (0.16)[3]	1.0000 (0.0006)
Modulla	1.62 (0.21)	1.0008 (0.0005)
Thalamus	1.90 (0.24)	1.0015 (0.0004)
Cerebral Cortex	2.52 (0.28)	1.0025 (0.0004)
Superior Colliculus	2.40 (0.30)	1.0026 (0.0002)
Cerebellar Cortex	3.45 (0.30)	1.0047 (0.0003)

[1] Data have been normalized to the radioactivity value obtained for cerebral white matter as: $\frac{\text{(counts/min/mgm. dry wt. tissue)/(counts/min/ml blood)}}{\text{counts/min/mgm. dry cerebral white matter)/(counts/min/ml blood)}}$

[2] Data have been normalized to the specific gravity value obtained for cerebral white matter as: $\frac{\text{Specific gravity brain area}}{\text{Specific gravity cerebral white matter}}$

[3] Figures in parentheses indicate the standard errors of the relative blood content and specific gravity values expressed as per cents of the normalized values. Measurements were taken from five animals.

TABLE 4

SPECIFIC GRAVITIES OF IRRADIATED TISSUES[1]

Time after Irradiation (hours)	Specific Gravity of Rabbit Brain	Specific Gravity of Rabbit Blood
0	1.0362 ± 0.0004[2] (12)[3]	1.0502 ± 0.0032 (9)
0.5	1.0367 ± 0.0007 (9)	1.0518 ± 0.0040 (9)
2	1.0373* ± 0.0009 (9)	1.0553 ± 0.0031 (9)
3	1.0371 ± 0.0010 (9)	1.0574* ± 0.0042 (10)
6	1.0353 ± 0.0008 (14)	1.0527 ± 0.0062 (9)
12	1.0349* ± 0.0010 (10)	1.0483 ± 0.0032 (6)

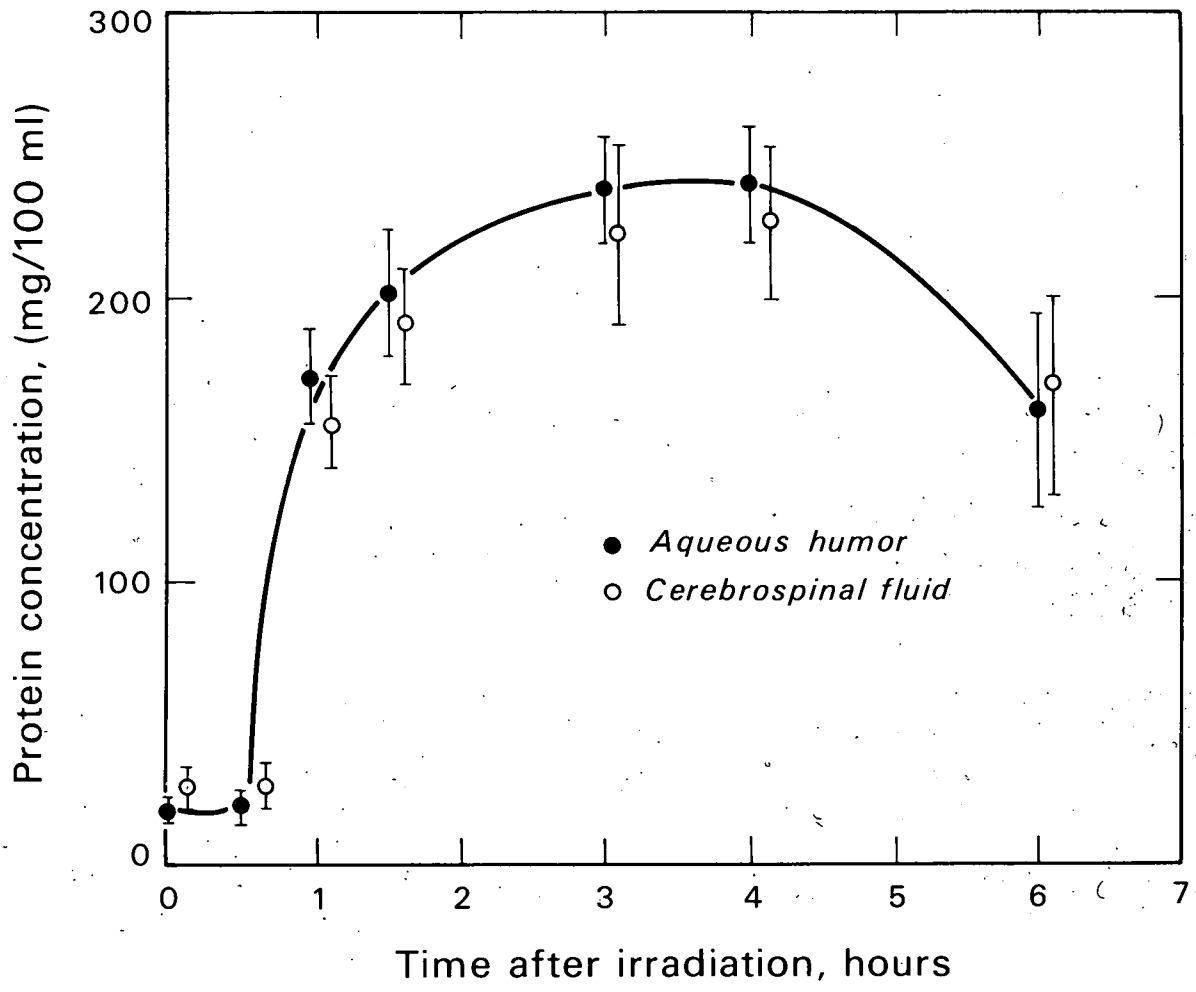
[1] Data taken from the work of Gerstner and Kent, 1957.

[2] Standard deviation of the mean.

[3] Indicates the number of animals used.

* Indicates values significantly different from pre-irradiation values at the 0.05 level of probability.

Figure 1. Changes in protein concentrations of aqueous humour and cerebrospinal fluid after 10,000 rads to the head of rabbits. Values are presented as the mean value and the standard deviation, with five animals per experimental point.



DBL 7111 6024

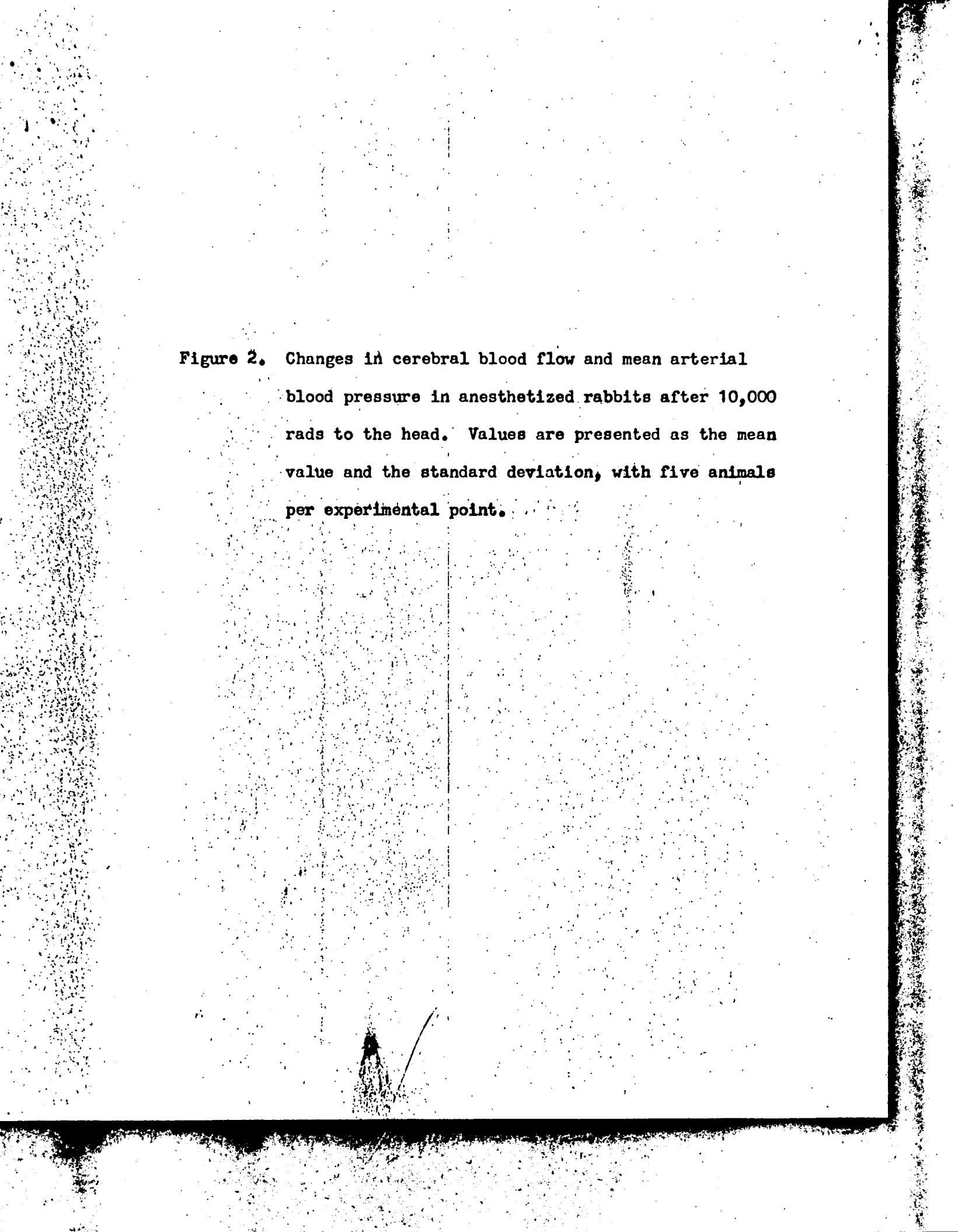
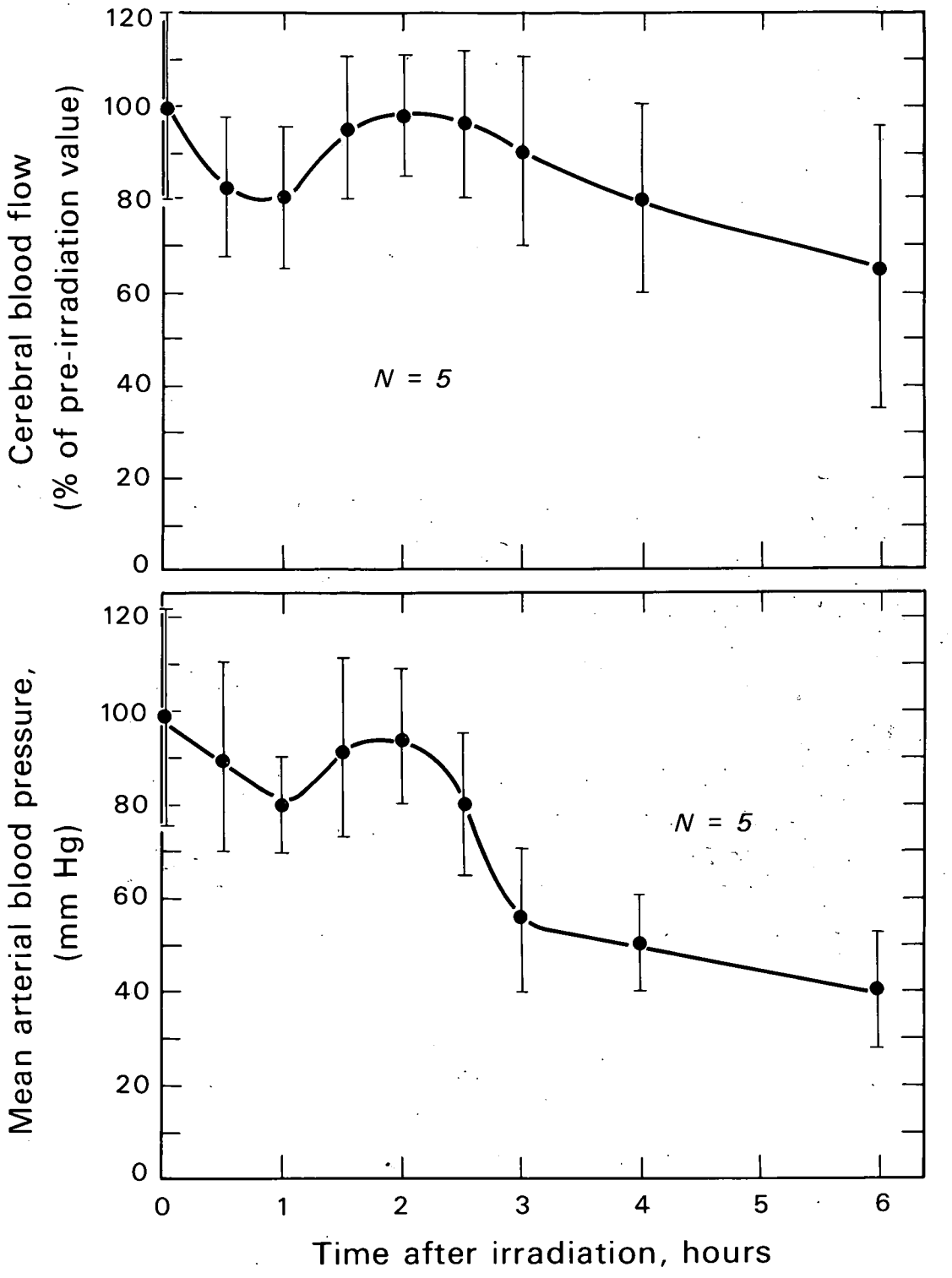


Figure 2. Changes in cerebral blood flow and mean arterial blood pressure in anesthetized rabbits after 10,000 rads to the head. Values are presented as the mean value and the standard deviation, with five animals per experimental point.



DBL 7111 6025