EFFECTS OF BLOOD PRESSURE ON CEREBRAL CIRCULATION

FUMIO GOTOH

*Department of Internal Medicine, School of Medicine,
Keio University*

(Received on November 28, 1958)

In order to grasp cerebral hemodynamics correctly during various diseased conditions, the relationship between blood pressure and various amounts in cerebral circulation must be clearly established as an important factor to control blood flow. Two standpoints are considered for the investigation of this problem. The first is to change blood pressure by some artificial means and measure corresponding values of cerebral circulation on the same individual, thereby investigating the relationship between these two after repetition. The second standpoint is to statistically investigate the correlation between these two on many individuals who have different blood pressure levels. The results heretofore obtained are mostly from the first view-point.

When blood pressure is changed either by drugs or some artificial procedures, however, it is difficult to avoid intervening influences due to the drug or procedure itself. Besides, it is impossible to carry on continuous investigation on the relationship between blood pressure and cerebral circulation in the wide range, as we are yet unable to pursue successive changes in cerebral circulation by means of N₂O method, the only clinically available method for the measurement of cerebral circulation. Therefore, there have been no systematic achievements so far with a view to investigating the relationship between blood pressure and cerebral circulation.

Whereas the second standpoint has a drawback of intermingling manifold physiological and pathological factors, it is also has an advantage of being able to grasp natural relationship between blood pressure and cerebral circulation. Besides, it is possible that the factors which modify the effects of blood pressure are either offset from the observations on many correctly sampled cases or excluded by statistical manipulations.

Thereupon, the role of blood pressure factor on the cerebral circulation was investigated from the second standpoint, and including the factor of age which was clarified by Aoki of the same department, the author gave consideration to

the interrelation among these factors and the cerebral circulation. Consequently, it is the purpose of this paper to bring the relationship between blood pressure and cerebral circulation into bold relief by statistical method, while excluding other factors to the utmost.

METHOD OF INVESTIGATION

149 cases were selected as the subject of study from among healthy persons and patients suffering from various diseases other than cerebrovascular disorders, heart disease and anemia which have been known to influence cerebral circulation. The correlation between various amounts in the cerebral circulation and blood pressure was statistically investigated taking the factor of age into consideration.

The cerebral circulation was measured by N₂O method, and the blood gas was analyzed by Van Slyke-Neil's method. After suitable rest in supine position, the blood pressure was determined by auscultation and a mercury sphygmomanometer applied to the arm, the mean arterial blood pressure was thereby calculated from this.

RESULTS

I. Cerebral blood flow and blood pressure.

1) Correlation between systolic blood pressure and cerebral blood flow.

Considering the factor of age, 149 cases were classified into 2 groups, one with 59 cases of persons who are below 34 years of age and the other 90 cases of persons over 35 years of age. Fig. 1 shows the correlation between systolic blood pressure and cerebral blood flow on each of the age groups respectively.

As can be clearly seen in the figure, in the younger group cerebral blood flow increases with the elevation of systolic blood pressure. Its correlation coefficient is 0.3336 indicating apparently significant correlation ($P < 0.01$). Its regression line is linear and the equation of regression line is shown by $y - 61.7 = 0.177(x - 132.5)$. Another problem here is that whether the factor of age intervenes even in the younger group. Age and systolic pressure show positive correlation, and age and cerebral blood flow show negative correlation as will be described later. Therefore, if the factor of age intervenes, systolic blood pressure and cerebral blood flow should show negative correlation. Actually, there is a contrary relationship, which makes it clear that the factor of age does not intervene in this case.

In the older group, elevation of blood pressure up to 160-170 mm Hg was accompanied with increasing cerebral blood flow, and further elevation of blood pressure brings about inversely the decline of cerebral blood flow, drawing a downward sloping curve. That is, its regression is curvilinear and correlation

ratio η_y is 0.4042 showing apparent correlation ($P < 0.01$).

Age and cerebral blood flow are not associated in this curvilinear relationship. Therefore, age cannot be considered as an intervening factor in this case. The

$$r = 0.3336 \quad (P < 0.01)$$

$$y - 61.7 = 0.177 (x - 132.5)$$

$$\eta_y = 0.4042 \quad (P < 0.01)$$

- Mean values of CBF classified by SP in the younger group.
- Regression line of CBF plotted according to SP in the younger group.
- Mean values of CBF classified by SP in the older group.
- Regression line of CBF plotted according to SP in the older group.

Fig. 1 Correlation between SP and CBF.

above curve should be regarded as an indication of the direct relationship between systolic blood pressure and cerebral blood flow. Thus, although systolic blood pressure and cerebral blood flow show a very close correlation, this relationship is quite different according to age.

As will be described later, this is considered to be due to the modification of primary relationship between blood pressure and cerebral blood flow by the latent pathological changes of the cerebral vessels attendant upon hypertension in old persons.

2) Correlation between diastolic blood pressure and cerebral blood flow.

The correlation between diastolic pressure and cerebral blood flow is as shown in Fig. 2. Cerebral blood flow decreases recti-linearly with the elevation of diastolic blood pressure. Its correlation coefficient is -0.2112 and apparently significant ($P < 0.01$). Its regression equation is shown by $y - 57.4 = -0.099$

($x-94.0$). That is, the relationship is quite contrary to that of systolic blood pressure.

According to the results obtained by Aoki of our department, it was made clear that cerebral blood flow decreases with age not only in the normotensive

$$r = -0.2112 \quad (P < 0.01)$$

$$y - 57.4 = -0.099 (x - 94.0)$$

- Mean values of CBF classified by DP.
- Regression line of CBF plotted according to DP.

Fig. 2 Correlation between DP and CBF.

group, but also in the hypertensive group. On the other hand, it can certainly be affirmed that from a common sense standpoint diastolic blood pressure also elevates with age. Therefore, it is necessary to investigate whether the relationship between diastolic blood pressure and cerebral blood flow is direct or nothing but a relationship between age and cerebral blood flow viewed from a different aspect. The cases that the author dealt with include both the normotensive and hypertensive persons. The tentative examination of the relationship between age and cerebral blood flow in regard to this group shows a significant negative correlation with a correlation coefficient of -0.3828 and coincides with Aoki's results. The correlation between diastolic blood pressure and age is apparently significant with a correlation coefficient of 0.522 substantiating a fact of common sense. Then, in order to clarify the relationship between diastolic blood pressure and cerebral blood flow when the factor of age was excluded, partial correlation coefficient was pursued, setting age at a certain level. The partial correlation coefficient turned out to be -0.0237 and indicated no correlation whatever between both mentioned above. That is, the relationship seen between diastolic blood pressure and cerebral blood flow was through the medium of age.

3) Correlation between mean arterial blood pressure and cerebral blood flow.

Correlation between mean arterial blood pressure and cerebral blood flow is shown in Fig. 3. Correlation coefficient is -0.1780 and significant ($P < 0.05$) negative correlation is observed. Its regression line is $y - 57.4 = -0.067(x - 113.4)$ indicating rectilinear decline of cerebral blood flow together with elevation of mean arterial blood pressure.

- Mean values of CBF classified by MABP.
- Regression line of CBF plotted according to MABP.

Fig. 3 Correlation between MABP and CBF.

It is necessary to investigate, however, the presence of the age factor even in case of mean arterial blood pressure, as there is possibility of the existence of similar factor mentioned in the previous chapter. Thereupon, the relationship between mean arterial blood pressure and age was investigated showing apparently significant positive correlation with a correlation coefficient of 0.4740 . It was already shown that age and cerebral blood flow show a negative correlation. Thereby, the partial correlation coefficient when age is determined is calculated from the correlation coefficient among each of mean arterial blood pressure, age and cerebral blood flow, which turned out to be 0.0042 denoting no correlation. That is, the relationship between mean arterial blood pressure and cerebral blood flow seen in Fig. 3 is through the medium of age as in the case of diastolic blood pressure, and there is no direct relationship between both. After all, even if age is determined, the only thing that bears close relationship with cerebral blood flow is systolic blood pressure.

II. Cerebrovascular resistance and blood pressure.

1) Correlation between systolic blood pressure and cerebrovascular resistance.

The relationship between systolic blood pressure and cerebrovascular resistance is very close, so the plotted mean values of cerebrovascular resistance classified by blood pressure are on a straight line as shown in Fig. 4. That is, as systolic blood pressure elevates, cerebrovascular resistance increases on a straight line. The correlation coefficient is 0.7803 and quite significant ($P < 0.001$). Its regression line is expressed by $y - 2.08 = 0.131(x - 161.3)$. However, it cannot be overlooked that quite similar circumstances exist even in case of cerebrovascular resistance. As it has been made clear that cerebrovascular resistance increases with age, it has to be proved that the increase in cerebrovascular resistance attendant upon the elevation of systolic blood pressure is not due to the advance in age. Therefore, the interrelation among these must first of all be clarified. Correlation

Fig. 4 Correlation between SP and CVR.

between age and cerebrovascular resistance is quite significant ($r = 0.7311$, $P < 0.001$) and this is also similar to Aoki's results. Besides, the relationship between systolic blood pressure and age is also very close ($r = 0.5027$, $P < 0.001$). The partial correlation coefficient between systolic blood pressure and cerebrovascular resistance obtained from the above three relationships on condition of a fixed age is 0.7002 and also significant ($P < 0.001$). That is, there is no intervening factor of age in this case, and even if age is the same, the higher the systolic blood pressure is, the stronger cerebrovascular resistance is shown.

2) Correlation between diastolic blood pressure and cerebrovascular resistance.

Correlation between diastolic blood pressure and cerebrovascular resistance is indicated in Fig. 5. A quite significant ($P < 0.001$) and positive correlation is seen in this case with a correlation coefficient of 0.7570 and regression equation is ex-

pressed by $y - 2.08 = 0.0244(x - 94.0)$. As the range of variation of diastolic blood pressure is narrow in comparison with systolic blood pressure, the inclination of its regression line is steeper than that of systolic blood pressure.

● Mean values of CVR classified by DP.
 — Regression line of CVR plotted according to DP.

Fig. 5 Correlation between DP and CVR.

The relationship between diastolic blood pressure and age, and the relationship between age and cerebrovascular resistance are already shown. Should the factor of age be excluded from the above three relationships by the same method as before, the direct relationship between diastolic blood pressure and cerebrovascular resistance would be expressed by a correlation coefficient of 0.6607 showing apparently significant ($P < 0.001$) positive correlation. Accordingly, elevation of diastolic blood pressure means an increase of cerebrovascular resistance irrespective of age.

3) Correlation between mean arterial blood pressure and cerebrovascular resistance.

The relationship between mean arterial blood pressure and cerebrovascular resistance is as shown in Fig. 6. As expected from the results obtained in cases of systolic blood pressure and diastolic blood pressure, mean arterial blood pressure has a linear relationship to cerebrovascular resistance. That is, the correlation coefficient is 0.8042 and quite significant ($P < 0.001$). Its regression equation is represented by $y - 2.08 = 0.0207(x - 113.4)$. The relationship between mean arterial blood pressure and age, and the relationship between age and cerebrovascular resistance are already shown. If age is set at a certain level as mentioned before in the previous chapter, the partial correlation coefficient becomes 0.7619, which also shows a significant ($P < 0.001$) positive correlation. There is no intervening factor of age also in this case. In summary of the above, it can be said that any of systolic blood pressure, diastolic blood pressure and mean arterial blood pressure

has a significant and positive correlation with cerebrovascular resistance and even if age is set, these relationships are unchangeable.

$$r=0.8042 \ (P<0.001)$$

$$y-2.08=0.0207 \ (x-113.4)$$

- Mean values of CVR classified by MABP.
- Regression line of CVR plotted according to MABP.

Fig. 6 Correlation between MABP and CVR.

III. Cerebral oxygen consumption and blood pressure.

- 1) Correlation between systolic blood pressure and cerebral oxygen consumption.

Fig. 7 is the indication of correlation between systolic blood pressure and cerebral oxygen consumption. Cerebral oxygen consumption shows a slightly declining tendency as systolic blood pressure elevates. Moreover, it has already been shown that elevation of systolic blood pressure and advance in age are parallel. Besides, according to Aoki's results, cerebral oxygen consumption is said to decrease with age in the hypertensive group. As hypertensive persons are included among the author's subjects of study, it must be investigated whether there is any influence due to the factor of age. First of all, correlation between age and cerebral oxygen consumption is investigated giving a result of an apparently significant negative correlation ($r=-0.3521$, $P<0.01$). The absolute values of its correlation coefficient is much larger than that between systolic blood pressure and cerebral oxygen consumption, thereby suggesting the participating factor of age. The factor of age was then excluded by the same method as before reversing the mark of correlation coefficient to $+0.0125$, which indicated no correlation. The tendency to decreasing cerebral oxygen consumption attendant upon elevating systolic blood pressure which was seen before was entirely due to the influence of age.

- 2) Correlation between diastolic blood pressure and cerebral oxygen consumption.

$$r = -0.1669 \quad (0.01 < P < 0.05)$$

● Mean values of CMRO₂ classified by SP.

Fig. 7 Correlation between SP and CMRO₂.

The relationship between diastolic blood pressure and cerebral oxygen consumption is as shown in Fig. 8. At first sight, the mean values in Fig. 8 seem to indicate elevating diastolic blood pressure accompanied with a tendency to seemingly decreasing cerebral oxygen consumption, but this is not really significant. This is considered to be due to the strong extent of dispersion.

$$r = -0.1425 \quad (P > 0.05)$$

● Mean values of CMRO₂ classified by DP.

Fig. 8 Correlation between DP and CMRO₂.

3) Correlation between mean arterial blood pressure and cerebral oxygen consumption.

As shown in Fig. 9, there is no established relationship between mean arterial blood pressure and cerebral oxygen consumption. After all, systolic blood pressure, diastolic blood pressure and mean arterial blood pressure have no influence whatever on cerebral oxygen consumption.

COMMENT

There have been no systematic contributions as yet concerning the relation.

● Mean values of $CMRO_2$ classified by MABP.

Fig. 9 Correlation between MABP and $CMRO_2$.

ship between blood pressure and cerebral circulation. Only the cerebral hemodynamics during hypertension or artificial hypotension has been discussed in connection with the above. Whereupon, Kety⁽¹⁾, Shenkin⁽²⁾ and others reported that in essential hypertension, only cerebrovascular resistance increases while cerebral blood flow and cerebral oxygen consumption are unchangeable. However, these results left age out of careful consideration.

The contributions with due regard to age have been made by Hafkenschiel⁽³⁾ and Tazaki⁽⁴⁾, any one of them are suggestive of a tendency to increasing cerebral blood flow in hypertension of young persons and decreasing cerebral blood flow in hypertension of older persons. Moreover, Crumpton⁽⁵⁾, Hafkenschiel⁽⁶⁾ and others have reported that, in coarctation of the aorta which is accompanied with an increase of effective blood pressure toward cerebral blood flow, an increase of cerebral blood flow and cerebral oxygen consumption as well as constant cerebrovascular resistance were observed, and that cerebral blood flow and cerebral oxygen consumption have all returned to normal after the operation.

Although, there have been many contributions⁽⁷⁾⁽⁸⁾⁽⁹⁾⁽¹⁰⁾ concerning hypotension by the use of various hypotensive drugs, these drugs are considered to have some influence upon cerebral blood vessels or the brain itself, and the results are conflicting according to the kind of the drugs. Therefore, it is difficult to estimate from these results the influence exerted by the lowering of blood pressure itself. The contribution on hypotension by means of sympathetic nerve blocking made by Kety et al. is excellent in that respect. That is, various amounts of cerebral circulation were measured before and after the lowering of blood pressure caused by procaine injection into lumbar subarachnoid space and the subsequent dilatation

of the vascular bed in an area which is distal to the brain. According to the above, the reduction of cerebrovascular resistance and decreased cerebral blood flow were observed and the reduction of cerebrovascular resistance was said to be ascribable to the reaction of cerebral blood vessels to the lowered blood pressure (This will be described later). Besides, they surmised that there is a tendency to maintain cerebral blood flow against the lowering of blood pressure, as there is relatively little correlation between the decrease of cerebral blood flow and the degree of lowering of blood pressure.

All of the above contributions were about cerebral circulation during hypertension or hypotension, and it is impossible to pursue the relationship between blood pressure and cerebral circulation continuously. The works of Atarashi⁽¹²⁾, Kato⁽¹³⁾ and Tazaki⁽⁴⁾ and their associates can be mentioned as touching this point. Atarashi stated that elevation of blood pressure especially of diastolic blood pressure in older persons is closely connected with the decrease of cerebral blood flow. Kato was of opinion that cerebral blood flow will decrease in proportion to the elevation of both systolic and diastolic blood pressure in hypertensive patients. These conclusions indicate the results of elevating blood pressure accompanied with decreasing blood flow which are seemingly contradictory to the practical principle concerning "pressure" and "amount of flow." This speaks of the admixture of physiological factors which modify pure physical relationship between pressure and flow. Whereupon, various factors which cause to change cerebrovascular resistance are considered to be working. One of the factors which can be grasped quantitatively is age. The above works did not inquire into age closely. Paying attention to this point, Tazaki investigated the relationship between blood pressure and cerebral circulation while considering the factor of age in hypertension. According to his report, similar results were obtained when the influence of age was not considered, however, when age was set at a certain level, neither systolic and diastolic blood pressure nor mean arterial blood pressure has correlation with amounts of cerebral circulation, and the only thing that has correlation with blood pressure is cerebrovascular resistance. These results were all within the framework of "hypertension," however, and although considerations have been given to age, only 4 out of 60 cases were in their 20s, the total number of cases less than the age of 40 was 5 and all of the remaining 55 cases were older than 40. Accordingly, the strong influence of hypertension in old persons is exhibited here and it should rather be called the relationship between blood pressure in hypertension of old persons and cerebral circulation. Therefore, the report clarified only a very partial and age-factor-modified aspect of relationships between blood pressure and cerebral circulation.

The author thereby tried to clarify the whole aspect of the relationships between blood pressure and various amounts of cerebral circulation from a much wider point of view. Even when the framework of "hypertension" was removed, diastolic blood pressure and mean arterial blood pressure have negative correlation with cerebral blood flow, which coincides with the results of Atarashi, Kato and others.

It is the same as Tazaki's results, however, that there is no correlation when certain age is set, showing age as a better index rather than diastolic blood pressure and mean arterial blood pressure in case the condition of cerebral blood flow is clinically estimated.

It is the relationship between systolic blood pressure and cerebral blood flow that is most interesting and different from the results obtained by the above-mentioned researchers. As shown in Fig. 1, in younger persons cerebral blood flow increases linearly accompanying with elevation of systolic blood pressure and, in older persons it has a curvilinear relationship with a blood pressure of 170 mmHg at the top of the curve. It is considered that the results obtained by the above-mentioned researchers took up and discussed only the downward portion of this curve. Whereas it is natural that latent cerebral arteriosclerosis is considered to be present in older persons, which affects cerebral circulation to various extents according to its degrees. Therefore it may well be said that the results obtained in younger persons is close to the original relationship between blood pressure and cerebral circulation. If cerebral blood flow is assumed to obey Poiseuille's law, cerebral blood flow should increase in proportion to the elevation of blood pressure, and linear regression in younger persons can be regarded as an expression of close aspect of the above.

On the other hand, it is estimated that the existence of hypertension will naturally accompany the constriction of arterioles and accelerate arteriosclerosis. Professor Murakami⁽¹⁴⁾ proved from the autopsy findings that the decrease of cerebral blood flow is more marked proportionate with higher blood pressure. It would be the curvilinear regression in older persons that represents this aspect. That is, as blood pressure elevates more than a certain degree in old persons, the influence of cerebral arteriosclerosis comes out in the foreground by the modification of original influence of blood pressure due to cerebral arteriosclerosis attendant upon hypertension. Therefore cerebral blood flow decreases conversely. Thus, elevation of blood pressure includes two contradictory factors. In other words, the primary cerebral blood flow increasing factor and the secondary decreasing factor, two of these contradictory factors are coexisting. The morbidity of hypertension is complicated by the various combinations of these two factors according to age.

It is considered that the results of Kety, Shenkin and others showed unchangeable cerebral blood flow by the offsetting of these two factors. Considering these two factors, it may be said as a matter of course that Hafkenschiel and Tazaki predicted the existence of a tendency to increasing cerebral blood flow in hypertension of youth and decreasing cerebral blood flow in hypertension of old age.

Fig. 10

Now, the schematic expression of this relationship is given as shown in Fig. 10. Transverse arrows indicate the magnitude of primary cerebral blood flow increasing factor and longitudinal arrows indicate the magnitude of secondary cerebral blood flow decreasing factor. In coarctation of the aorta and juvenile hypertension cerebral blood flow increases by the superiority of primary factor, in hypertension of middle age well-balanced primary and secondary factors result in constant cerebral blood flow and in hypertension of old age and cerebral arteriosclerosis with hypertension, the decrease of cerebral blood flow is seen as a result of larger secondary factor.

As stated above, the relationship between blood pressure and cerebral blood flow shows an entirely different aspect according to age. On the other hand, according to Aoki of this department, the relationship between age and cerebral blood flow is different in each of normotensive group and hypertensive group. That is, cerebral blood flow decreases curvilinearly in the former and linearly in the latter. Accordingly, in order to grasp cerebral hemodynamics correctly during various pathological conditions, the relationship among age, blood pressure and cerebral circulation must be grasped collectively.

Fig. 11 Interrelation among CBF, BP and Age.

The relationship among the above three in three dimensions is illustrated in Fig. 11. Taking age on axis x , systolic blood pressure on axis y and cerebral blood flow on axis z , the mean values of the amounts of cerebral blood flow for the various combinations of age and blood pressure are represented by a curved surface ABCD. The point A shows hypotension (within physiological limits) in younger persons. The point B shows hypertension in young persons, it is understood that the amount of cerebral blood flow is the largest at this point because of its highest position. The point C represents hypertension of old age and it is situated at the lowest position indicating the smallest cerebral blood flow. The point D shows hypotension of old age and it is characteristic that the point is located at a rather higher position than the point C. The straight line AB denotes the linear increase of cerebral blood flow accompanying with elevation of blood pressure in young persons. The curved line DC denotes that the largest amount of cerebral blood flow is located at the blood pressure level of 170 mmHg and cerebral blood flow decreases conversely by further elevation of the blood pressure from that level onward.

Besides, the curved line AD and straight line BC denote that cerebral blood

flows decreases curvilinearly by normal or below normal blood pressure and linearly by hypertension. Despite a generally steep and high incline at the side of hypertension, the curved surface has an especially marked downward sloping at the point C. This speaks of the existence of a secondary cerebral blood flow decreasing factor enough to cover the primary action of cerebral blood flow increasing factor. That is, as stated before, hypertension brings about secondary cerebral arteriosclerosis in old persons and the degree of the cerebral arteriosclerosis is parallel with the extent of hypertension. It is estimated that the decrease of blood flow was brought about for the above reason. This fact coincides with Aoki's result that, "the decrease of cerebral blood flow as a result of an advance in age is more marked in hypertensive persons than in case of normotensive persons." The projection of this curved surface on xz plane is an influence of blood pressure which was clarified by the author.

Although it has already been clarified by Kety⁽¹¹⁾, Prof. Aizawa⁽¹⁵⁾, Tazaki and others that cerebrovascular resistance is closely connected with mean arterial blood pressure. According to the author's results, it is also very closely related with not only mean arterial blood pressure but also systolic and diastolic blood pressure. That is, as shown in Figures 4, 5, and 6, cerebrovascular resistance increases linearly in proportion to elevation of blood pressure and this relationship is unchangeable even when certain age is set. In general, it has been imagined that there is a mechanism to maintain cerebral blood flow at a fixed level by increasing cerebrovascular resistance as blood pressure elevates.

As seen clearly by the results of young persons in Fig. 1, however, cerebral blood flow is not necessarily maintained at a certain level. Besides, it is very doubtful whether the so-called calculated increase of cerebrovascular resistance attendant upon elevation of blood pressure really means an increase of cerebrovascular resistance in its true sense. Because, cerebrovascular resistance (CVR) is calculated by a formula of $CVR = \frac{MABP}{CBF}$ and by just looking at this formula, it is estimated that there is a very close relationship between cerebrovascular resistance and blood pressure even without waiting for the experimental results. This formula consists on the hypothesis that cerebral blood flow obeys Poiseuille's law. For example, when blood pressure is doubled, the calculated value of cerebrovascular resistance will increase unless cerebral blood flow is also doubled.

In other words, even if blood pressure and cerebral blood flow showed a linear relationship, the calculated value of cerebrovascular resistance will increase as blood pressure elevates, unless the straight line goes through an origin. Therefore, the results seen in Figures 4, 5 and 6 may be called rather natural outcomes. It would be premature to draw deduction from these results alone that there is

a mechanism which maintains cerebral blood flow by increasing cerebrovascular resistance against the elevation of blood pressure. The only thing that can be said here is that cerebral blood flow cannot increase in proportion to the elevation of blood pressure. It would be necessary to re-investigate the formula to calculate cerebrovascular resistance so as to expect a correct conclusion.

The solution of this problem requires a knowledge of the relationship between blood pressure and cerebral blood flow under the condition of fixed cerebrovascular resistance (in its true sense). It should be borne in mind, nevertheless, that, maintenance of cerebrovascular resistance at a fixed level is technically very difficult and further research is desired in that respect. A cautious attitude must be taken to discuss variations in the values of cerebrovascular resistance calculated by the present method in connection with the variations in cerebrovascular resistance in its true sense.

Although it has been said for a long time that, cerebral oxygen consumption is relatively maintained at a certain level under various conditions, the author showed that cerebral oxygen consumption is not influenced by the variation of blood pressure. Tazaki and Aoki reported that, cerebral oxygen consumption declines in hypertension with the advance in age, however, this should be interpreted not so much due to the influence of hypertension as by the aging augmented by hypertension—probably cerebral arteriosclerosis.

SUMMARY AND CONCLUSION

The relationship between blood pressure (BP) and cerebral circulation measured by nitrous oxide method was statistically investigated in 149 subjects without evidence of disease which might affect the cerebral hemodynamics.

1) The relationship between systolic blood pressure (SP) and cerebral blood flow (CBF) was different in the younger group as compared to the older group. In the younger group (under 34 years of age), there was a close statistical correlation between elevating SP and increasing CBF, and its regression was linear. In the older group (over 35 years of age), elevating SP up to 160 mmHg was accompanied with increasing CBF, and from 170 mmHg onward, there was a gradual decline in CBF. That is, its regression was curvi-linear.

2) Between elevating diastolic or mean arterial BP and decreasing CBF, there were significant correlations. Excluding the factor of age, however, these were not significant.

3) Cerebral vascular resistance (CVR) showed a distinct correlation with SP, DP and MABP, whether the factor of age was excluded or not.

4) There was no significant correlation between cerebral oxygen consumption

(CMRO₂) and BP.

From these results, it came to the conclusion that CBF was most affected by SP, elevation of which meant not only a primary factor to increase CBF, but also a secondary factor to decrease CBF accelerating the cerebral vascular change.

REFERENCES

1. Kety, S. S. et al.: J. Clin. Invest. 27:511, 1948.
2. Shenkin, H. A. et al.: J. Clin. Invest. 32:459, 1953.
3. Hafkenschiel, J. H. et al.: J. Clin. Invest. 33:63, 1954.
4. Tazaki, Y.: J. of Jap. Soc. Int. Med. 45:731, 1956.
5. Crumpton, C. W. et al.: J. Lab. & Clin. Med. 40:789, 1952.
6. Hafkenschiel, J. H. et al.: Proc. Soc. Exp. Biol. & Med. 71:165, 1949.
7. Bodechtel, G.: Münch. Med. Wschr. 96:507, 1954.
8. Finnerty, F. A. et al.: J. Clin. Invest. 33:1227, 1954.
9. Aizawa, T., Gotoh, Y. et al.: J. Jap. Soc. Int. Med. 43:120, 1954.
10. Moyer, J. H. et al.: Am. J. Med. 14:2, 1953.
11. Kety, S. S. et al.: J. Clin. Invest. 29:402, 1950.
12. Atarashi, J. et al.: The 20th Convention of Jap. Soc. of Circulation, 1956.
13. Kato, T. et al.: Sogo Igaku 13:781, 1956.
14. Okinaka, S.: Cerebral vascular disorders, Saishin Igaku Co., Osaka, 1955.
15. Aizawa, T.: Annual report at the 20th Convention of Jap. Soc. of Circulation, 1956.