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Corti - inference of contrary recruitment  
phenomenon (hypothesis) and the application  
to diagnosis -.

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# Mechanism of sound susceptibility in organ of Corti - inference of contrary recruitment phenomenon (hypothesis) and the application to diagnosis -.\*

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## Abstract

In order to make the mechanism concerned with the sound-susceptibility in the organ of Corti clear, we observed the organ of Corti with the phase-contrast microscope, after the microdissection of the cochleae in human, dogs, guinea pigs and hamsters by Engstroöm's surface preparation technique. As a result, we have formulated a hypothesis for the mechanism of the sound-susceptibility in the organ of Corti. Further, we have inferred the contrary recruitment phenomenon (hypothesis), by explaining theoretically such a clinical fact as the recruitment phenomenon or the cochlear hearing loss by applying our first formula of hypothesis. Finally, we described the application of the contrary recruitment phenomenon (hypothesis) to the early discovery or diagnosis of the false normal ear or cochlea, in other words, latent hearing loss.

**KEYWORDS:** application, diagnosis

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**MECHANISM OF SOUND SUSCEPTIBILITY IN ORGAN  
OF CORTI  
— INFERENCE OF CONTRARY RECRUITMENT  
PHENOMENON (HYPOTHESIS) AND THE  
APPLICATION TO DIAGNOSIS —**

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*Abstract:* In order to make the mechanism concerned with the sound-susceptibility in the organ of Corti clear, we observed the organ of Corti with the phase-contrast microscope, after the microdissection of the cochleae in human, dogs, guinea pigs and hamsters by Engström's surface preparation technique. As a result, we have formulated a hypothesis for the mechanism of the sound-susceptibility in the organ of Corti. Further, we have inferred the contrary recruitment phenomenon (hypothesis), by explaining theoretically such a clinical fact as the recruitment phenomenon or the cochlear hearing loss by applying our first formula of hypothesis. Finally, we described the application of the contrary recruitment phenomenon (hypothesis) to the early discovery or diagnosis of the false normal ear or cochlea, in other words, latent hearing loss.

About mechanism operating in the sound-susceptibility of the inner ear, especially of the organ of Corti, many theories have been advanced to date. We consider it necessary to study such a mechanism from the aspect of sound-vibration of the basilar membrane, particularly of the organ of Corti. It seems that the investigation needs to be carried out, as precisely as possible, not only from the vibration of the whole organ of Corti, but also from manner of the vibration in each part or each cell of the organ. In view of this, we investigated repeatedly the mechanism to be operating in the vibration of each part or each cell of the organ of Corti by the procedures to be described later in this paper.

As a result of this study we have recognized again the importance of the organ of Corti which has an area of tunnel formed by pillar cells, and

propose here hypothesis of the mechanism operating in the sound-susceptibility in the organ of Corti or in hair cells.

On the basis of this hypothesis we would like to explain a recruitment phenomenon, infer the existence of a contrary recruitment phenomenon (hypothesis) and consider their application to diagnosis.

#### MATERIALS AND METHODS

The inner ears used in the study comprised 36 human ears (34 from adults and 2 from fetus), 12 ears of adult dogs, 14 of mature guinea pigs, and 20 of hamsters (mature 6 and neonatal 14).

Human cochleae specimens were prepared from the temporal bones collected mostly from the human corpses at several to ten add postmortem hours and fixed immediately. With dogs five cochleae were fixed immediately after sacrifice, and seven were fixed *in vivo* under general anesthesia to prevent postmortem change. With guinea pigs and hamsters the temporal bones were taken out immediately after sacrifice and at once put into the fixative solution, buffered paraformaldehyde-glutaraldehyde solution, pH 7.2, then the fixative procedures in the next stage were carried out as follows.

In the case of human, dogs and guinea pigs the fixative solution was perfused from the round window through the oval window to fix the membranous cochleae.

With hamsters the oval and the round windows were opened, further several holes were made on these cochleae in the same fixative solution as these cochleae were too small for perfusion. In this manner the fixative solution was readily led into the inside of the cochleae, membranous cochleae.

After keeping the cochleae in the fixative solution for 24 hours or more at 4°C, they were again fixed and stained with osmic acid (OsO<sub>4</sub>) solution.

With human, dog, and guinea pig specimens, 0.5% osmic acid solution was perfused from the round window via the oval window for five minutes as in fixation. The cochleae were immersed in the osmic acid solution for 15 minutes and then washed with 70% alcohol for five minutes. With hamster specimens, the cochleae were immersed in 2% osmic acid solution for 30 minutes, washed with 70% alcohol and washing was repeated further twice at interval of five minutes, each with fresh alcohol.

All these specimens were immersed in 70% alcohol and kept in a refrigerator until used.

For the observations of the specimens, membranous cochleae were microdissected by Engström's surface preparation technique under magnifying glass (12×, 25× and 50×) or under the phase-contrast microscope (100×), and they were observed under the phase-contrast microscope (100×, 200×, 400×, 500× and 1000×).

#### RESULTS AND DISCUSSION

Needless to say, it would be most desirable to have the specimens with

least postmortem change and artifact, but it is also advisable to study specimens of each part and individual cells of the organ of Corti separately. For this purpose we intentionally created artifacts in four ears each of human and guinea pig specimens and tried to isolate individual cells as much as feasible to observe, in this instance, responses of the individual cells to extrinsic forces.

Incidentally, we observed the destruction of the organ of Corti believed to have resulted from abnormal stimulation of violent vibration in the four cochleae of dog.

We also found scar formation of hair cells mainly in human inner ear. However, in some ears the postmortem changes were so great that such a phenomenon could not be detected. Further we made comparative study of hair cells in each row, especially, those in the outside and the inside. The details of our observations are described in the following items.

#### *A. Observation of Artifact:*

It was found that artifacts often occurred in the processes of microdissection and they could be roughly divided into a relatively large artifact and a relatively small one.

##### *1. Findings of the relatively large artifact.*

In the observation of the organ of Corti with the basilar membrane as a whole with a special attention to relatively severe and wide artifacts produced by the direct or indirect extrinsic force, we found most frequently such an artifact in the area of tunnel.

That is, no matter how elastic and tough the tissue of the basilar membrane was, the membrane began to have the first separation between the outer pillar cells and the first outer hair cells when the extrinsic force was exerted to the whole of the basilar membrane, and with a still stronger force the membrane split itself between the inner and outer pillar cells. In the latter separation, the outer pillar cells were separated between the side of head-plate and the side of area attached in the basilar membrane, yet the outer pillar cells were united with the inner pillar cells in the upper side (head-plate) and were fast united with the basilar membrane in the lower side, or the outer pillar cells were just separated in the upper area (head-plate) which were in contact with the inner pillar cells.

In such a process the organ of Corti was separated at the border of the area of tunnel into two parts; namely, the part of outside (side of outer hair cells) and the part of inside (side of inner hair cells). Such phenomena of the separation readily occurred in the basal end side, particularly in Hook's area of the basilar membrane.

*Consideration* : The above findings may be explained as follows.

In the microdissection the area of tunnel seems to function as a fulcrum, the area exterior to the tunnel may move by the force exerted on the whole basilar membrane, and this area receives the strongest impact. It would be understood from the anatomical relation in the basilar membrane and the area of the outside (stria vascularis and spiral ligament) with the osseous spiral lamina of the inside, that the artifact in the area of tunnel occurred most frequently in the basal end-side especially in Hook's area. In the apical and middle coils the area of tunnel may hardly receive an excessive extrinsic force during the microdissection, as the basilar membrane and the osseous spiral lamina are practically smooth and the stria vascularis, etc., on the outside are not so thick as in the basal coil. On the contrary, at the basal end-side the basilar membrane and osseous spiral lamina are slightly curved, and the stria vascularis, etc. on the outside are much thicker and tougher than on the apical side. Accordingly, the area in the tunnel on the basal end-side is apt to receive the excessive extrinsic force in the microdissection. Such an anatomical explanation seems to be reasonable, because this tendency particularly is remarkable in the Hook's area and this area has a greater curvature than other areas of the basilar membrane.

Thus we may give our consideration on the pillar cells at the time when the basilar membrane is separated in the area of tunnel. The pillar cells adhere very firmly to the basilar membrane at the bottom of the pillar cell group and the connection between the outer and inner pillar cells is also strong on the upper side (head plate). However, the connection on the upper side seems to be not so strong as at the bottom of the pillar cells.

Considering the artifact in the area of tunnel, the connection on the upper side of the pillar cells seems to be elastic enough to be possible to cause the phenomenon of discrepancy even if this discrepancy is so slight.

2. *Findings of the relatively small artifact* :

Outer hair cells, Hensen's cells and Claudius' cells were readily destroyed or divided by a very small force from the outside, for instance, even by a very slight touch. Therefore, these cells seemed to be very fragile. Although Deiters' and Boettcher's cells were fragile and were easily destroyed, they were not so fragile as the above-mentioned cells. Particularly Deiters' cells were hard to be divided from the basilar membrane or destroyed by a small force. Pillar cells seemed to be the most difficult to be damaged comparing with the other cells on the basilar membrane, and to be the strongest and most elastic cells. Further the connection of pillar cells and basilar membrane was undoubtedly much stronger than that of Deiters' cells and others.

The artifact was found hardly in the area of the inside of inner pillar cells, and inner hair cells were scarcely damaged. Especially rare was the artifact in the internal spiral sulcus. This part is the site rarely to be touched by mistake in the microdissection, and has the strong pillar cells on the outside. In addition, these cells on the modiolar side seemed to have a firmer connection than the cells on the outside of the tunnel.

The hairs of the hair cells appeared to be most easily damaged in various parts, but the cuticular lamina at its apex of the hair cells seemed to be very resistant to destruction. This may be explained as follows. In the observation of the outer hair cells that were damaged by mistake in the microdissection, the topside, cuticular lamina of the outer hair cells, had often been kept almost intact although the outer hair cells had not only the hairs but also the bodies of the cells destroyed and lost.

The same was true with outer hair cells as well as Deiters' cells and pillar cells as far as their cuticular lamina of the apex was concerned.

In contrast, with the inner hair cells we could not find such phenomena in the cuticular lamina. Namely, we found that the inner hair cells were hardly destroyed in the microdissection. As we mentioned already, even if they were destroyed, we believe that the force from the outside would be too strong for the inner hair cells and the cuticular lamina to remain intact.

In the observation of the artifact in the tectorial membrane, this membrane was easily severed accidentally, because it is relatively thin and very slender. But we consider that this membrane itself is a rather firm tissue.

*B. Attempt to Isolate the Organ of Corti into Separate Parts and Individual Cells for the Observation :*

In attempt to observe the behaviors of different parts and individual cells of the organ of Corti placed under extrinsic forces, the organ was placed in glycerin and observed under the phase-contrast microscope (magnification  $100\times$ ).

After this procedure, these specimens were again observed in detail under the phase-contrast microscope ( $200\times$ ,  $400\times$ ,  $500\times$  and  $1000\times$ ).

The results of this study were as follows.

1. Tectorial membrane was easily to be isolated.
2. Hensen's, outer hair and Claudius' cells was easily separated from the cells or tissue at the bottom side, and Deiters' cells and those cells located at the inner side of pillar cells; namely, the inside from the tunnel, remained on the side of the basilar membrane. Boettcher's cells were separated with Claudius' cells etc., or remained with Deiters' cells in the basilar membrane.
3. With the organ of Corti after removing the tectorial membrane, we

observed the mobility or resistibility of individual cells under a slight extrinsic force, and found that Hensen's cells moved easily by the slightest force and outer hair cells had the mobility of the next grade. As to the mobility of outer hair cells, we found that they could not be moved alone, but they could always be moved together with Hensen's cells. That is, Hensen's cells showed the highest mobility and the outer hair cells in the outermost outside adjacent to Hensen's cells were easily moved together with Hensen's cells. Although these outer hair cells were easily moved with Hensen's cells, the mobility seemed to decrease in proportion as they were situated on the rows of more inner side. In the resistibility, the resistance of outer hair cells to moving force was stronger than that in moving Hensen's cells alone.

These findings indicate that not only Deiters' cells on the bottom side but also pillar cells inside are concerned with the mobility or resistibility of outer hair cells. Actually, when a stronger force is exerted on these cells to be separated later, there occurs the sliding of tunnel; namely, pillar cells together with outer hair cells, etc. In this isolation procedure, Hensen's cells began to be separated first of all, which was followed by the separation of outer hair cells that were isolated from Deiters' cells. At that instance the outer hair cells were found to have moved with Deiters' cells.

The mobility of pillar cells in the area of tunnel and inner hair cells seemed to be much less than the mobility of Hensen's, outer hair and Deiters' cells on the outside of pillar cells, because the pillar and inner hair cells could not be moved by the force in the same grade by which Hensen's, outer hair and Deiters' cells could be moved, and these pillar cells and others required a much stronger force. Accordingly, the procedure of the separation inside of tunnel required a much stronger force and was more difficult to be achieved, especially difficult was the separation of inner hair cells. From this fact it was considered that the cells in this area had a firmer, mutual adhesion.

With Claudius' and Boettcher's cells we could not observe the mobility such as Hensen's cells and others, and we could separate them easily by a less force.

4. More precise details in the separation of outer hair cells can be explained as follows. When a very slight force is exerted gradually after the first separation of Hensen's cells, the outer hair cells are elevated first with Deiters' cells and stretched themselves. When the procedure is temporarily suspended at this stage, these cells retract to the former or normal position slowly as a stretched rubber band would. Therefore, it is considered that the connection between the outer hair and Deiters' cells is elastic and these cells themselves are also elastic.



In our further attempt to separate the first outer hair cells from the outer pillar cells, which is more difficult than the separation of these cells from Hensen's cells, we found that, when this procedure was suspended halfway, these outer hair and outer pillar cells also tended to resume this original position. Accordingly, the flexibility and stability of outer hair cells seem to be dependent on the synergistic action of not only Deiters' cells but also Hensen's cells on the outside and pillar cells on the inside, i. e. of those cells located in the area of the tunnel.

5. Next, the separation of inner hair cells required a much stronger force and was much more difficult than that of outer hair cells as mentioned already. In this instance, we could not observe the similar flexibility and stability of inner hair cells as observable with the outer hair cells. Therefore, it was considered that inner hair cells had a much stronger connection with the bottom side and the vicinity than outer hair cells.

6. In the separation of Deiters' cells from basilar membrane, evidently a more direct and much stronger force was required than in the separation of outer hair cells from Deiters' cells. After the exposure of Deiters' cells by separating outer hair cells, they were seen curved by applying a force not strong enough as to separate them, but on releasing such a force they resumed the original position. These observations indicate that Deiters' cells are flexible but stable and strong, and they are firmly connected with the basilar membrane.

7. The separation of the outer and inner pillar cells on the upper side, i. e. at the reticular lamina, was more difficult than that of the outer hair cells from Deiters' cells. The separation of pillar cells from the basilar membrane needed a stronger force and was more difficult than in the case with Deiters' cells. In these procedures the same phenomena were more remarkably observed as in Deiters' cells on the addition or elimination of the extrinsic force. When the force was slightly increased, pillar cells became curved at a little upper side from the connected area between pillar cells and basilar membrane without being separated, or were broken off in this bent part, and only the connected area of pillar cells remained on the basilar membrane. In the separation of this connected part from the basilar membrane, we had to apply a stronger force to exfoliate the bottom side of this part along with the basilar membrane. Therefore, it was considered that pillar cells were the strongest, most elastic and most stable cells in the organ of Corti, and the connection between pillar cells and basilar membrane was strongest.

8. On comparing the outer pillar cells with the inner pillar cells, we could hardly find any appreciable difference, except for the fact that the

former were slightly longer and had a more slanted connection with the basilar membrane than the latter.

In comparing the separation of outer pillar cells from the first outer hair cells with that of inner pillar cells from inner hair cells, the procedure in the latter proved to be much more difficult than that in the former. The connection between the outer pillar cells and the first outer hair cells was not so firm, and in this area an elastic movement was observed during the separation procedures. On the contrary, the connection between the inner pillar cells and the inner hair cells was very strong and rigid, and in this area elastic movement was not observable.

9. The separation of the cells inside; namely, on modiolar side from inner hair cells, was more difficult than Claudius' cells outside, and then the cells in the modiolar side seemed to have been more firmly connected.

10. In the observation of the basilar membrane we could ascertain this membrane to be elastic, stable and very strong tissue, but the fissure or separation was relatively easily accomplished from the outside to the inside.

The side of basal end, especially Hook's area, was easy to be separated in the area of tunnel to the interior and the exterior, as already stated in the observation of the artifact of the organ of Corti.

*Comment*: In comparing the action of the extrinsic force from the outside or sound-vibration of the outer and inner pillar cells, the outer pillar cells seem to have much more mobility than the inner pillar cells. The reason for it may be explained by the fact that the former are only connected with the upper side; namely, headplate of the first outer hair cells is very free and are located in more movable side of the basilar membrane, but the latter are more firmly connected with the inner hair cells which are restricted in their movement. In addition, the latter are located in the modiolar side of the basilar membrane and within a short distance from the osseous spiral lamina. Added to this, as we mentioned already, the outer pillar cells are slightly longer and more slanted in the connection with the basilar membrane than the inner pillar cells, and furthermore, the headplate of the outer pillar cells are in the reticular lamina connected with that of the outer hair cells that are much more easily movable than the inner hair cells. Accordingly, the outer pillar cells would be easily moved by an extrinsic force, that is, the outer hair, Deiters' and Hensen's cells.

The above-stated consideration is related to the difference in the behaviors of the outer and inner hair cells to the extrinsic force or to sound-vibration. Therefore, the outer hair cells are considered to have much more movability than inner hair cells.

*C. Observation of the Damage Caused in the Organ of Corti by Violent Vibration:*

This study was based on an interesting finding accidentally observed in the four ears out of the twelve ears during the investigation of the inner-ears of dogs. One dog was sacrificed after fixing its inner ears, membranous cochleae (two ears), for five minutes by perfusion of the fixative solution *in vivo* under general anesthesia to prevent the postmortem change. With another dog its ears (two ears) were fixed by the same method immediately, after sacrifice. Subsequently, the four temporal bones were taken out with a strong electric saw that had been never used, but as these temporal bones proved to be too big, the circumference of these inner ears was again cut by the saw. The other procedures were exactly the same as in other eight ears; that is, these cochleae were observed with phase-contrast microscope after they had been fixed, stained and microdissected in the same manner. The results of the observation are as follows.

In the observation of the organ of Corti in apical and middle coils, all the cells seemed to be normal, because hair, pillar and Hensen's cells, etc. were arranged well without any apparent pathological finding in these cells.

But in the observation of basal coil we were surprised to observe the organ of Corti damaged very violently but regularly. The organ of Corti in this area was more or less damaged almost in the whole basal coil. The grade of damage was most severe in the middle area of the basal coil, and grade decreased towards the sides of apex and basal end. Tectorial membrane had been isolated already in this area, but the damage in this membrane was hardly observed.

These findings had never been observed in the usual artifact in the microdissection or pathological study. This severe damage of the organ of Corti seemed to have been due to a violent vibration of the electric saw used in cutting the circumference of the cochleae.

Here we would describe more in details from the largest damage to the smallest in the organ of Corti as follows.

1. In the middle area of the basal coil damaged most severely, the outside from the border cells in the internal spiral sulcus had lost all the cells on the basilar membrane resulting in the exposure of the basilar membrane itself. At a short distance from this area bilaterally on both sides of the apex and basal ends, the area where the inner pillar cells attached to the basilar membrane, only remained sparsely with their nuclei in the form of slender and flat cells.

The side of scala tympani in the basilar membrane, tympanic lamella, had also lost the cells appearing thin. The grade of the damage decreased

peripherally from the area of the greatest damage.

2. On the margin of the basilar membrane several rows of Claudius' cells were observed, and the inner pillar cells at the area of their attachment became more distinct with an increase in their number. In parallel with this the remnant of the outer pillar cells could be observed sparsely scattered on the area of their attachment to the basilar membrane.

3. Claudius' cells increased in number from several rows to about ten rows gradually towards both sides of the apex and basal ends. Keeping pace with the increase of Claudius' cells, the remnants of the inner and outer pillar cells increased and the area of their attachment to the basilar membrane also widened gradually. There could be seen some remnants of outer pillar cell bodies in several places. These cell bodies looked like the withered trees felled by typhoon from their roots. These outer pillar cells had lost their reticular lamina on the head side, and in this region Deiters' cells began to leave their traces on the basilar membrane. The number of the cells remaining on tympanic lamella began to increase.

*Discussion:* There arises a question why we can observe some cell bodies of the outer pillar cells that are supposedly located in more unstable conditions, while we do not see the cell bodies of the inner pillar cells that are located in more stable conditions. We may explain this question as follows.

Since the strength of the inner and outer pillar cells is considered to be about the same, this might be attributed to the difference in the relations between these cells and surrounding cells or in the situations of these cells.

Judging from the results of our observation that we described in the chapters A and B, the inner pillar cells cannot escape their destruction along with the inner hair and inner phalangeal cells, and the inner pillar cells alone cannot remain intact when the inner hair cells are destroyed by the violent vibration, because these cells are very firmly connected with one another.

Whereas the outer pillar cells, being in contact with the outer hair and Deiters' cells on both sides headplate and bottom, there is a big space among these cells, that is, Nuel's space. Hence, the outer pillar cells would be able to accommodate themselves to an extrinsic force much more readily than the inner pillar cells. Therefore, while the outer pillar cells still remain, the separation would occur in the reticular lamina on the upper side, and these outer pillar cells would much less be influenced by the neighboring cells to become much more free, agile and readily resistant against the violent vibration. As these cells originally are elastic, stable and strong cells, the outer pillar cells can remain in the basilar membrane.

4. Further away from the area of the largest damage, the rows of Claudius' cells are about the same ten rows, and tympanic lamella becomes almost normal, and the inner and outer pillar cells remaining begin to form the tunnel together on the basilar membrane. Almost all the outer pillar cells in this area show their reticular lamina on the head side in orderly rows.

In the observation of the inside tunnel, on modiolar side more in detail, although the outer pillar and inner hair cells remain in an almost perfect order, the inner pillar cells have lost not only their headplate but also the upper half of their cell bodies here and there. Further with the advancement toward the periphery where there is less damage, such phenomena decrease and the inner pillar cells are seen without the loss and form a complete tunnel together with outer pillar cells.

*Discussion:* We would like to consider the phenomena that the inner pillar cells had lost the upper half in spite of the existence of the outer pillar and inner hair cells. In the inner and outer pillar cells, such a connection at the headplate seems to be strong, but it seems to be much weaker than that in each bottom side of the basilar membrane. The outer pillar cells are elastic and tough, aside from these situations and conditions that are much more free in relation to the neighboring cells than the inner pillar cells, as mentioned already. Accordingly, if the inner and outer pillar cells vibrate enormously by a violent vibration, and crash into the side of the inner hair cells that are much more difficult and resistant to vibrate than the outer hair cells, the inner pillar cells will be attacked on both flanks between the outer pillar cells and the side of the inner hair cells. Consequently, the upper half of the inner pillar cells will be torn off to be separated and be obliterated from the center of the cell bodies.

As stated above and mentioned in Discussion 3, the difference in the response between the inner and outer pillar cells to the vibration seems to be related to the difference in the response between the inner and outer hair cells, and is very suggestive of the mechanism of the sound-susceptibility in the organ of Corti, especially that of hair cells.

5. Still further away from the most damaged area on both sides, the outer hair cells of the first and second rows begin to appear in addition to the above-mentioned cells, but the outermost cells (usually the third row of the outer hair cells), Deiters' cells immediately underneath and Hensen's cells on the outside cannot be observed.

6. Further away from the most damaged area, all the outer hair cells persist on the heels of the above-mentioned cells, but Hensen's cells on the outside, Claudius' and Boettcher's cells in the underside have been lost as to be exposed to the basilar membrane itself of this region.

7. Further close to the least damaged area or the normal area on both sides, the torn end of Hensen's cells is exfoliated along with Claudius' cells underneath to float laterally above outer hair cells, and further on these cells assumed apparently normal position. Observing more precisely this region that give normal appearance, the area of Hensen's cells has slid slightly laterally, giving an appearance as it had slid down laterally on Claudius' cells.

8. Further closer to the normal area from the area of Hensen's cells, which was dislocated laterally, there is observed an unusual upheaval of the area of Hensen's cells laterally upward.

On the heels of this unusual upheaval phenomenon, at last, the area of Hensen's cells became normal and the organ of Corti can be judged as normal on the whole. The areas that the organ of Corti is judged normal are Hook's areas of the basal end side and the neighborhood of the junction between the basal and middle coil of the apical side.

*Discussion*: Thus far we described the results of the observation on the grade of the damage from the most damaged area in the middle of the basal coil to the normal area. Such a damage is considered to have occurred accidentally by an unusual and furious vibration, and acutally such a case seems to be very rare. But the damage of the organ of Corti observed in these cases has shown us almost all grades of the damage. Accordingly, the phenomena in the damage of the organ of Corti seem to have a very important meaning, when the damage of the organ of Corti is considered in connection with the sound-vibration in each locality or in individual cells of the organ of Corti.

It follows that the phenomena in the damage of the organ of Corti seem to suggest the following points.

The area presumed to be normal last of all, the area of Hensen's cells, is most liable to be damaged by the vibration, and other areas or cells are more difficult to be damaged in proportion to their location closer to the modiolar side. In other words, when some part in the basilar membrane resonates with sound-vibration and vibrates, the area of Hensen's cells is liable to vibrate most strongly and the other areas to vibrate the lesser further inside. In hair cells, the outermost row of the outer hair cells is liable to vibrate most, and then the inner hair cells are to vibrate less closer inside, and then the inner hair cells are to vibrate least.

Such a consideration seems to be reasonable in view of the results of the observation described already in Chapters A and B.

*D. The Scar-formation in the Hair Cells:*

It is a common knowledge that the hair cells collapse and their place is

replaced by the scar when they are exposed to an excessive sound or noise, or to a medicinal poisoning or as a result of the symptoms of senility.

By applying the surface preparation technique to the research of the cochleae, generally we can observe all the hair cells and can study the existence of the scar or the grade of the scar, except for specimens with severe postmortem-change or the areas of the artifact in the hair cells.

Now, after microdissection of the cochleae by the surface preparation technique, we observed the scar-formation in the hair cells and obtained the results as follows.

1. The scar-formation was observed considerably in the outer hair cells, but it was hardly observable in the inner hair cells.

2. It was very rare to find the scar in the area of inner hair cells alone when all the outer hair cells were normal.

3. When the inner hair cells were replaced with the scar, invariably the outer hair cells located at the site corresponding to such a region were also replaced by a scar in practically every case. Accordingly, the collapse of the inner hair cells signifies usually the collapse of all of the outer hair cells located in the region corresponding to the area of the collapsed inner hair cells.

In other words, generally it is considered that the outer hair cells first collapse, then the inner hair cells collapse and both of these areas are replaced by the scar.

4. As to the scar-formation of the outer hair cells, the stronger is such a tendency the further out is the location of the row of hair cells, but such a tendency decreases closer inside, and then more normal hair cells can be observed.

*Comment*: From these findings it is assumed that the collapse of the outer hair cells can occur relatively readily starting from the outermost row to the inner rows but it rarely occurs with the inner hair cells. Comparing these results with those mentioned in chapters of A, B and C, this phenomenon of the scar-formation seems to suggest that the outer hair cells of the outermost row are most liable to vibrate by the sound-stimulation, and the hair cells become less liable to vibrate closer inside, especially so with the inner hair cells which vibrate only by a violent sound-stimulation.

#### *E. The Comparative Observation of the Hair Cells :*

Following the observations in Chapters of A, B, C and D, we have also carried out comparative study on the hair cells and present here the results as concisely as possible.

1. The comparative observation of the outer and inner hair cells

These results may be summarized as follows.

	Outer hair cells	Inner hair cells
Hairs	seem to be slender and frangible	seem to be thick and durable
Disposition of Hairs	W form	flat W form or straight laterally
Nuclei	somewhat smaller	slightly bigger
Cell bodies	slender and fragile	thick and durable
Connection with environment	coarse	intimate
Connection with supporting cells	not so strong	very strong
Supporting cells	very flexible	little flexible
Movability	remarkable	poor
Location	middle side of the basilar membrane	side of osseous spiral lamina of the basilar membrane

## 2. The comparative observation of the outer hair cells in each row

The difference in the outer hair cells of each row seemed to be very little as compared with that between the outer and inner hair cells. If we must choose, the cells in the outermost row, usually, in the third row seemed to be slightly more slender and more fragile than those in the inner rows, usually, those of the second and first rows. Of those in the inner rows, those of the second row seemed to have the same relation, as was stated above, when compared with the first row. The movability seemed to be most remarkable in the outermost row decreasing toward inner rows.

*Comment:* Comparing these results with those of Chapters A, B, C and D, it becomes more evident that the hair cells of the outermost row are most apt to vibrate by the sound-stimulation and those located closer inside become more difficult to vibrate.

As to the ability of the hair cells to convert vibration-energy into electric energy when vibrated or excited by a sound-stimulation, such a convertibility cannot be said to be uniform in all the hair cells. Namely, the inner hair cells seem to possess more convertibility than the outer hair cells, if the sound-stimulation is strong enough to excite these hair cells. In comparing the outer hair cells according to rows, the ability seems to grow stronger as the rows proceed to inner sides, though the difference is slight.

## DISCUSSION

From the observation and the consideration in Chapters A~E, the results may be integrated as follows, though some parts are repetitions.

The organ of Corti is situated on the basilar membrane which is elastic,



stable and very strong, aside from the organ itself being composed of the pillar cells that are in themselves elastic, stable and strong, and serve as the framework of this organ. Accordingly, the organ of Corti can be roughly divided into two parts: the area of the inner pillar cells and the other of the outer pillar cells, and the outer side is apt to vibrate and the inner side is less apt to vibrate.

Considering the outside area that seems to vibrate easily; namely, the area of the outer hair cells, the outer hair cells seem to vibrate easily as they perceive a feeble sound-stimulation, because they have an elastic connection with not only Hensen's and Deiters' cells but also with outer pillar cells, in addition to the elastic connection among outer hair cells themselves. In other words, when some part of the basilar membrane resonates to vibrate by some sound-stimulation, the vibration of the outer hair cells is remarkably amplified as compared to a faint vibration of the basilar membrane in the feeble sound-stimulation, because Hensen's cells on the outside of the outer hair cells and Deiters' cells beneath vibrate readily and the outer hair cells themselves also vibrate easily, and then all these cells vibrate in unison. Next on increasing the sound-stimulation, pillar cells, particularly outer pillar cells, join in the vibration to cooperate with the above-mentioned cells, and as the sound-stimulation increases, the cooperation of these pillar cells seems to grow more indispensable, and thus the role of the pillar cells seems enhance them to perceive a stronger sound-stimulation. At this stage, Claudius' and Boettcher's cells seem to play a subsidiary role as paving stones on the exterior and the inferior sides.

In view of the above-mentioned consideration, the outer hair cells may be able to vibrate to perceive not only a very feeble but also a considerably strong sound-stimulation.

On the contrary, the inner hair cells are so situated to be more difficult to vibrate by the sound-stimulation than the outer hair cells, and the structure of the inner hair cells is such that they are less able to vibrate than the outer hair cells. In other words, the inner hair cells considered to be stronger than the outer hair cells are connected with the supporting cells much more firmly than the outer hair cells, besides the supporting cells being attached to the basilar membrane, thus these cells have little flexibility.

Accordingly, the inner hair cells seem to vibrate to perceive the sound only by a strong sound-stimulation, and they seem not to vibrate by a feeble or a moderate sound-stimulation but usually they seem to be a spare existence that does not operate. In other words, the outer hair cells seem to perceive a feeble and a moderate sound and the inner hair cells seem to perceive a strong sound. Thus we cannot exclude the consideration that there is a

remarkable difference in the manner of the sound-vibration between the outer and the inner hair cells.

Then, there arises a question whether there is the difference in the response to the sound-vibration among outer hair cells of each row. First of all, it is necessary to take up the area that is most easy to vibrate by the sound-vibration in the organ of Corti. This area should correspond to such an area that is damaged most by an unusual and furious vibration, or the area that has received the change first even though the sound-vibration is not so strong, which is readiest to receive the energy of the vibration dynamically or theoretically. The area is considered to be the area of Hensen's cells, as stated already.

Therefore, when the organ of Corti is given a very feeble sound-vibration, Hensen's cells vibrate first to undergo transformation or upheaval, then the vibration seems to proceed to the inner side; namely, to the outer hair cells as the sound-vibration increases. When the outer hair cells receive the vibration from Hensen's cells on their outside, first the outermost hair cells seem to vibrate with Hensen's cells being cooperated by those Deiters' cells located underneath and on the basilar membrane, then those of the inner rows seem to vibrate in proportion to the increase of the sound-vibration. In other words, we cannot but consider that there should be some differences in the response to the sound-vibration among the outer hair cells of each row. But the difference among these individual rows seems to be much less than that between the outer and inner hair cells, and then the outer hair cells of each row are considered to vibrate almost simultaneously to perceive the sound when the sound-vibration increases in degree.

Summarily, we consider that the vibration of Hensen's cells occurs first, then the vibration proceeds to the inside as the sound-stimulation increases. This consideration seems to be reasonable from the results of the observation as has been stated above, and this reasoning is supported by the results appearing in literature.

BÉKÉSY (1953) observed that the vibration began from Hensen's cells to proceed to the inside, in the observation of the vibration of the organ of Corti by the strong sound-stimulation. JORDAN *et al.* (1973) observed that the most prominent scar occurred in the outermost row of the outer hair cells and the grade decreased as the row proceeded to the inside, in the study of "Cochlear pathology in monkeys exposed to impulse noise." And then, they presumed that this phenomenon would be based on the mechanism that the outer hair cells would receive the most severe vibration, referring to the result of the observation by BÉKÉSY (1953).

On the other hand, STEBBINS *et al.* (1969) found the scar of the hair cells

to be of a greater extent in the inner hair cells than in the outer hair cells in the some part, after giving intramuscular injection of Kanamycin sulfate and Neomycin sulfate to monkeys. But the results of their observation are not inconsistent with those of our observation and the consideration, because their data are based on the injury of the hair cells caused by chemicals and the mechanism differs completely from that of the injury of the hair cells caused by the sound-stimulation.

In the study "Cytologic development of hair cells of the normal hamster cochlea" (in print), we found that the development of the inner hair cells was much earlier than that of the outer hair cells and the development of the each row of the outer hair cells was delayed as the row proceeded to the outside. If we consider teleologically this development from the mechanism of the sound-susceptibility in the hair cells, we may point out the following points.

The susceptibility of the feeble sound is not necessary in the neonatal stage, and especially in this stage it seems to be more convenient that the noise is less. Accordingly, for the time being, this stage seems to be sufficient enough to receive only a strong sound, and for that reason it would be necessary for the inner hair cells to develop first in order to vibrate by the strong sound only. Therefore, the outer hair cells that are considered to vibrate by a feeble sound may develop first from the inside row then to the outside and may be able to perceive more feeble sound gradually, along with the development of the other organs.

Although the above-mentioned teleological supposition may be radical of logic, this supposition seems to explain indirectly the mechanism of the sound-susceptibility in the organ of Corti or the hair cells from the aspect of the development of the inner ear, particularly of the hair cells.

From the analyses of the result of the observation and the consideration of the literature, as stated above, we would like to advocate a hypothesis to the mechanism of the sound-susceptibility, in the organ of Corti, particularly of the hair cells as follows.

A hypothesis to the mechanism of the sound-susceptibility  
in the organ of Corti, particularly of the hair cells  
and a theoretical consideration.

In the sound-susceptibility in the organ of Corti, the area of Hensen's cells begins to vibrate first of all. When the sound-stimulation is very feeble, this area alone vibrates and this vibration does not reach the hair cells, thus the sound is not susceptible at this stage. The range of the vibration spreads to the hair cells and the sound becomes susceptible, as it in-

creases, then a stronger energy of the vibration is imparted to the organ of Corti. On receiving a sound-stimulation the area of Hensen's cells is the most ready to receive the energy of the vibration and is always the site that vibrates first, whether the sound is feeble or strong. Hensen's cells vibrate with accompaniment of the transformation or upheaval of the area, in proportion to the degree of the sound-stimulation, triggering the hair cells to vibrate continuously. The organ of Corti cannot perceive a feeble sound till the vibration of Hensen's cells reaches the outermost row of the outer hair cells as the sound-stimulation increases. The middle row of the outer hair cells and then the inner row of the outer hair cells vibrate to perceive a stronger sound as the sound increases further. The inner hair cells do not vibrate to perceive a very strong sound until the sound-stimulation approaches close to its maximum, only then can they vibrate to perceive a large sound. When this strong sound increases still more and the excitability of the inner hair cells reaches its maximum, the sound-pressure at that time is equivalent to the maximum sound that the organ of Corti can perceive.

As stated above, the outer hair cells of the outermost row participate in the susceptibility of the minimum feeble sound that the inner ear is possible to perceive, and those hair cells of inner row participate in the sound-susceptibility in step with the increase of the sound. In the environment of the ordinary sound, the vibration of the outer hair cells is sufficient to perceive the sound. Therefore, the inner hair cells do not participate in the sound susceptibility until a strong sound-stimulation is given, so that usually they exist as the auxiliary cells.

As to the outer hair cells that vibrate readily to perceive the sound-vibration of a feeble or moderate sound-pressure, their manner of participation is more prompt and accelerative with those cells situated in more inner row, as the feeble sound gradually increases. That is, once those cells of the outermost row begin to vibrate to follow the vibration of Hensen's cells, those of the middle row vibrate easily to perceive the sound by a slight increase in the sound-stimulation, and those of the inner row, the first row, vibrate readily to perceive the sound by a less increase in the sound-stimulation than in the middle row.

Next, by the comparative observations of the hair cells, it is considered that the hair cells vibrate by a sound-stimulation to bring about an electric energy as follows. The excitability of the inner hair cells does not reach the maximum to bring about the maximum electric energy possible till the inner hair cells have received a much stronger sound-stimulation than the outer hair cells. Although the difference in the manner of response to the sound-stimulation is slight among the outerhair cells, those cells in the inner

row requires a stronger sound-stimulation to reach its maximum excitability to bring about the maximum electric energy possible.

In other words, the inner hair cells can react to a much stronger sound than the sound which the outer hair cells can, and they can acquire a much greater electric energy.

In comparing the capability of the outer hair cells according to rows, those hair cells located in more inner side are capable of reacting to a stronger sound and acquire a greater electric energy.

We presented a hypothesis of the mechanism of the sound-susceptibility in the organ of Corti from the aspects of the hair cells so far described, and again we will take up this mechanism from the following points.

In order to analyze and evaluate the vibration of the organ of Corti by the sound-stimulation, Hensen's, Deiters' and pillar cells and others that help the vibration of the hair cells need to be taken into our consideration as to their functions of the vibration in the basilar membrane.

On this point BÉKÉSY (1953) described the form of the vibration of these cells in relation of the pillar cells with the basilar membrane, we would like to explain theoretically our supposition by the figures.

The arrows pointing upward and downward in the Types 1 and 2 in Fig. 1 show the area of the greatest vibration in the basilar membrane. The wave-like arrows pointing both sides signify the amplitude and the spread of the vibration.

Type 1 shows the absence of any cells that help the vibration of the hair cells, and the area of C in the central part is the most ready to vibrate by keeping their fulcra of both ends; A and B. A is the area where the basilar membrane shifts to the spiral ligament, and B is the margin of the osseous spiral lamina.

Although the vibration spreads to the inside and the outside; namely, to the side of modiolus and the side of spiral ligament as shown by the wavy arrow-mark with the increase of the sound-stimulation, the vibration of the hair cells in Type 1 is difficult and becomes more difficult as the hair cells proceed to marginal sides of the basilar membrane, because the hair cells in Type 1 depend only upon the vibration of the basilar membrane. Therefore, the inner hair cells hardly

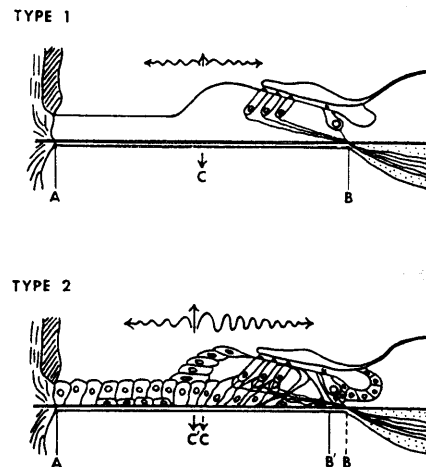


Fig. 1.

can vibrate.

Next, Type 2 is a case that has the supporting cells and the pillar cells to help the vibration of the hair cells, and then A and B' are the fulcra in the vibration of the basilar membrane, and C' is the area of the greatest vibration in the center between A and B'. B' is the area where the inner pillar cells adhere to the basilar membrane, and it is very interesting and very important for the vibration of the hair cells that C' corresponds to the area of Hensen's cells. This supposition is based on the results of the observations on B shifting to B'.

That is, the inner pillar cells, the inner hair cells and the supporting cells are all firmly connected with each other, and the supporting cells are attached to the basilar membrane. It follows then, that since these cells have very little elasticity, the inner area from the inner pillar cells is considered to be affiliated to the side of the osseous spiral lamina, the side of modiolus, in the vibration of the organ of Corti.

Now, in the consideration of the vibration of the hair cells (Type 2 compared with Type 1), it is easy to understand that the area of the hair cells in Type 2 vibrates much more readily than Type 1, as shown in Fig. 1.

Furthermore, the inner and the outer pillar cells are very strong, elastic and stable and are very firmly adhered to the basilar membrane, but on the contrary, such a connection in the upperside is not only elastic but also seems to present an inconsistent phenomenon in the vibration though only slightly. Therefore, in the presence of the tunnel composed of the inner and the outer pillar cells and the basilar membrane, the basilar membrane of A B' in Type 2 vibrates much more readily by keeping the fulcra at A and B' than Type 1. In this Type 2 it is obvious that the most vibrant area, the area of greatest amplitude, is C' located in an equidistance from A and B'. This area corresponds to the area of Hensen's cells. Thus, it is clear that the area of Hensen's cells vibrates most readily on receiving a sound-stimulation. This fact coincides with the result of the observation as stated above.

Accordingly, as the area of Hensen's cells is most apt to acquire the energy of the vibration in the organ of Corti on receiving a feeble sound, experimentally and theoretically, the area that begins to vibrate first is the area of Hensen's cells. Hensen's cells are assumed to be of a bow-shape connected with the reticular lamina of the outermost row of the outer hair cells from the area of Claudius' cells. When the central area of the basilar membrane, the area of Hensen's cells, vibrates upward and downward, the energy should proceed chiefly inward to the outer hair cells by the structure of Hensen's cells. Hence, the vibration-energy in the area of Hensen's cells should reach the headplate of the outer hair cells in the outermost row first

to have these hair cells vibrate to both the inferior and lateral directions.

Therefore, if we take the relation in the situation of Hensen's cells, individual rows of their outer hair cells, Deiters' cells and pillar cells, etc., or these gradients on the basilar membrane, as well as their flexibility and stability, the outer hair cells should vibrate in consonant with the vibration of Hensen's cells as the sound-stimulation increases. Namely, as a feeble sound-stimulation increases gradually, the vibration of the outer hair cells should begin first in the outermost row and proceed to the inner row, and the direction of the vibration should be the composition of the upward and downward directions and the inward and outward directions, that is, the composition of the vertical and horizontal directions to be the diagonal direction.

Meanwhile, if the tectorial membrane cooperates with the vibration of the hair cells, the membrane should vibrate more easily in proportion as the area is further toward outer margin, and the amplitude should be bigger as well. Accordingly, the outer hair cells are considered to perceive the sound-stimulation more readily in proportion as they approach to further outer rows.

Next, although the range of the vibration of the basilar membrane propagates to the inside and outside from the area of Hensen's cells as the sound-stimulation increases, the propagation of the vibration to the inner side is much more prompt due to the cooperation of Hensen's, Deiters', outer hair and pillar cells than of the vibration to the outer side, and in addition, these cells, especially, the outer hair cells, vibrate at a greatly amplified rate.

The undulatory arrow of Type 1 in Fig. 1 shows the vibration of the basilar membrane itself, and the inward and undulatory arrow of Type 2 shows the amplified vibration proceeding to the inner side with increasing speed in the outer hair cells on the basilar membrane. In other words, when the sound-stimulation increases gradually from the feeble sound, the participation in the vibration of the outer hair cells becomes more prompt with an increasing speed in the inner row receiving the vibration from Hensen's cells, and still further inner row seems to vibrate to perceive the sound by less increase in the sound-stimulation.

On the other hand, the mechanism of the sound-susceptibility in the inner hair cells may be explained as follows. The whole area of B-B' in the modiolar side is not necessary to vibrate like the area of A-B', but the vibration of the outside area of the pillar cells; namely, the area of A-B', increases with the increase of the sound-stimulation, and finally the vibration-energy as a whole of the outside area makes the inner hair cells vibrate by the mediation of the upper area of the tunnel, which is the combined area of the outer and inner pillar cells. Consequently, the inner hair cells located inside

can perceive the sound without the vibration of the entire area of B-B'.

From the above consideration we can see the significance of the existence of the pillar cells. As the outside of the pillar cells vibrates very easily in the presence of the pillar cells, it is possible that the outer hair cells perceive a feeble sound. In contrast, the inside of the pillar cells is very difficult to vibrate. But the increase of the sound-stimulation does enable the inner hair cells located inside to vibrate by the above-stated mechanism, enabling these cells to participate in the sound-susceptibility.

Thus, the organ of Corti is endowed with a power to perceive not only a feeble sound but also a strong sound by having the area of tunnel constituted of the pillar cells that are very strong, elastic and stable, consequently the function of the sound-susceptibility in the organ of Corti is enhanced conspicuously.

Now, Fig. 2 illustrates our integrated hypothesis and theoretical consideration by a schematic drawing to show the mechanism of the sound-

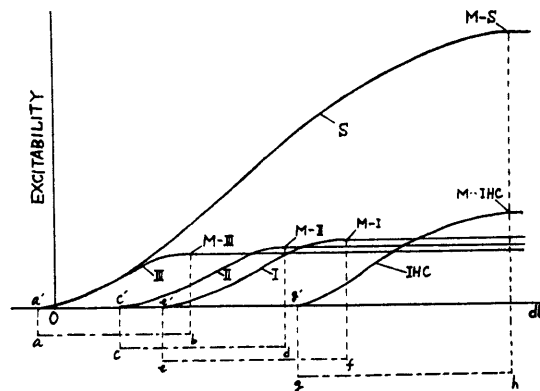


Fig. 2. O: minimum threshold of hearing.

a', c', e' and g': The values of the sound-pressure when IIIrd, IInd and Ist outer hair cells and inner hair cells respectively begin to vibrate to be excited by the sound-stimulation (dB).

III, II, I and IHC: IIIrd, IInd, Ist outer hair cells and inner hair cells.

M-III, M-II, M-I and M-IHC: Representing points where III, II, I and IHC respectively have reached their maximum excitability.

M-III<M-II<M-I<M-IHC: These mean as follows.  
a-b<c-d<e-f<g-h

Representing the magnitudes of sound-stimulation to be converted into electric energy in the order of III, II, I, and IHC.

S: Summation of the excitability of all the hair cells. That is, summation of the electric energy to be propagated to spiral ganglion cells.

M-S: Summation of the maximum excitability in all the hair cells. In other words, maximum electric energy that is available to be transported to spiral ganglion cells.



susceptibility in the organ of Corti, particularly of the hair cells, from the aspect of the conversion of the sound-stimulation into the electric energy.

As the outer and inner hair cells consist of three rows and one row generally, the third row of the outer hair cells implies to be the outermost row adjacent to Hensen's cells in the figure. The grade of the excitability in the each row in the sound-stimulation is shown by respective curves of III, II, I and IHC, and these individual curves are considered to correspond to the process of the generation of the electric energy that each row of the hair cells converts the energy of the sound-vibration into electric energy.

Accordingly, the curve-S which is the summation of the excitability of all the rows of the hair cells is presumed to represent the summation of the electric energy generated in the each row of the hair cells.

The mechanism in the hair cells may be interpreted that the interval between curves II and I is less than that between curves III and II. It indicates that the outer hair cells located further inside begin to vibrate by a less increase in the sound-pressure (dB) with the increase of the sound-stimulation, then they start to generate the electric energy.

On the contrary, the wide interval between curve I and IHC means that the inner hair cells cannot begin to vibrate until the sound-stimulation has reached much stronger than that which makes the first outer hair cells vibrate. In other words, it means that the inner hair cells do not begin to vibrate until the faculty of the sound-susceptibility in the outer hair cells has approached the limit, as the inner hair cells are an auxiliary existence situated on the side of modiolus and is difficult to vibrate.

Next, an increasing maximum-excitability is in the order of curves III, II, I and IHC in Fig. 2, meaning that the inner the row the greater is the faculty of hair cells in converting the sound-stimulation into the electric energy. This reasoning is based on our views that the faculty in the inner hair cells is much higher than that in the outer hair cells and the faculty in each row of the outer hair cells is higher, though the difference is slight, further to the inner row, from the observation of the organ of Corti.

According to the mechanism as was stated above, the electric energy that is converted from the energy of the sound-vibration in the hair cells may be conducted to unmyelinated nerve fibers, myelinated cochlear nerve fibers and further spiral ganglion cells.

#### Explanation of Recruitment Phenomenon or Cochlear Hearing Loss by the Above-mentioned Hypothesis and the Application to Diagnosis

It is a matter of common knowledge that perceptive hearing loss is diag-

nosed on the basis of the injury to the cochlea ; namely, to hair cells, if the test of recruitment phenomenon is positive.

In other words, this type of hearing loss can be diagnosed by using Fowler's loudness balance test, Jerger's SISI test (Short increment sensitivity index test), Lüscher's D. L. test (Difference limen test) and Békésy's self-recording audiometry.

All of these diagnostic methods are the tests that utilize the phenomenon in the following manner. It is the phenomenon by which the ear of hearing loss on the injury of the hair cells perceives sound more excessively than normal ear within the range of hearing, and such an ear with hearing loss is more sensitive to perceive the change of the intensity of sound, i. e. the sound-pressure, than normal ear, and it can discriminate better a slight change in the sound-pressure than normal ear.

Not speaking of normal ear and retrocochlear hearing loss, it is easy to understand that the recruitment phenomenon is negative in the conductive hearing loss, because all of the curves in Fig. 2 make a parallel move from the normal position to the right direction in consonant with degree of the injury of the sound-conduction.

Now, we would present a theoretical explanation for the recruitment phenomenon or cochlear hearing loss from the results of the observation and the hypothesis to the mechanism of the sound-susceptibility in organ of Corti.

The first problem is how the injury of the cochlea, the hair cells, is brought about. As the outer hair cells are usually arranged in three rows and the inner hair cells are in one row, the third row of the outer hair cells means the outermost row of the hair cells generally. Therefore, from the consideration of our observation and hypothesis, the injury of the hair cells naturally would begin from the third row of the outer hair cells, and the injury will proceed in the order of the second to the first row and finally to the inner hair cells. The degree of the injury of the hair cells is severest in the third row of the outer hair cells and it decreases further inside.

As to hair cells, now, we may evaluate concretely the changes in the faculty of the sound-susceptibility as a whole of the hair cells, or as a whole of the organ of Corti, according to the degree of hair cell injury.

First, in the case of a slight injury to the hair cells, the hair cells in this state cannot perceive a feeble sound that the normal hair cells can, but the injured hair cells begin to be excited by a little stronger sound-pressure than in the normal hair cells, and at last they can approach the same maximum excitability as the normal hair cells to generate the maximum electric energy, when the sound pressure is sufficient.

The excitability-curves in the slight injury of the hair cells take a

parallel move slightly from the normal curves to the side of the stronger sound-pressure in the right direction. From the fact that the hair cells of the outermost row are injured most severely which decreases towards the inner row, the parallel move of these excitability-curves is most conspicuous in the outermost row and decreases further inside. As the inner hair cells are considered to be the auxiliary cells that do not usually respond to a feeble or a moderate sound-pressure, the excitability of the inner hair cells is considered to be almost the same as the normal inner hair cells in the stage of the slight injury of the hair cells. At this stage, the inner hair cells are still normal and the excitability-curve will hardly move.

Accordingly, these excitability-curves in each row of the outer hair cells should approach each other by aggregating in the direction of the excitability-curve of the inner hair cells, as shown in Fig. 3.

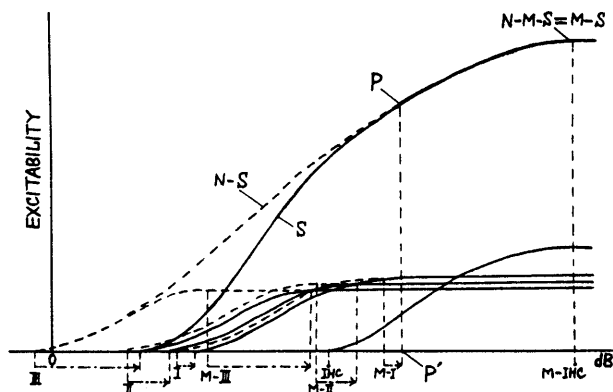


Fig. 3. Dotted curves: Excitability-curves in normal hair cells.  
 N: Normal.  
 S and M-S: The same as the explanation in Fig. 2.  
 P: Presents the confluent point of Curves S and N-S.  
 P': Sound pressure at P.

Therefore, curve-S which is the summation of the electric energy generated in hair cells of each row has a steeper gradient than the normal curve (N-S). It implies that, when the organ of Corti with injured hair cells is once excited to generate the electric energy by a certain grade of the sound-pressure, the increase in the electric energy generated along with the increase of the sound-pressure is more prompt than that in the normal hair cells. In other words, in the ear with cochlear hearing loss it is possible to generate the same grade of the electric energy as normal ear by a slight increase in the sound-pressure than in normal ear, within the range of the sound-pressure possible of perceiving. And all of the electric energy generated in such a

process is transported to the spiral ganglion cells of the area.

That is, the ear with cochlear hearing loss can discriminate a slight change in the sound-pressure better than normal ear within the range of the sound-pressure that is possible to be perceived, and then the recruitment phenomenon is positive in this type of the hearing loss. As these curves S and N-S in Fig. 3 correspond to each other in P, the sound-pressure at P is P'-dB and then the injured cochlea and the normal cochlea generate the same grade of the electric energy by the same sound-pressure; namely P'-dB. However, as the gradient of the curve S is steeper than that of the curve N-S, the increase of the electric energy generated in the organ of Corti of the injured cochlea is quicker than that of the normal cochlea. Therefore, in the subjective sound-sensation with the same grade of the electric energy, the injured cochlea should perceive the electric energy a little more sensitively than normal cochlea.

Accordingly, when Fowler's loudness balance test is possible with the sound-pressure near P'-dB, the balance will be attained at the sound-pressure a little less than P'-dB and the recruitment phenomenon becomes completely positive. The normal ear would require a little stronger sound-pressure than P'-dB, to have the same sound-sensation as the injured ear perceives in the sound-pressure of P'-dB. On account of this, with the sound-pressure stronger than the sound-pressure that produces a complete recruitment phenomenon, it is obvious that normal ear needs a stronger sound-pressure than the injured ear to attain the same grade of the subjective sound-sensation in both ears.

Next, with the ear having a moderate injury of the hair cells, as long as the sound-pressure at this stage is sufficient, the injured hair cells should still be excitable to generate the electric energy as normal hair cells. However, for the generation of the electric energy by the excitation of the hair cells, the injured hair cells require a stronger sound-pressure than the hair cells with a slight injury, and the inner hair cells begin to receive injury. As a result, the excitability-curves in each row of the hair cells move further to the right, and these curves ultimately will approach each other by moving to the right, as indicated by our observations that the grade of injury of the hair cells becomes severer toward the outer rows.

Especially in the excitability-curves of the outer hair cells considered to be injured more severely, these curves would move to the right and approach each other so conspicuously that these curves nearly overlap and finally the outer hair cells of all rows begin to be excited almost simultaneously.

Therefore, the gradient of curve S which is the summation of the electric energy generated by the excitability of all the injured hair cells is steeper than that of curve N-S in normal ear as in Fig. 4, and it is understandable

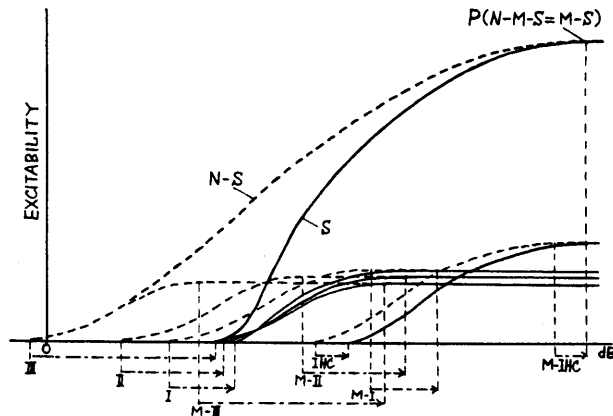


Fig. 4. Dotted curves: Excitability-curves in normal hair cells.  
 N: Normal.  
 S and M-S: The same as the explanation in Fig. 2.  
 P: Presents the confluent point of Curves S and N-S.

that recruitment phenomenon becomes positive in the case with the cochlear hearing loss. When curve S and curve N-S meet at P, the sound-pressure at P is too strong to actually conduct the audiometry under a strong sound-pressure. Thus, with such a cochlear hearing loss, recruitment phenomenon appears incompletely positive, if Fowler's loudness balance test is possible.

Next, in the case with a severe injury of the hair cells, the maximum electric energy generated by these injured outer hair cells is not only less than that in normal outer hair cells, but also it cannot be maintained at the maximum level, at the maximum excitability. Consequently, these excitability-curves in each row of the outer hair cells move to the right, and these curves are reduced as in Figs. 5 and 6. The inner hair cells are not so apt to receive injury and the excitability-curve in the inner hair cells moves only to the right without deviation and the grade of injury is slight as shown in Figs. 5 and 6. The gradient of the curve S is steeper than that of the curve N-S in the first half, on the side of the weaker sound-pressure, and persists in the same grade or less in the latter half, on the side of the stronger sound-pressure. In such a cochlear hearing loss, the audiometry is usually carried out by the sound-pressure in the first half of the curve S, because the output of the audiometer is generally in the range of the sound-pressure corresponding to the first half of the curve S, and the recruitment phenomenon is positive. Even if the audiometry is possible in the stronger sound-pressure and Fowler's loudness balance test is possible, the recruitment phenomenon is incompletely positive as the curve S and N-S do not confluence nor approach.

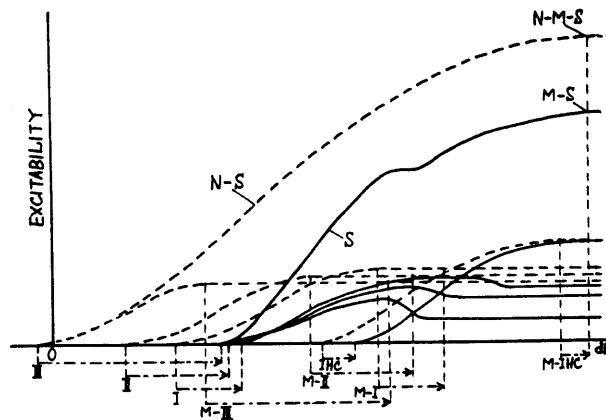


Fig. 5. Dotted curves: Excitability-curves in normal hair cells.  
 N: Normal.  
 S and M-S: The same as the explanation in Fig. 2.

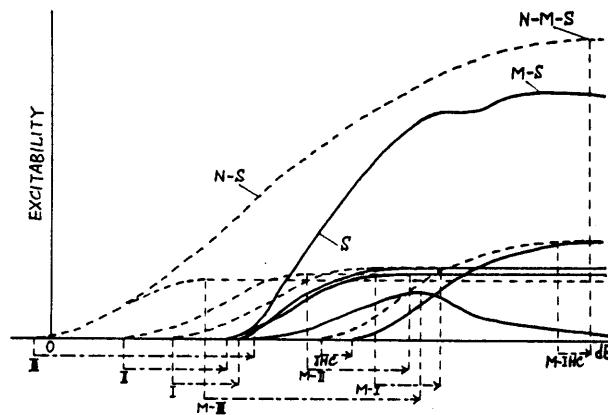


Fig. 6. Dotted curves: Excitability-curves in normal hair cells.  
 N: Normal,  
 S and M-S: The same as the explanation in Fig. 2.

Now coming to the cochlear hearing loss with very severe injury of the hair cells, the outer hair cells at this stage may have lost the function completely or collapsed and have been replaced by the scar. Accordingly, only the inner hair cells are excited to generate the electric energy and the excitability-curve itself corresponds to the curve S in the Figs. 3~6. But the

gradient of this curve may be almost of the same grade as that of the normal curve N-S. When the function of the inner hair cells is further injured severely, the gradient may decrease to be less than that of the normal curve N-S. At this stage, the recruitment phenomenon may be negative as an exception. In any event, when the hair cells are injured very severely, the test of recruitment phenomenon itself may be difficult to conduct.

Thus far, we have explained the recruitment phenomenon or the cochlear hearing loss theoretically by applying our hypothesis based on the results of our experiments and observations.

It is well known that actually the sound in the range of 500~4000 Hz is suitable for the test of the recruitment phenomenon. The reason for it lies in the fact that the sound in this range makes it possible for the hair cells excited to generate the electric energy in a wide range of the sound-pressure, not only in a feeble sound but also in a strong sound.

On the other hand, in such a frequency of sound it means the following that the hair cells can react on a wide range of the sound-pressure. When the sound-pressure is strong enough in spite of the considerable injury to the hair cells, the injured ear can still hear the sound, and the faculty of the sound-susceptibility in the injured ear approaches that of the normal ear with the increase of the sound-pressure. This phenomenon is of a great interest because it is clinically very convenient as the human speech range is within the frequency of 500~2000 Hz.

Finally we would take up the application of the hypothesis to the mechanism of the sound-susceptibility in the organ of Corti for the diagnosis of the hearing loss. It is noteworthy that the shapes of these curves S that are the summation of the excitability of the individual hair cells are very similar to the articulation curve in the speech audiometry (Figs. 2~6). Especially, the curves S in Figs. 3~6 are similar to the articulation curve that is found in the speech audiometry of the cochlear hearing loss. These articulation curves seem to suggest the manner of the individual hair cells in the sound-vibration. For instance, when the articulation curve is similar to the curve S in Fig. 3, the curve may mean only a slight or a moderate injury to the outer hair cells. When the curve is similar to the curve S in Fig. 4, the curve may mean not only a moderate injury of the outer hair cells but also a slight injury of the inner hair cells. When the outer hair cells are injured severely and the inner hair cells are injured slightly, the curve may be similar to the curve S in Figs. 5~6. Finally, when the curve becomes only a small curve of chevron even under a very strong sound-pressure, the outer hair cells almost collapse to transform into the scar, and the inner hair cells may somehow be excited to generate the electric energy despite their injury.

Inference of the Contrary Recruitment Phenomenon (Hypothesis)

from the foregoing hypothesis and the application to Diagnosis

In the foregoing chapters, we have explained that the cochlear hearing loss may be diagnosed to be positive generally in recruitment phenomenon, on the basis that the injury of the hair cells proceeds from the outermost row to the inner row and the grade of the injury is severer toward outer row. However, it is difficult to say at once that all of the cochlear hearing loss is based uniformly on such an injury of the hair cells, so that the injury of the hair cells (the cochlear hearing loss) may be classified into three types.

- a. Type where the injury of the hair cells proceeds from the outermost row to the inner row in good order. —outside type.
- b. Type where the injury of the hair cells proceeds diffusely as a whole without the difference between the outer and inner rows. —mixed type or diffuse type.
- c. Type where the injury of the hair cells proceeds from the inner hair cells to the outer row. —inside type.

First of all it was already explained in the foregoing chapters that recruitment phenomenon might be generally positive in type-a. In type-b, recruitment phenomenon may be positive or negative, by the shape (gradient) of the excitability-curves of the individual hair cells and by the manner of the approach among these curves or the accumulation of these curves.

Accordingly, in the cochlear hearing loss it is understandable that recruitment phenomenon is not always positive in all the cases and is negative not only in the very severe injury of the hair cells but also in the manner of the injury to the hair cells as in some of the cases belonging to type-b.

In any event, the cochlear hearing loss in type-a and b is easily diagnosed to be perceptive hearing loss generally by the audiometry that we use in measuring the minimum threshold of hearing, and at least is easy to differentiate from the normal hearing. Even if the cochlear hearing loss is combined with the conductive hearing loss, the grade of the perceptive hearing loss is measured by testing the minimum threshold of bone conduction.

However, in the injury of the cochlea where the injury begins from the inner hair cells of the innermost row like type-c, we are confronted with the problem that is entirely different yet very important in applying the foregoing hypothesis to the mechanism of the sound-susceptibility in the organ of Corti.

Now, supposing that we measure the minimum threshold of hearing by the conventional audiometry in the injured cochlea where only the inner hair cells are injured and the outer hair cells are normal, then in applying the foregoing hypothesis to the result of the audiometry, the minimum threshold



of hearing would be normal and it can be diagnosed as of normal hearing, because by our hypothesis the minimum sound audible is dependent upon the electric energy generated by the excitability of the outermost row of the hair cells. Therefore, even if all the rows of the outer hair cells are excited almost simultaneously by a feeble sound, the inner hair cells which vibrate to be excited only by a strong sound and are usually an auxiliary existence do not react under such a feeble sound-pressure, as the cochlea needs in measuring the minimum threshold of hearing.

In other words, the differential diagnosis between the injured cochlea where the inner hair cells alone are injured and the normal cochlea cannot be accomplished by measuring the minimum threshold of hearing only. Therefore, such a special type of the injured cochlea cannot be discovered by the conventional audiometry and is diagnosed as to have the same faculty in the hearing as the normal cochlea.

For this reason, we would now take up the question whether or not there really exists an injured cochlea where the inner row of the hair cells, especially the inner hair cells, are injured. There are so many types of the hearing loss; occupational hearing loss, senile hearing loss, Ménière's disease, and hearing loss by medicinal intoxication, viral infection or embolism, etc.

In all of these types of hearing loss, we cannot completely rule out that the injury to the inner hair cells alone does not occur accidentally. In the presumption of the greatest possibility for the injury to the inner hair cells alone, first of all the injury to the cochlea by the medicinal intoxication may be mentioned, then viral or bacterial infection and embolism can be considered as the cause of the special type of the injured cochleae.

On the basis of our observations and hypothesis, in the case of occupational or senile hearing loss, it is difficult to assume that the inner hair cells alone are injured, while it is safe to say that the inner hair cells alone or at least, the inner hair cells are injured first by the medicinal intoxication, etc., as the mechanism of the injury of the hair cells in the medicinal intoxication and others is known to differ from that of the hair cells in the noise. As stated already, STEBBINS *et al.* (1969) observed a greater injury to the inner hair cells which ultimately turned into a scar after intramuscular injection of Kanamycin and Neomycin to monkeys. Their observation seems to indicate that the inner hair cells alone can be injured first of all due to the difference in the supply of the blood or nutrition or by the metabolic difference among the hair cells themselves.

In the chronic suppurative inflammation of the middle ear and the otosclerosis, the postoperative hearing drops sometimes not only in the air conduction but also in the bone conduction, though the hearing-improvement

appears to be almost certain in the preoperative audiometry and the operation is successful, besides the postoperative progress is favorable. There certainly would be cases whose cause cannot be sufficiently explained by the unskillful operation, tympanosclerosis or labyrinthitis etc., even though not so many. Such cases, indeed, seem to correspond to the special type of the cochlear hearing loss where the injury to the hair cells begins in the inner hair cells, first of all.

Now, we will take up the injured cochlea where the inner hair cells have lost their function by the collapse already and also the outer hair cells of Ist and IInd rows are injured severely. In the audiometry of such an injured cochlea, the minimum threshold of hearing will be normal or almost normal as the outer hair cells of the outermost row have the normal function, when we apply our hypothesis to the mechanism of the sound-susceptibility in the organ of Corti. Accordingly, in the ear that has the chronic suppurative inflammation of the middle ear combined with such an injured cochlea, the operation for hearing-improvement is indicated as the bone conduction is normal or almost normal. Subsequently, the cochlea, the organ of Corti, receives much stronger sound-pressure than under the preoperative condition due to the restoration of the conductive mechanism. But since all of the hair cells except those of the outermost row are injured severely, the curve S, the summation of the excitability of these hair cells, will fall to show a very small gradient. Therefore, when the cochlea receives a much stronger sound-pressure, the actual and subjective sensation of the sound is not increased in parallel with the increase of the sound-pressure. That is, under such a decreased sensation of the sound, the injured cochlea cannot perceive a strong sound as the normal ear which perceives it as an abnormally strong sound. Such an injured cochlea is indifferent to a strong sound and may be defenseless even in the very strong sound. Accordingly, the injured hair cells that remain usually idle in the preoperative stage except when using the hearing-aid may be exposed to a strong sound-pressure always after the restoration of the conductive mechanism and may have exhaustion, hypofunction and collapse of the hair cells. Besides, in such a special, injured cochlea where the inner hair cells have lost the function already, the Ist and IInd rows of the outer hair cells also are injured severely and the IIIrd row of the outer hair cells only barely retains normal function, and the curve S, the summation of the excitability of individual hair cells, shifts remarkably to the right and the gradient of the curve S decreases to transform into almost horizontal line, when the IIIrd row of the outer hair cells is injured severely. In other words, the hearing loss becomes very severe approaching close to deaf.

From the above considerations, the cochlear hearing loss where the injury

of the hair cells begins from the inner hair cells like type C should be included in the severe hearing loss due to the severe perceptible hearing loss occurring within a short period of time. Further, the injured cochlea like type C is to be included actually in the cochleae diagnosed to be normal simply by the normal minimum threshold of the hearing in the audiometry, and such a false normal ear (cochlea) does really exist.

Now, a very singular phenomenon will be observed in the audiometry of such an injured cochlea, when the foregoing hypothesis is applied on the supposition that such a false normal cochlea does actually exist. In the true normal ear, the excitability-curves of individual hair cells under the sound-stimulation may appear as respective curves in Fig. 2 and the summation may resemble the curve S in Fig. 2. But in a false normal ear, the gradient of the curve S may decrease under an increased sound-pressure due to the injury of the inner row of the hair cells, though the beginning of the sound-susceptibility (the minimum threshold of hearing) might appear to be as in the true normal ear. Since the decrease of the gradient of the curve S is dependent upon the grade of the injury of the hair cells, the gradient of the curve S may increase again by some increase in the sound-pressure due to a slight injury of the inner hair cells or may never increase but rather decrease due to a severe injury to the inner hair cells.

In other words, a false normal ear cannot discriminate a slight change in the sound-pressure as sensitively as the true normal ear, though the minimum threshold of hearing might be in the normal range. In the case of a slight injury to the inner hair cells, the false normal ear may become more sensitive to a further increase in the sound-pressure. On the contrary, in severe injury, the false normal ear may be much more insensible to the change of the sound-pressure than the true normal ear with increased sound-pressure.

We are of the opinion that there is a strong possibility of existence of false normal ear: namely, the false normal ear (or cochlea) which cannot have the same sound-sensation as the true normal ear to the sound-pressure in a certain range may really exist, even among those ears are diagnosed as normal by the normal air conduction in the audiometry or normal by the normal bone conduction in the conductive hearing loss.

This singular phenomenon is completely contrary to the recruitment phenomenon observable in the cochlear hearing loss, where the sound-stimulation increases from a feeble sound-pressure to a stronger sound-pressure, the sound-sensation of the ear with a positive recruitment phenomenon approaches to the sound-sensation of the normal ear with the increase of the sound-pressure and in some cases it becomes stronger than that of the normal ear under a strong sound-pressure, as the ear is more sensitive to the change of the sound-

pressure than the normal ear though the beginning of the sound-sensation is delayed. But this false normal ear (cochlea) must be more insensible to the change of the sound-pressure in a certain range of the sound-pressure than the true normal ear (cochlea), though the beginning of the sound-sensation remains in the normal range as well as in the conductive hearing loss bone conduction remains in the normal range.

We would call this singular phenomenon "contrary recruitment phenomenon" and define as follows.

Definition of the contrary recruitment phenomenon (hypothesis): In the ear where the minimum threshold of hearing in air conduction or bone conduction in the conductive hearing loss is in the normal range, this phenomenon is positive, when the ear becomes more insensible to the change of the sound-pressure than the true normal ear in a certain range of the increased sound-pressure. Such an ear is a false normal ear (or cochlea), whose hair cells of the inner rows are injured. When the ear is as sensitive to the change of the sound-pressure as the true normal ear in the range of a feeble sound to a strong sound, this phenomenon is diagnosed to be negative and the ear (or cochlea) truly normal.

Then, on such a supposition, we may find the false normal ear among those ears diagnosed as normal by the conventional audiometry, if we apply the singular phenomenon to the audiometry. Therefore, this contrary recruitment phenomenon may be applicable to the diagnosis.

This phenomenon may be applied to the discovery or diagnosis in the early stage of the false normal ear (or cochlea). It may be applied to the early discovery of the hearing loss due to chemical poisoning. In the medication that is toxicant to the hearing organ, the test of this phenomenon is indicated immediately, even if the air conduction or bone conduction is normal. When this phenomenon is negative, the ear may be diagnosed as the true normal ear or, in conductive hearing loss, the true normal cochlea. On the contrary, when it is positive, the ear may be diagnosed as the false normal ear or cochlea in its latent stage of the hearing loss. In such a case, early countermeasures should be carried out at once, as the injury must have occurred already in the cochlea, the hair cells of the inner rows, especially the inner hair cells though the hearing loss is not yet suspected.

Important points to be pointed out here are that we should diagnose such a latent hearing loss which the family or the patient cannot realize nor can be discovered by the conventional audiometry. In the application of the hypothesis to the mechanism of the sound-susceptibility in the organ of Corti, the actual hearing loss should not begin in such an ear as the injury of the hair cells begins from the inner hair cells, until the injury reaches the outer-

most row of the outer hair cells. By this stage all the rows of the hair cells may be injured more or less already. Therefore, when the diagnosis is possible by the customary audiometry, the stage is already too late and then the ear may be followed by a severe hearing loss sooner or later.

We can find the significance of the application of the contrary recruitment phenomenon to the diagnosis, in that the latent hearing loss may possibly be diagnosed before the irretrievable serious situation. Such a false normal ear should be much more insensible to a strong sound than the true normal ear though the ear does not hinder speaking in the daily life. Accordingly, it may be possible to determine the grade of the injury in each row of the hair cells by measuring the range of the sound-pressure when the phenomenon is positive. Further, in the cases where the injury of the hair cells begins from the inner hair cells as those cases of the viral or bacterial infection and embolism in the area of hair cells, this phenomenon should be examined. And it may be able to make the estimation of the operation more precisely that a preoperative examination of this phenomenon enables us to establish more precise operation procedures for the hearing-improvement in the ear with the bone conduction normal in the audiometry but diagnosed to have conductive hearing loss. Especially, this phenomenon is useful in the case where the conductive hearing loss is suspected to be complicated with the false normal cochlea due to chemical intoxication or infection. When the examination is negative, the postoperative hearing-improvement may be anticipated to a fair degree, but when it is positive, the postoperative prognosis may be less or may hardly be anticipated according to the grade of the injury of the inside hair cells.

Finally we would like to offer some additional explanations concerning the application of the contrary recruitment phenomenon (hypothesis) to the diagnosis. In such a hearing loss due to the special type of the injury of the cochlea; in the hearing loss where the injury of the hair cells begins from the inner hair cells, in which finally the injury has reached the outermost row of the outer hair cells and then actual hearing loss starts, the hearing aid should be used very carefully even if the hearing has improved. Because the hearing in such a case may chiefly depend upon the outermost row of the outer hair cells which are most apt to be injured by a noise or a strong sound-pressure, in addition, the severe injury of the outermost row of the outer hair cells may be directly connected with the severe hearing loss, as the inside rows of the hair cells must have been injured already in this special type of the injured cochlea.

Further, we intend to conduct further studies for establishing a concrete diagnostic method, its clinical application and the substantiation of our fore-

going hypothesis.

SUMMARY

The observation and consideration in the organ of Corti were carried out by the phase-contrast microscopy from the various angles, after the microdissection of the cochleae in human, dogs, guinea pigs, and hamsters by Engström's surface preparation technique. We have formulated a hypothesis for the mechanism of the sound-susceptibility in the organ of Corti on the basis of the results of the observation and the consideration of the literature. Further, we have inferred the contrary recruitment phenomenon (hypothesis), by explaining theoretically such a clinical fact as the recruitment phenomenon or the cochlear hearing loss by applying our first formula of hypothesis. Finally we stated the application of the contrary recruitment phenomenon (hypothesis) to the diagnosis as well.

These may be summarized as follows.

1. The hypothesis for the mechanism of the sound-susceptibility in the organ of Corti, particularly the hair cells and the theoretical consideration :

First the area of Hensen's cells vibrates by a very feeble sound-stimulation, then the outermost row of the outer hair cells vibrates to perceive the sound-stimulation with the increase in the sound-pressure, further the vibration proceeds to further inner rows of outer hair cells with a greater increase of the sound-pressure to perceive a stronger sound-stimulation. In addition, the vibration of the outer hair cells proceeds from the outermost row to inner row acceleratively as the sound-stimulation increases.

In contrast, the inner hair cells vibrate under a very strong sound-pressure to perceive such a strong sound-stimulation, only when the outer hair cells have reached their maximum excitability by a strong sound-stimulation. That is, the inner hair cells play a role of auxiliary cells in the sound-susceptibility and may not operate in the sound-stimulation that is not so strong. Accordingly, the inner hair cells participate in the susceptibility of the sound-stimulation much later than the outer hair cells, as the sound-stimulation gradually increases from a feeble sound to a stronger sound. However, the inner hair cells have much greater faculty than the outer hair cells in the conversion of the sound-stimulation into the electric energy. On comparing the faculty in each row of the outer hair cells, it is slightly greater in the inner side than in the outer side row.

Further, on the basis of findings, we inferred the excitability-curves in each row of the hair cells and tried to give our theoretical explanations of the foregoing hypothesis in details.

2. Explanation of recruitment phenomenon or cochlear hearing loss by our hypothesis and its application to diagnosis :

In the cochlear hearing loss, we inferred the excitability-curves in each row of the hair cells on the basis of our hypothesis in relation to the sound-pressure which stimulates the hair cells, and then we have tried to explain theoretically the recruitment phenomenon or cochlear hearing loss. Next, as the curve representing the overall electric energy converted from the energy of the sound-vibration by each row of the hair cells was very similar to the articulation curve in the perceptive hearing loss with positive recruitment phenomenon, the shape of the articulation curve was considered to represent the area or grade of the injury in each row of the hair cells, hence its application to more exact diagnosis was pointed out.

3. Inference of the contrary recruitment phenomenon (hypothesis) from the foregoing hypothesis and its application to diagnosis :

After classifying the cochlear hearing loss according to the injury in each row of the hair cells into three types, we applied our hypothesis for the mechanism of the sound-susceptibility in the organ of Corti to these types to evaluate the cochlear hearing loss. The results may be summarized as follows.

Such an ear (cochlea) more insensible to the increased sound-pressure within a certain range than the true normal ear (the true normal cochlea in the conductive hearing loss) should exist among the ears diagnosed to be normal ear or normal cochlea by the conventional audiometry. Such an ear or cochlea should correspond to the injured cochlea where the injury to the hair cells begins from the inner hair cells and has the latent hearing loss.

As this singular phenomenon is completely contrary to the recruitment phenomenon, we defined this phenomenon as the contrary recruitment phenomenon (hypothesis) and we described its application to the early discovery or diagnosis of the false normal ear or cochlea (latent hearing loss).

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