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Anatomy. — „*Contribution to the knowledge of the development of the vertebral column of man*”. By Prof. Dr. E. W. ROSENBERG.

(Communicated at the meeting of March 30, 1912).

The investigation, about which I wish to make a communication, was in the first place made by me with the intention, to test by new material my view regarding the existence of processes of transformation in the vertebral column of man, because this view, though it has been affirmed by several investigators, has been repeatedly contradicted, also of late years.

Furthermore I wished to make my investigation owing to a plan, communicated by me a long time ago, to utilize the work in the preparation-room for a purely scientific purpose ¹⁾.

In view of both intentions it was necessary to obtain a knowledge as complete and exact as possible, of the differences in form and composition, that the vertebral column of full-grown man can show, and moreover in such a way, that always the whole vertebral column and not only a part of it is examined. Neither was it allowed to make a choice among the objects that were at disposal, whereby preference was given to rare or more interesting observations; all the available vertebral columns, provided that they were complete, were to be used for the investigation. But on account of the anthropological side of the scientific work in the preparation-room, I had to put aside the vertebral columns of anonymous persons and of persons belonging to other nations than the Dutch.

Consequently my investigation regards the vertebral columns of born Dutchmen.

On account of the small number of corpses that were at my disposal at Utrecht, I was obliged to collect during a period of time, running from the autumn of 1888 to the end of 1899, in order to get 100 vertebral columns that satisfied the requirements.

In the period from 1900 till the present day a second hundred has not yet been obtained.

In the treatment of the vertebral columns I have not followed the usual method of preparation by which maceration is applied, because small parts are easily lost when is followed this method and because in adjusting again the bones of a vertebral column, isolated by maceration, arbitrariness and inaccuracy cannot be avoided.

¹⁾ E. ROSENBERG, Eine vergleichende Beurtheilung der verschiedenen Richtungen in der Anatomie des Menschen. Antrittsvorlesung, gehalten in Utrecht d. 28. Sept. 1888. Leipzig 1889, p. 43—47.

E. ROSENBERG, Ueber wissenschaftliche Verwerthung der Arbeit im Praeparirsaal. Morpholog. Jahrbuch, Bd. XXII, p. 561—589. 1895.

I have preserved the objects in alcohol, and prepared them myself with knife and pincette, by which operation the bones remained connected by natural ligaments. The preparations are placed in alcohol and a number of the drawings have been copied at an enlargement of $\frac{5}{8}$ ¹⁾.

If one can agree to the view that transformation-processes take place in the vertebral column, the examined 100 vertebral columns can be divided, on account of certain peculiarities of these processes, into two groups.

One group contains 80 specimens, the other 20. These figures indicate already, that the first mentioned group is the more important one. This be therefore discussed first.

Not one of the 80 vertebral columns is perfectly identical with another.

Most points of difference are little deviations in form, which however morphologically are not without signification. If one leaves these aside, and pays only attention to differences that are so great, that they can influence the formula of the vertebral column, one sees, that in the group of 80 vertebral columns *ten different forms* are represented, which can be indicated by formulas. These are the formulas *If* to *IHa* and *Ihc* to *IIIb* of the subjoined list; vide page 82.

As an explanation of these formulas it be pointed out, that the vertebrae are indicated by figures, denoting their place in the column. The counting starts from the atlas as the first vertebra.

The vertebrae in different vertebral columns that are indicated by the same figure, are morphologically equivalent, because it has appeared, that in case of transformations of vertebral columns no vertebra falls out of the series, or is newly formed in the series between vertebrae, that exist already.

According to their form the vertebrae are taken in groups — the regions of the vertebral column — and the vertebrae in each region are indicated by letters corresponding with the names of the regions.

The vertebrae of the cervical region are indicated by *cv*. In the normal vertebral column this region contains the first vertebra up to the 7th included.

The vertebrae of the dorsal region are indicated by *d*. There are 12, consequently the 8th up to the 19th included. They are characterized by the fact, that each vertebra is provided with one pair of ribs movably united to it.

¹⁾ These drawings were demonstrated at the meeting; they will be published on another occasion.

The vertebrae of the lumbal region are indicated by *l*. There are 5 of them, consequently the 20th up to the 24th vertebra included. Their peculiarity is, that reduced ribs are completely coalesced with the transverse processes, consequently projecting parts are formed which are called *processus laterales*.

The vertebrae of the sacral region are indicated by *s*. There are 5 of them, consequently the 25th up to the 29th vertebra inclusive; they have *processus laterales* of the same morphological value as the lumbal vertebrae. But the sacral vertebrae have these *processus* fused together at the lateral extremities on either side of the body. This occasions the formation of the *pars lateralis sacri*, with which the girdle of the lower extremity articulates. The bodies of these vertebrae fuse likewise together at the formation of the *os sacrum*.

The vertebrae of the caudal region are indicated by *cd*. There

LIST OF FORMULAS OF THE VERTEBRAL COLUMN.

<i>IV</i>	1.—7. <i>cv</i>	8.—18. <i>d</i>	19.—23. <i>l</i>	24.—28. <i>s</i>	29.—32. <i>cd</i>
(<i>III</i> <i>f</i>)	1.—7. <i>cv</i>	8.—18. <i>d</i>	19.—23. <i>l</i>	24. 28. <i>s</i>	29.—33. <i>cd</i>)
(<i>III</i> <i>e</i>)	1.—7. <i>cv</i>	8. 18. <i>d</i>	19.—23. <i>l</i>	24.—28. <i>s</i>	29. <i>scd</i> 30.—33. <i>cd</i>)
(<i>III</i> <i>d</i>)	1.—7. <i>cv</i>	8.—18. <i>d</i>	19.—23. <i>l</i>	24.—29. <i>s</i>	30.—33. <i>cd</i>)
(<i>III</i> <i>c</i>)	1.—7. <i>cv</i>	8.—18. <i>d</i>	19. <i>dl</i> 20.—23. <i>l</i>	24.—29. <i>s</i>	30.—33. <i>cd</i>)
<i>III</i> <i>b</i>	1.—7. <i>cv</i>	8.—19. <i>d</i>	20.—23. <i>l</i>	24.—29. <i>s</i>	30.—33. <i>cd</i>
<i>III</i> <i>a</i>	1.—7. <i>cv</i>	8.—19. <i>d</i>	20.—23. <i>l</i>	24. <i>ls</i> 25.—29. <i>s</i>	30.—33. <i>cd</i>
<i>III</i>	1.—7. <i>cv</i>	8.—19. <i>d</i>	20.—24. <i>l</i>	25.—29. <i>s</i>	30.—33. <i>cd</i>
<i>II</i> <i>f</i>	1.—7. <i>cv</i>	8.—19. <i>d</i>	20.—24. <i>l</i>	25.—29. <i>s</i>	30.—34. <i>cd</i>
<i>II</i> <i>e</i>	1.—7. <i>cv</i>	8.—19. <i>d</i>	20.—24. <i>l</i>	25.—29. <i>s</i>	30. <i>scd</i> 31.—34. <i>cd</i>
<i>II</i> <i>d</i>	1.—7. <i>cv</i>	8.—19. <i>d</i>	20.—24. <i>l</i>	25.—30. <i>s</i>	31.—34. <i>cd</i>
<i>II</i> <i>c</i>	1.—7. <i>cv</i>	8.—19. <i>d</i>	20. <i>dl</i> 21.—24. <i>l</i>	25.—30. <i>s</i>	31.—34. <i>cd</i>
<i>II</i> <i>b</i>	1.—7. <i>cv</i>	8.—20. <i>d</i>	21.—24. <i>l</i>	25.—30. <i>s</i>	31.—34. <i>cd</i>
<i>II</i> <i>a</i>	1.—7. <i>cv</i>	8.—20. <i>d</i>	21.—24. <i>l</i>	25. <i>ls</i> 26. 30. <i>s</i>	31.—34. <i>cd</i>
<i>II</i>	1.—7. <i>cv</i>	8.—20. <i>d</i>	21.—25. <i>l</i>	26.—30. <i>s</i>	31.—34. <i>cd</i>
<i>I</i> <i>f</i>	1.—7. <i>cv</i>	8.—20. <i>d</i>	21.—25. <i>l</i>	26.—30. <i>s</i>	31.—35. <i>cd</i>
(<i>I</i> <i>e</i>)	1.—7. <i>cv</i>	8.—20. <i>d</i>	21.—25. <i>l</i>	26.—30. <i>s</i>	31. <i>scd</i> 32.—35. <i>cd</i>)
(<i>I</i> <i>d</i>)	1.—7. <i>cv</i>	8.—20. <i>d</i>	21. 25. <i>l</i>	26.—31. <i>s</i>	32.—35. <i>cd</i>)
(<i>I</i> <i>c</i>)	1.—7. <i>cv</i>	8.—20. <i>d</i>	21. <i>dl</i> 22.—25. <i>l</i>	26.—31. <i>s</i>	32.—35. <i>cd</i>)
(<i>I</i> <i>b</i>)	1.—7. <i>cv</i>	8.—21. <i>d</i>	22.—25. <i>l</i>	26.—31. <i>s</i>	32.—35. <i>cd</i>)
(<i>I</i> <i>a</i>)	1.—7. <i>cv</i>	8.—21. <i>d</i>	22.—25. <i>l</i>	26. <i>ls</i> 27.—31. <i>s</i>	32.—35. <i>cd</i>)
(<i>I</i>)	1.—7. <i>cv</i>	8.—21. <i>d</i>	22.—26. <i>l</i>	27.—31. <i>s</i>	32.—35. <i>cd</i>)

are 4 of them, consequently the 30th up to the 33rd included. They are characterized by a very reduced form.

On the boundaries between the regions vertebrae may be found showing the peculiarities of vertebrae of two regions.

Between the dorsal region and the lumbal region a vertebra may occur, bearing on one side of the body a small rib and on the other a processus lateralis. Such a vertebra is called dorsolumbal vertebra and indicated in the formula by *dl*.

Between the last typical lumbal vertebra and the first sacral vertebra a vertebra may exist, touching either on the right or the left with its thickened processus lateralis the pars lateralis of the sacrum or uniting with it. This is a lumbosacral vertebra indicated by *ls*.

Between the sacrum and the first caudal vertebra a vertebra may exist, not showing on one or on either side the connection with the pars lateralis, yet being united with the body of the preceding vertebra. This intermediate form is called a sacrocaudal vertebra and is indicated in the formula by *scl*.

Now the ten forms of the vertebral column that are represented in the group of 80 specimens can be regarded more closely.

One of these forms is the "normal vertebral column": it has the formula *III*.

The nine others differ among each other and with regard to the normal vertebral column especially in that part that contains the distal part of the dorsal region with the sternum and the arcus costarum and further all following regions in a distal direction.

In the cervical region likewise differences are to be detected, they are however not so great, as to influence the formula. Though these differences are by no means without signification, I shall not discuss the cervical region, in order not to take up too much time, and I shall likewise pass over in silence the arcus costarum and confine myself to that part of the vertebral column that begins at the 18th vertebra; this is in *all* specimens the 11th dorsal vertebra.

By many authors the different forms of the vertebral column occurring beside the so called normal vertebral column, are in a certain respect contrasted with the latter.

They are looked upon as variations or varieties or fluctuating modifications that are a result of the variability of the organism. These deviating forms are consequently regarded as oscillations, surrounding a constant form, representing the central point — i.e. the normal vertebral column — either at equal distances or in an irregular manner.

In my opinion this view which of late years has still been defended e.g. by DWIGHT¹⁾, BARDEEN²⁾, FISCHEL³⁾ is not very satisfying.

In opposition to this view I wish to hold another, at which one arrives when making use of the notions of comparative anatomy and certain results of embryology.

If we cast a look at the above ten formulas, we are struck by the difference in the number of vertebrae as regards both the whole vertebral column and the praesacral and the dorsal part.

In a vertebral column of the formula *Ij'* 35 vertebrae are extant in toto, among which are 25 praesacral and 13 dorsal ones.

On the contrary we find in a vertebral column of the formula *IIIb* in toto 33 vertebrae, 23 of which are praesacral and 12 dorsal.

Now comparative anatomy teaches, that if we leave out of consideration the stages of the vertebral column, which form the beginning of the phylogenesis of this organ, a comparatively greater number of vertebrae characterizes a more primitive state. Consequently a vertebral column of the formula *Ij'* is more primitive than a column answering to the formula *IIIb*.

And as embryological investigation⁴⁾ has shown us, it is true, that a lumbar vertebra can be transformed into a sacral vertebra, but the opposite process has not been demonstrated, and further, because the study of the development of the vertebral column of man has proved, that a little rib can fuse with the transverse process of a vertebra, and consequently can contribute to the formation of a processus lateralis, but never has anything been observed, which

¹⁾ TH. DWIGHT, Description of the Human Spines showing Numerical Variation in the Warren Museum of the Harvard Medical School. Memoirs of the Boston Society of Natural History vol 5. N. 7. 1901 p. 237—312.

TH DWIGHT, Numerical Variation in the Human Spine, with a Statement concerning Priority. Anatom. Anzeiger. Bd. XXVIII p. 33—40; 96—102. 1906.

²⁾ CH. R. BARDEEN. Numerical vertebral Variation in the human Adult and Embryo. Anatom. Anzeiger. Bd. XXV 1904 p. 497—519.

CH. R. BARDEEN, Studies of the development of the human skeleton. With 13 pl. American Journ. of Anatomy. Vol. IV N. 3 p. 265—302 Pl. 1—XIII. 1905.

Compare likewise the chapter written by BARDEEN: "Die Entwicklung des Skeletts und des Bindegewebes" in the Handbuch der Entwicklungsgeschichte des Menschen, herausgegeben von F. KEIBEL und F. P. MALL. Bd. I Leipzig 1910 p. 326, p. 360—362.

³⁾ A. FISCHEL, Untersuchungen über die Wirbelsäule und den Brustkorb des Menschen. Anatom. Hefte. Herausgegeben von F. MERKEL und R. BONNET. Bd. XXXI p. 459—588. M. Tf. 51—60. 1906.

⁴⁾ Regarding the observations to be taken into consideration here, vide: E. ROSENBERG, Bemerkungen über den Modus des Zustandekommens der Regionen an der Wirbelsäule des Menschen. Morpholog. Jahrbuch Bd. XXXVI H. 4 p. 609—659. 1907.

might prove that a vertebra without any ribs is being provided with the latter in the course of ontogenesis, so, in view of these facts, a vertebral column of the formula *If* is more primitive than others that have fewer praesacral vertebrae and fewer dorsal vertebrae.

Consequently we may take the vertebral column *If* as our starting-point when considering the above mentioned 10 formulas.

If now in a vertebral column of this form the 35th vertebra is completely reduced, the result is a vertebral column of the formula *II* which, otherwise, with regard to the composition of the regions, corresponds with the vertebral column *If*. When comparing the illustrations, however, one can see that in the vertebral column *II* the 13th pair of ribs consists of smaller bones and that the processus lateralis of the 25th vertebra are thicker, and that they are likewise nearer to the pars lateralis sacri.

These are but little differences of form, but they are forerunners of greater ones.

This is already seen in the specimen, representing the formula *Ila*. Here the 25th vertebra is a lumbosacral vertebra.

This state of things becomes intelligible, when we consider, that the sacrum is formed, because the girdle of the lower extremities rests on the vertebral column and that therefore a number of vertebrae fuse. Further one must pay attention to the fact that the girdle of the extremity, (being the ossa coxae), is not connected with the whole extent of the pars lateralis but only with a proximal part of it. This fact shows, that the pars lateralis did not come into existence at once in its whole extent, but developed successively, and the part of the pars lateralis that in a given vertebral column is in connection with the ossa coxae, has been formed later or is younger, than the part lying more distally; this part was previously connected with these bones, but lost this connection because the girdle of the extremity was displaced in a proximal direction.

At first sight this view seems to be a very hypothetical one, but it can be proved.

Let us suppose that the girdle of the extremity in a vertebral column of the formula *II* be removed only a little in a proximal direction, then the 25th vertebra is more strongly influenced by the ossa coxae. The more intense functional requirements cause a stronger development of the processus laterales, which can soon increase so much, that on one side of the body the thickened processus lateralis touches the pars lateralis and unites with it. In this way the 25th vertebra can become a lumbosacral vertebra.

This has been the case with the vertebral column *Ila*, where the

thickened processus lateralis is already connected with the right hand os coxae. Moreover the vertebral column *IIa* shows, that the 13th pair of ribs is still more reduced; they are still only little pieces of bone which are however movably united with the processus transversi.

In the vertebral column *IIc* we see, that the 25th vertebra is on both sides of the body attached to the pars lateralis and has consequently become the first sacral vertebra. And as in the distal part of the vertebral column no important modification has taken place, we find now a sacrum consisting of six vertebrae. At the same time at the 20th vertebra on one side the rib has fused with the vertebra, on the other side the rib has remained extant. Consequently the vertebra has become a dorsolumbal vertebra. Now there are only 4 lumbar vertebrae extant, as is likewise the case in *IIa*.

The next form, *III*, develops, when, on both sides of the body, at the 20th vertebra rudimentary ribs have disappeared as independent parts. This vertebra has now become the first lumbar vertebra; there are again 5 lumbar vertebrae, and in the praesacral part the arrangement has taken place that characterizes the normal vertebral column. In the sacrum there are however still 6 vertebrae to be found.

In vertebral columns of the form *IIe* the praesacral part is conform to that of *III*. At the distal extremity of the sacrum, however, now peculiarities can be observed, showing that the 30th vertebra is loosened from the sacrum. In the specimen represented the pars lateralis is interrupted between the 29th and the 30th vertebra on the right side of the body, in other specimens this is the case on the other side or on both sides; in these cases the 30th vertebra is only connected with the sacrum by its body. In all these cases the 30th vertebra has become a sacrocaudal vertebra.

If now the 30th vertebra is separated from the sacrum also with regard to the body, then a vertebral column is formed that is indicated by the formula *III*. This has a sacrum composed again of 5 vertebrae. But now of course 5 caudal vertebrae are extant, because, as already in the form *II*, the 34th vertebra still closes the series.

The consequence of a complete reduction of the 34th vertebra is a vertebral column of the normal form; the formula is indicated by *III*, which has been done for good reasons.

If we compare namely the formula *III* with the formula *II*, it appears, that the dorsolumbal boundary, the lumbosacral boundary, and the sacrocaudal boundary have all three been displaced one vertebra in a proximal direction, and that at the end of the vertebral column one vertebra has disappeared.

It is not for the first time that in the so-called normal vertebral

column displacement of the boundaries of the above-mentioned regions has caused the existence of 5 lumbal, 5 sacral and 4 caudal vertebrae but, as can be shown with great probability, it is for the third time in the course of the phylogenetical development of the human vertebral column. In vertebral columns of the formula *II* it is the second time that such an arrangement has taken place. This follows from observations in a vertebral column, in which, in so far as at present the history of the human vertebral column is known to us, for the first time groups of 5 lumbal, 5 sacral, and 4 caudal vertebrae have appeared. These observations will be cited afterwards.

This induced me, to divide the formulas into groups indicated by figures. This facilitates the general survey and gives, as will afterwards prove, still another advantage.

Now we have still to look at the formulas *IIIa* and *IIIb*.

From the formula *IIIa* it appears, that now the 24th vertebra has obtained a lumbrosacral form. And the illustration shows, that the 12th pair of ribs is a little shorter than in the vertebral column *III*. This points to a beginning reduction of the mentioned pair of ribs.

The form *IIIa* is evidently analogous to the form *IIa* and, like this, the vertebral column *IIIa* shows that a removal in a proximal direction of the girdle of the extremity occasions a modification in the composition of the regions, and that the formation of a lumbosacral vertebra is again the first act in the progress of the transformation-process.

The formula *IIIb* and the sketched specimen represent a further advancement of the process. The 24th vertebra has now become the first sacral vertebra, we can, however, easily conclude from the form of this vertebra that from a lumbal vertebra it has been transformed to a sacral vertebra. Of course there are now again 6 sacral vertebrae, as in the case of the sacra of *IIc* and *IIId*. In vertebral columns of the form *IIIb* we see distinctly, that the 12th pair of ribs has been reduced still more; in one of the specimens it is almost as little as the 13th pair of the vertebral column *If*.

If we take now a survey of the ten forms of the vertebral column just discussed, we may, in my opinion, assert that the view as if nine of these forms should only be insignificant oscillations of the organisation, surrounding as variations or varieties a constant form — the normal vertebral column — in an irregular way, does not explain the stated facts in a satisfactory manner. On the contrary these facts confirm the view I have defended long since.

It is so clear, that the discussed forms of the vertebral column are parts or links of a morphological succession or chain (morpho-

logische Reihe) that when describing the forms I could hardly help assigning a share in this description to the part of the phylogenetical development that is to be inferred from this chain.

Because the separate forms can be joined together freely and in a definite direction to a morphological succession, it is clear, that there is no contrast between a normal form of the vertebral column and varieties. All these ten forms are principally of equal value; they are representatives of stages of development, following each other successively.

The so-called normal vertebral column is the form that is at present numerically predominant.

Vertebral columns representing the formulas *I*f to *II*f are retarded forms that have stopped at different stages, preceding stage *III*.

And of course forms with a formula as *III*a or *III*b must be regarded as forms of a higher development than the normal vertebral column, having the value of future forms.

It seems to me that this view is more satisfying than the other and at the same time admits of the possibility of a certain application, which the other does not allow.

The application, I mean, becomes evident, when we pay attention to the fact, that the stages of development hitherto stated distinguish themselves, with only one exception, by only one phenomenon of transformation that can be indicated in the formula. The distance between each other of these stages of development is consequently in a morphological sense the same.

This is the case with the stages *I*f to *II*a and *II*c to *III*b.

If however we compare the forms *II*a and *II*c, we see that in the latter two phenomena of transformation are present, namely a transformation of the 25th vertebra into a first sacral vertebra, and of the 20th vertebra into a dorsolumbal vertebra.

The distance between these two forms is consequently greater than between the others. This suggests the supposition, that between the stages *II*a and *II*c a stage might exist, characterized by the fact that the 25th vertebra has already become a sacral vertebra, whilst the 20th vertebra has still remained the last dorsal vertebra.

To this answers a formula *II*b, which I have inserted into the series provisionally as an hypothetical one. I have in vain looked for such a form among the 100 vertebral columns under consideration. When studying the specimens, which I am collecting for the second hundred, I have however found the designated form of the vertebral column and even three times.

The formula *II*b is therefore no longer an hypothetical one.

The confirmation of one deduction of such a nature causes us to construe others from the observations we have made.

Now that the series of formulas from *If* to *IIIb* shows no longer an hiatus, it is possible, proceeding from the extremities of the series, to follow to a certain degree the process of transformation forward and backward, and to indicate the stages by hypothetical formulas.

The formula *IIIb* is analogical to the formula *IIb*, and in analogy to the formula *IIc* we can add to the formula *IIIb* a formula *IIIc*, indicating that the last dorsal vertebra of *IIIb*, the 19th of the series, has become a dorsolumbal vertebra.

When, by reduction of the rib still existing on one side of the 19th vertebra, this becomes a first lumbar vertebra, then we have the form *IIId*, in which, as in *IIIb* and *IIIc*, a sacrum consisting of 6 vertebrae must be extant.

Now we can imagine, that the 29th vertebra becomes a sacrocaudal vertebra and thus the formula *IIIc* is given.

And when now this 29th vertebra has passed into the series of the caudal vertebrae, the result is a vertebral column having the formula *IIIIf*, which, as the formulas *IIIf* and *If*, is characterized by the existence of 5 caudal vertebrae, the last, however, is now the 33rd of the series.

The reduction of this 33rd vertebra gives a formula *IV*, an analogon to formula *III*, and now once more the dorsolumbal boundary, the lumbosacral boundary and the sacrocaudal boundary have been displaced one vertebra in a proximal direction, and at the distal extremity one vertebra has disappeared. Consequently for the fourth time successive groups of 5 lumbar, 5 sacral, and 4 caudal vertebrae would be extant.

I have not hesitated to mention these conclusions, because formula *IV* may indeed not be considered to be a hypothetical one. A vertebral column of this composition has been described more particularly by TENCHINI¹⁾ in Parma, who however adheres to the then already refuted doctrine of excalation, and supposes, that the 12th dorsal vertebra with its ribs is entirely missing. A similar vertebral column has also been observed and briefly described by BIANCHI²⁾ in Siena.

Whether this process will continue further, cannot be said with certainty; it might be possible.

1) L. TENCHINI, Mancanza della dodicesima vertebra dorsale e delle due ultime coste etc. L'Ateneo Medico Parmense, Anno 1. Fasc. 2 p. 97—132. Parma 1887.

2) S. BIANCHI, Sulla frequenza delle anomalie numeriche vertebrali nello scheletro dei normali e degli alienati. Atti della R. Accad. dei Fisiocritici in Siena. Ser. IV, vol VII Fasc. 1—2. p. 29, osservazione V. Siena 1895.

Now, proceeding from the actually observed form *If*, one might cast a look into a comparatively ancient period of the history of the vertebral column.

If in analogy of the formulas *III* to *II* one were to construe succeeding formulas to the formula *If*, the first in succession would be a formula, denoting the 31st vertebra as a sacrocaudal vertebra: *Ie*.

The latter must be preceded by a form of the vertebral column in which the 31st vertebra is the last and moreover the sixth sacral vertebra: *Id*. Here the 21st vertebra must be the first lumbar vertebra as in the formulas *IIC* to *Ie*.

Inasmuch as now a first lumbar vertebra is developed from a last dorsal vertebra, after it has passed through the stage of a dorsolumbar vertebra, the next following more primitive form must possess the 21th vertebra as dorsolumbar vertebra, as is indicated in the formula *Ic*.

And this must have been developed from a form in which the 21st vertebra is the last and moreover the 14th dorsal vertebra, which characterizes the formula *Ib*. In this formula the 26th vertebra is the first of a sacrum, consisting of 6 vertebrae. A first sacral vertebra, however, develops from a last lumbar vertebra, after it has been lumbosacral vertebra.

Consequently we can imagine a formula, showing the 26th vertebra as lumbosacral vertebra, in which at the same time 14 dorsal vertebrae and 4 lumbar vertebrae are extant, besides a sacrum, consisting of five vertebrae. This is indicated in the formula *Ia*.

And if now we go one step more backward, then it must be possible to find a vertebral column in which the 26th vertebra is the last and moreover the 5th lumbar vertebra, then a sacrum of 5 vertebrae must follow and 4 caudal vertebrae must succeed to this, the last of which is the 35th vertebra of the series. This gives the formula *I*.

With regard to the formulas *Ie* to *Ia* I must admit, that they are purely hypothetical; with regard to formula *I*, however, I should wish to cite an observation, answering almost entirely to this formula.

First I must, however, briefly fix the attention to a peculiarity, occurring in vertebral columns standing on the ten stages mentioned.

If a special stage is represented by more than one specimen we see in these specimens differences that have a morphological signification.

As an example I wish to cite the stage *IIIa*, which is represented by three vertebral columns.

One glance at the illustrations is sufficient to see that these three

specimens form a morphological progression, demonstrating a beginning of the reduction of the 12th pair of ribs.

At the same time it is very clear that these three specimens cannot be directly derived the one from the other, that consequently they do not form what might be called a descensional succession.

This shows the 24th vertebra. In specimen 1 the contact with the sacrum has been formed on the *right* side of the body, in the two other specimens on the *left* side. These three specimens consequently belong at least to two successions that have diverged, be it only in a slight degree.

And if in the specimens 2 and 3 we carefully examine the pars lateralis, then it appears from observations, which we cannot enter into particulars upon here, that the specimen 3 which, with regard to the twelfth pair of ribs, is higher developed than the specimen 2, is, with regard to the facies auricularis, more primitive than the specimen 2. Thus, likewise between these two specimens, there exists a slight divergence of development. All three specimens are consequently the extremities of three independent progressions of development, though they may be only very short.

As a second and last example the two specimens representing the stage *IIIb* may serve.

We see that the reduction of the 12th pair of ribs has reached a higher degree; in the specimen 2 these ribs are already so little that they look much like much reduced 13th ribs. Together with the specimens of the stage *IIIa* these two specimens exhibit, in the most convincing manner, the gradual reduction of the 12th pair of ribs.

The 24th vertebra is in the stage *IIIb* first sacral vertebra, and it is obvious that, in specimen 1, it is transformed in a slighter degree than in specimen 2.

With regard to these points (I leave other points out of discussion) specimen 2 is doubtless the higher developed one. That this specimen does not after all directly continue the line of development of specimen 1, but deviates from it divergently, appears from the position of the facies auricularis, which in specimen 2 is a less transformed one than in specimen 1. This is likewise seen, when considering the 30th vertebra. In specimen 2 this vertebra has still cornua coccygea, whereas these have already almost completely disappeared in specimen 1. This points likewise to divergent development.

This divergency of development is shown by all specimens belonging to any stage. It is however so slight that the specimens remain unmistakably within the boundaries of the separate stages.

It is however of importance to ascertain this divergency, because

it enables us to interpret the vertebral columns in the second, smaller group.

One need only suppose, that the divergency of the direction of development increases more or less, then forms must originate that do no longer fit in the frame of the separate stages, but are connected with every stage as *accessory forms*, as they might be called.

These forms remain by local, relative retardation or by local acceleration of the transformation, either below the stage, to which they belong, or they are a little more developed. But always they diverge from the direction that leads from one special stage to the other, and thereby they form, as it were, side-branches, which are however very short, because the several accessory forms are, as a rule, only represented by one single specimen.

The second group contains 20 vertebral columns, and these represent 17 different forms that can be denoted by formulas.

Only as one single example I wish to cite an accessory form, belonging to stage *II*. In this stage the 20th vertebra is the 13th dorsal vertebra; if this vertebra through comparatively too rapid transformation becomes a first lumbal vertebra, whilst the other parts of the vertebral column remain unaltered, then a vertebral column has been formed with 6 lumbal vertebrae. And we see that this column has not followed the line of development leading to stage *IIa*, because to this stage only 4 lumbal vertebrae belong. It has followed a side-path that leads away from the main-route and soon ends.

Let me mention a second example.

In the list of formulas stage *IIIb* is followed by a hypothetical stage *IIIc*, in which the 19th vertebra is a dorsolumbal vertebra. I have now found a vertebral column, belonging to the second group, in which the 19th vertebra has this form. To the left exists a processus lateralis and to the right a rudimentary 12th rib, which is about to fuse with the vertebra.

Further we find 4 lumbal vertebrae and a sacrum, consisting of 6 vertebrae, the 24th to the 29th, as must be the case in a stage *IIIc*. In so far everything agrees with what is indicated in the hypothetical formula. But the vertebral column I am dealing with, has only 3 caudal vertebrae and not 4, as the formula requires, the 32nd vertebra is the last.

Consequently I cannot regard this vertebral column as a representative of a stage *IIIc*; but it may be conceived as an accessory form to such a stage. By acceleration of the transformation at the distal end the 33rd vertebra has been reduced comparatively too early.

It seems to me that this observation makes it very probable that

it will be possible, to find the stage *IIIc*, which for the present is still hypothetical.

Principally in the same way the probability of the existence of the most primitive stage *I* can be shown.

This appears from observations I was allowed to make on a vertebral column in the anatomical institute of Leiden.¹⁾

On account of the existence of articular planes on the 20th and the 21st vertebra it is certain that these vertebrae were provided with movable ribs that were missing in the preparation.

So here 14 dorsal vertebrae are to be found as formula *I* requires. Further we see 5 lumbal vertebrae, the 26th vertebra is the last lumbal one, then follows a sacrum, consisting of the 27th to the 31st vertebra, as the formula indicates. The caudal vertebrae of the preparation are defective, so that we cannot know whether the 35th vertebra was the last. The 32nd and the 33rd vertebrae are extant in the preparation, they have however a sacrocaudal form.

Consequently this vertebral column does not answer entirely to formula *I*, it is a little more primitive and may be regarded as an accessory form to a stage *I*.

The examples cited show that the accessory forms can likewise be explained, if we admit the view, that the various forms are not irregular varieties, but the consequences of special processes of development.

Having this view, we need no longer explain the existence of the various forms by the so called variability. This does indeed not give an explanation at all, neither does it make us understand that the great majority of the vertebral columns forms a morphological progression.

The observations I have made, become however intelligible, if we consider that when a species, consisting of many individuals, is in a state of phylogenetical development, it would be highly improbable, that all the individuals should be transformed with exactly the same rapidity.

If there is, however, a difference of rapidity or intensity of the transformation, then it is evident, that, at a given period, in individuals living at the same time, very different stages of the process of development of the whole species will be represented by groups of the individuals.

And this is what we have seen.

At the same time it is clear now, why the great majority of the

¹ E. ROSENBERG. Ueber eine primitive Form der Wirbelsäule des Menschen Morphol. Jahrbuch Bd XXVII, H. 1. p. 1—118, Tf. I—V. 1899.

individuals form a continuous progression of stages of development.

If we survey the whole progression, we can observe that the difference, existing between the most primitive stage and the highest, is greater than the differences in the composition of the vertebral columns not only in some species, but even in several genera of Primates.

Consequently it is not an unimportant part of the history of the human vertebral column that the formulas allow us to survey.

Three dorsal vertebrae have successively become proximal lumbar vertebrae, three distal lumbar vertebrae have the one after the other been lodged in the proximal part of the sacrum, and from the distal extremity of it gradually three vertebrae have passed into the caudal region, which has lost three vertebrae at the extremity.

The diminution of the number of praesacral vertebrae does, however, not necessarily involve a shortening of the trunk; by measurements we can come to the conclusion, that in the higher stages the bodies of the vertebrae become higher and this occasions a compensation.

In the sternum and the arcus costarum, too, analogous modifications take place.

All these observations justify the notion, that in the region of the trunk an important transformation is working; the processes in the vertebral column can certainly not take place, if the parts of the body, surrounding this extensive organ, do not participate in the transformation.

The knowledge of these processes must consequently exercise an influence on the descriptions which systematical and topographical anatomy give of the composition of the trunk. Both branches of science pay too little attention to the transformation of the organism.

I cannot enter into further details on this subject now; in conclusion I wish only to point out in a few words the importance of the series of formulas with regard to anthropology.

This becomes apparent when we consider, how the vertebral columns are arranged by the series of the stages.

The result appears from a graphical representation ¹⁾.

On horizontal lines, answering to the stages, the specimens belonging to each stage are indicated by dots.

At the end of each line the accessory forms are indicated by marks, placed either a little lower or a little higher, further is denoted, what characterizes each accessory form.

The rows of the representatives of each stage have been placed

¹⁾ This will be published in another communication.

symmetrically in relation to a line, indicating the route or course that is followed by the transformation of the species. If we consider this representation, it is in the first place remarkable that the so-called normal vertebral column has not the absolute majority, but only a relative one. There are in the stage *III* 26 vertebral columns.

Further the attention is drawn by the fact that the stages *IIf* and *IIf* contain a rather great number of specimens.

In the stage *IIf* the 30th vertebra is a sacrocaudal vertebra. The loosening of this vertebra from the sacrum is morphologically a complicated process; it is therefore clear that it is not so soon finished, and that consequently a rather great number of individuals are at the same time in stage *IIf*. There are 23 of them.

In stage *IIf* 5 caudal vertebrae are extant, the last is the 34th vertebra. This must be reduced, then the stage *III* is attained. The reduction of this vertebra is morphologically a comparatively simple process, consequently there are fewer specimens found in this stage than in stage *IIf*. This reduction, however, is physiologically of little importance; this may be a reason of retardation of the process, so that after all as many as 14 individuals have stopped in this stage.

It stands to reason that the more primitive and the most modified forms are found only in small numbers in the relative stages.

As the series of the formulas allows of an arrangement of the examined vertebral columns, this series gets the value of a *scale* or *standard* by which we can ascertain the degree of development, reached by the examined organ for every group of men that can anthropologically be distinguished.

It is true the number of 100 vertebral columns is not sufficient to pronounce a decisive opinion in an anthropological regard.

But in a methodological regard the result we have obtained is, in my opinion, sufficient to confirm the conviction, that, by this method, when many individuals are examined, it is possible to fix for every nation the degree of development, attained with regard to the organ examined or to other organs, provided that for each a series of stages be established.

So I am of opinion that it would be worth while applying this method of investigation to races of men that in anthropological regard stand widely apart from each other.

This might be done, if in preparation-rooms of various countries, provided with the required number of corpses, the same investigations were made.

It is very likely that rather different arrangements of individuals by the scale of the formulas would be found, and that it would

be possible to characterize anthropologically the different races of men by indicating the differences in the character and the intensity of the processes of transformation.

And if the vertebral column should be chosen for such an investigation, an opinion about the degree of organisation attained would certainly not rest on too narrow a basis, as the vertebral column is in contact with many organs that surround it, and actively or passively participate in its transformation.

Physics. — “*On vapour-pressure lines of binary systems with widely divergent values of the vapour-pressures of the components.*” (In connection with experiments of Mr. KATZ). By Prof. PH. KOHNSTAMM. (Communicated by Prof. VAN DER WAALS).

§ 1. *General character of the vapour-pressure lines derived from the differential quotients.* The theory of the p, x -lines of binary mixtures was developed by VAN DER WAALS in Verslagen Kon. Ak. v. Wet. (3) 8 p. 409 and These Proc. III p. 163 (See also Cont. II p. 120 et seq.) on the supposition that the quantity μ'_{x_1} occurring there may

be represented by $-\frac{d\frac{a_x}{b_x}}{dx}$, and so is only dependent on the critical temperature of the mixture taken as homogeneous. VAN DER WAALS showed later on that a further approximation may be obtained by the introduction of the quantity p_c , the vapour-pressure of the mixture taken as homogeneous. Then:

$$\mu'_{x_1} = \frac{dp_c}{dx}$$

while:

$$-l \frac{p_c}{p_k} = f\left(\frac{T_k}{T} - 1\right).$$

In a recently published paper¹⁾ I showed that a number of particularities of the vapour-pressure lines follow from these equations. Since then Mr. KATZ's investigations²⁾ and the results communicated

obtained was $\frac{3}{2}R$. It was mentioned during the discussion at the Conseil SOLVAY, Nov. 1911 that Professor KAMERLINGH ONNES and myself had undertaken an investigation of γ_{Λ^0} by KUNDT's method for hydrogen at temperatures down to that of liquid hydrogen, but this investigation has not yet been completed.

¹⁾ Zschr. f. phys. Ch. 75 p. 527.

²⁾ These Proc. Vol. XIII p. 958.