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Exchange of Phosphorus in Human Teeth.

Further Experimental Investigations, Using Radioactive Phosphorus as Indicator.[1]

By

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A number of investigators have studied the question of whether the post-eruptive tooth enamel is capable of exchanging substances with dentin and saliva respectively (see for example W. J. GIES (23), F. FABER (21), CHASE (18), KARLSTRÖM (26), WANNENMACHER (31, 40), NYGAARD ØSTBY (33), WOLF and NEUWIRT (32), BAŽANT and STUDNIČKA (15), FORSHUFVUD (22)).

Various methods of investigation have been employed, attention being given in particular to the possibility of permeation of dyes into the enamel. Vital staining via the dentin has been tried by several workers (e. g., BODECKER and LEFKOWITZ (17) BERGGREN (16), and has recently been accomplished by BERGGREN in case of children and young people, at any rate as far as the inner and intermediate enamel is concerned. Several investigators (PICKERILL (28), SPRAWSON (30), WANNENMACHER (31, 40), etc.) have demonstrated that dyes may permeate into the enamel from without, in vivo as well as in vitro.

These investigators have furnished valuable information regarding the permeability, but have not solved the problem of the exchange of the normal constituents of the enamel. This — the main — problem can be investigated with the aid of radioactive isotopes as indicators — a method which was introduced into biology by HEVESY (3—7) (see also A. KROGH (10), J. H. LAWRENCE (11), R. ÖHNELL (13), and K. KJERULF-JENSEN (8)).

[1] Paper read before the Danish Odontological Society, and the Biological Society, Copenhagen, April 28. 1942.

By introducing a mixture of an element and its radioactive isotope into an organism we are able to register the path of the atoms. The radioactive isotope serves as an indicator for the whole amount of substance administered. The element is "labelled" so that it is possible to distinguish between the atoms which were present in the substance introduced and those which were already in the organism.

Quantitative determination of the radioactive isotope may be undertaken by means of the GEIGER-MÜLLER counting tube (described e. g., by T. BJERGE (1) and HILDE LEVI (12)).

Radioactive phosphorus (P^{32}) is particularly well suited for investigations of the metabolism of dental hard tissues, 1) because phosphorus is a significant constituent of the teeth, 2) because it is possible to prepare P^{32} in quantities sufficiently large for experiments in human beings, and 3) because P^{32} has a half life (14.5 days) which is suitable for biological investigations.

Earlier Investigations.

Table 1 presents a record of earlier in vivo investigations of the exchange of phosphorus in teeth, using radioactive phosphorus, the table including all papers which have come to the knowledge of the present authors.[1]

In an earlier publication (P. O. PEDERSEN and BODIL SCHMIDT-NIELSEN (50)) we have reviewed the papers appearing up till then, and here we shall mention only the most important findings which have been published since.

In experiments on a dog, MANLY, HODGE and VAN VOORHIS found that the uptake of P^{32} was the same in the dentin of the different teeth, and of the same order of magnitude as in the dense diaphysial bone. In the *uncovered* enamel only traces of P^{32} were found. The authors themselves were of the opinion that the reason that no distinct activity could be found in the enamel was that the dosage was rather small.

SOGNNAES and VOLKER (51), in some excellent investigations on 5 dogs and 8 cats, found that the surface enamel aquired P^{32} from saliva, but could find only a very small exchange between dentin and enamel, so small that the radioactivity in the surface enamel was scarcely measurable when saliva had no access to the surface of the teeth. In a young adult monkey a substantially greater activity was found in the enamel of unerupted third molars, still in a state of mineralization, than in the enamel of the erupted teeth.

[1] The most recent American and English literature has not been accessible.

Table 1.

In vivo investigations on the exchange of phosphorus in dental hard tissues, using radioactive phosphorus as indicator

In rats	In cats	In dogs	In man
Chievitz & Hevesy[38, 39] (1935, 1937)	Hevesy, Holst & Krogh[42] (1937)	Manly, Hodge & van Voorhis[47] (1940)	Hevesy, Holst & Krogh[42] (1937)
Hevesy, Holst & Krogh[42] (1937)	Armstrong & Hevesy[41] (1940)	Sognnaes & Volker[51] (1941)	Lawrence, Scott & Tuttle[45] (1939)
Manly & Bale[46] (1939)	Sognnaes & Volker[52, 51] (1940, 1941)		Pedersen & Schmidt-Nielsen[50] (1941)
Born *et al.*[36, 37] (1940)	Barnum & Armstrong[35] (1941)		Pedersen & Schmidt-Nielsen (1942)
Erbacher & Wannenmacher[44] (1941)			
Also in a monkey: Sognnaes & Volker[51] (1941)			

Our results (50) from experiments with children are contemporaneous with those of SOGNNAES and VOLKER, and in rather close agreement with them. We too found that P^{32} can be acquired by the surface enamel from saliva, and that the exchange between dentin and enamel is very small.

From the results of his early in vitro experiments, ARMSTRONG (41) concluded that P^{32} is not acquired by the surface enamel from saliva, but in a later investigation (with BARNUM (35)) he shares the view of SOGNNAES-VOLKER and PEDERSEN-SCHMIDT-NIELSEN.

Interesting in vitro experiments on teeth and dental tissues in the presence of solutions containing radioactive phosphorus have been made by HEVESY (4), ARMSTRONG (34, 35, 41), MANLY and LEVY (48), as well as by HODGE, VAN HUYSEN, BONNER and VAN VOORHIS (43).

The Authors' Own Investigations.

One object of the investigations which will be described in the following was a closer study of the exchange between enamel and saliva, a phenomenon which we had no opportunity to elucidate sufficiently in our earlier investigations. Another object was to

investigate the exchange in devitalized teeth. Finally, an orientation was wanted as to whether it was possible by means of P^{32} to answer the question of a remineralization of partly decalcified (carious) enamel. (Cf. HEAD (25), PICKERILL (28), ANDRESEN (14), WOLF and NEUWIRT (32)). This involved an investigation of the uptake of P^{32} in acid treated enamel surfaces.

A. Investigations on the Exchange Dentin/Enamel and Saliva/Enamel in a 12-Year Old Girl. 3 Sound Vital Teeth were Investigated.

Person I. ♀. 12 years. Weight 60 kg. Only slight liability to caries. Orthodontic considerations required the extraction of 3 sound teeth (4 +, + 4 and 1 —).[1]

A solution of Na_2HPO_4, containing 46.5 million relative radioactive units[2], was given orally. Before the ingestion, 4 + was treated for 5 minutes with 5 % HNO_3 and carefully washed. 1 — and + 4 were not treated in this way. + 4 was equipped with a tight fitting jacket of German silver, extending a little up under the gingival margin. The jacket was attached by means of phosphate cement (Bayer).

On the following days, samples of urine and saliva (unstimulated) were collected at intervals. 11 days after the administration of radioactive phosphorus, 4 +, + 4 and 1 — were extracted under local anesthesia.

The periodontal membrane was removed from the extracted teeth. The surface of the teeth was washed in running, distilled water for at least 15 minutes. The teeth were split lengthwise, the pulp removed, and pulp residue washed off. The *dentin* was cut off in centrifugal direction, the crown dentin and the root dentin being kept separate. The innermost layer was not included in the samples. The *cementum* was ground off from without. So was the *enamel*, by means of small carborundum stones (a new stone for each sample), using binocular magnifying glass. The crown fragments were repeatedly split in the longitudinal direction of the crown, so that the dento-enamel junction constantly could be observed on very narrow pieces. In the following, the term "*outer enamel*" applies to samples containing about $^1/_3$ of the total enamel thickness. The "*intermediate enamel*" is the rest, up to the proximity of the dento-enamel junction. The gingival part of the enamel was not included, partly because the enamel here is very thin, and partly because, in case of + 4, saliva might have had access to this part of the enamel via the crevice and the cement used in attaching the jacket.

[1] Here and in the following the teeth are designated according to HADERUP's nomenclature. + denotes the teeth of the upper jaw, — the teeth of the lower jaw. Teeth on the right side have + or — after the number of the tooth, teeth on the left side have the symbol before.

[2] About $^2/_3$ are reckoned to be resorbed.

It will be seen that the preparation technique employed is not quantitative since it is somewhat incidental how thick layers are ground off. Minor deviations in radioactivity of identically designated tissue samples from different teeth (tables 2 and 3) may therefore be explainable solely by the fact that the samples are more or less diluted by deeper lying, less active layers.

For various reasons the inner enamel was not investigated. When grinding off this part of the enamel, the chance of getting the samples contaminated with dentin will be very large. The flotation method of MANLY and HODGE (27) is better suited for this purpose, but even this method does not make it certain that the samples are absolutely free from dentin. To investigate a series of different enamel fractions (separated by means of their different specific gravities), as carried out by SOGNNAES and VOLKER (51) is in our case out of the question. That can only be done in experiments in animals where it is possible to work with the entire dentition, and therefore possible to obtain far greater samples (better conditions of measurement).

The samples were placed in small aluminium dishes and, out of regard to the absorption of the radiation, mixed with inactive dentin powder to bring them to the same volume, whereupon they were fixed with shellac. The radioactivity was measured in GEIGER-MÜLLER counters. To insure reliable determinations, all samples were measured from 2,000 to 6,000 counts. The samples having very low radioactivity (about 0.5 count/min. higher than the background) were counted alternately with the background for 24—36 hours.

Table 2 records the results for the different dental hard tissue samples obtained from person I. The radioactivity reported is per gram of tissue, and is calculated as percentage of the dose administered. The figures are given with a mean error which is calculated on the basis of the accuracy of the measurement.

Special attention is called to the fact that while the radioactivity in the intermediate enamel from all three teeth, and in the outer enamel from the tooth with jacket[1] (+ 4) is of the same order of magnitude as the error of measurement, just measurable radioactivity is found in the outer enamel of the uncorroded tooth (1 —), and pronounced activity in the outer enamel of the corroded tooth (4 +). In the last mentioned case, the radioactivity of the outer enamel is double that of the crown dentin. In the uncorroded 1 — the activity of the outer enamel is 1/6 that of the crown dentin. In case of + 4 (with jacket), no such ratio

[1] The jacket cement is not active, thus the saliva has not had access.

Table 2.

Investigations on the exchange of phosphorus in vital teeth

Person I.

(♀ 12 years. Orally: 46.5×10^6 units of P^{32})

Tooth extracted 11 days after the ingestion	Percentage of ingested dose per g $\times 10^{-4}$					Ratio	
	Enamel		Dentin		Cementum	Crown dentin: Outer enamel	Root dentin: Crown dentin
	Outer	Intermediate	Crown	Root			
4 +, treated with acid; no jacket	4.8 ± 0.1	0.3 ± 0.1	2.3 ± 0.1	10.5 ± 0.2	11.0 ± 0.3	0.5 : 1	4.5 : 1
+ 4, not treated with acid; with jacket[1]	-0.3 ± 0.1	0.0 ± 0.1	2.6 ± 0.1	9.7 ± 0.2	16.4 ± 0.8		3.7 : 1
1 —, not treated with acid; without jacket	0.6 ± 0.1	0.0 ± 0.1	3.4 ± 0.2	10.1 ± 0.2	12.8 ± 1.5	5.7 : 1	3 : 1

[1] Cement attaching the jacket: $-0.1 \times 10^{-4} \pm 0.1$.

can be given, but it may be assumed that the radioactivity of the outer enamel is not more than 1/30 that of the crown dentin (PEDERSEN and SCHMIDT-NIELSEN (50 b, p. 664)). Between the radioactivity in root and crown dentin we find the same ratio as in our earlier investigation (50 b, p. 665), viz., between 6 : 1 and 3 : 1. The ratio root dentin/cementum is about 1 : 1.3 and is of the same order of magnitude as previously found by us in case of a single tooth (50 b, p. 666).

B. Investigations on the Exchange Saliva/Enamel and Cementum/Root Dentin in a 19-Year Old Man. 6 Devitalized Teeth were Investigated.

Person II. ♂. 19 years. Weight 57.5 kg. Very high susceptibility to caries. Two devitalized teeth were to be extracted because of periapical affection — four other teeth, likewise devitalized, should have the crown wholly or partly removed as part of the conservative treatment.

A solution of Na_2HPO_4, containing 34 million relative radioactive units, was given orally.

Since the conditions of the teeth in this case vary a great deal, the individually examined teeth will be described in some detail:

+ 2. Root-filled about 4 months previously (pulpitis chronica simplex). Was not treated with acid. Equipped with jacket immediately

before the ingestion. 7 days later the crown was removed at the cervix. The samples were prepared by grinding off, as described above.

6 +. Root-filled 3 weeks previously (pulpitis chronica simplex). *Before* the ingestion treated with 5 % HNO_3 for 5 min. and washed. No jacket. 3 days after the ingestion the surface enamel was ground off without access of saliva (rubberdam) and after careful washing with distilled water. (In table 3 this layer is designated as enamel layer I). At the same time crown dentin was cut and the dentin of the root canals reamed off. 23 days after the ingestion the whole crown was removed at the cervix. A sample was prepared of what was *now* the surface enamel (in table 3 designated as enamel layer II).

3 +. Root-filled 3 weeks previously (pulpitis chronica simplex). Not treated with acid before the ingestion. No jacket. 5 days later, without access of saliva (rubberdam) crown and root dentin were cut and reamed off. 10 days *after* the ingestion, the enamel surface was treated for 5 min. with 5 % HNO_3. 24 days after the ingestion, the crown was removed at the cervix, and samples were prepared of the surface enamel.

6 —. Root-filled 3 weeks previously (pulpitis chronica simplex). Not treated with acid and no jacket attached. 22 days after the ingestion, the crown was removed at the cervix. It was only possible to prepare samples of the enamel.

— 6. Under root-canal treatment 7 weeks previous to the ingestion (pulpo-paradentitis chronica). X-ray examination showed a minor rarefaction around the apex of the mesial root, and that the remainder of the paradental tissue was sound. Devitalized pulp of the crown was removed 4 weeks, and devitalized pulp of the root 6 days before the ingestion. Paper points with buffer disinfectant "Dipa" were present in the root canals.

No acid treatment was applied and no jacket attached. 8 days after the ingestion, the tooth was extracted under local anesthesia. Along the buccal and lingual gingiva acute caries with emolliated dentin was found. The emolliated dentin was removed until hard, slightly discolored dentin was reached. A sample of the latter was obtained. Otherwise samples were prepared as previously described, though in this (and the following) case samples of the cementum and two samples of the root dentin were prepared, viz., an inner and an outer sample. At the preparation of the sample of the outer root dentin, the cutting was extended towards the cementum as far as it was possible without contaminating the sample with the cementum.

5 —. Root-filled 3 weeks previously (pulpo-paradentitis chronica). Rather extensive, but superficial acute caries of the enamel was found. The X-ray examination disclosed a periapical rarefaction of slight magnitude, and that the remainder of the paradental tissue was sound.

No acid-treatment was applied and no jacket attached. Extraction 21 days after the ingestion. Samples were prepared of the surface enamel and of the inner and outer root dentin, as well as the cementum.

In case of both of the last mentioned teeth, that part of the root in which the periodontal membrane was distinctly pathologically changed was not included.

Table 3.

Investigations on the exchange of phosphorus in devitalized teeth

Person II.

(♂ 19 years. Orally: 34 × 10^6 units of P^{32})

Tooth	Percentage of the ingested dose per g × 10^{-4}				
	Enamel (surface)	Dentin			Cementum
		Crown	Root		
+ 2 Not treated with acid; with jacket	0.1 ± 0.1	—0.6 ± 1.0			
6 + Treated with acid *before* the ingestion; ground 3 days after; no jacket	Enamel layer I: 2.3 ± 0.1 Enamel layer II: 1.7 ± 0.1		0.1 ± 0.3		
3 + Treated with acid 10 days *after* the ingestion; no jacket	0.0 + 0.6	0.7 ± 0.6	1.9 ± 2.3		
6 — Not treated with acid; no jacket	0.7 ± 0.4				
— 6[1] Not treated with acid; no jacket		0.0 ± 0.1 Carious dentin: 26.9 ± 0.7	inner —0.2 ± 0.1	outer —0.1 ± 0.1	11.5 ± 0.4
5 —[1] Not treated with acid; no jacket Acute caries of surface enamel	3.3 ± 0.2		inner —1.1 ± 0.8	outer —0.2 ± 0.3	5.4 ± 0.3

[1] extracted

The results for person II are recorded in table 3. It is here seen that the enamel from the tooth with jacket (+ 2) does not show any measurable radioactivity. The enamel from the tooth that was treated with acid 10 days *after* the ingestion does not show any measurable activity either, but the measurement of this sample was less accurate. Both enamel layers from the tooth which was treated with acid before the ingestion and later ground

3 days after the ingestion (6 +), show distinct radioactivity, and so does the enamel from the tooth with superficial caries of the enamel (5 —). Thus we find that corroded, ground or carious enamel surfaces will take up more P^{32} than intact enamel surfaces.

The values of the radioactivity of the crown dentin and the inner as well as the outer root dentin of the devitalized teeth investigated do not exceed the error of measurement when it is a matter of non-carious dentin. But the dentin removed from the deeper layers of the carious dentin shows an even very considerable radioactivity. We learn from this result that P^{32} to a high degree permeates emolliated dentin, and that admixture of carious (and the immediately surrounding) dentin will have so decisive influence that it is absolutely necessary to avoid it in experiments dealing with normal conditions.

Finally we shall mention that the radioactivity of the cementum is of the same order of magnitude as in the vital teeth from person I (table 2).

C. Investigations on the Excretion of Radioactive Phosphorus in Urine and Saliva.

The excretion of P^{32} in urine and saliva was followed in the 2 persons. In case of person I a series of samples of saliva and urine was available, while only a few urine samples were on hand in case of person II.

Fig. 1 is a graphical representation of the excretion of P^{32} in saliva and urine from both persons. Since the contents of phosphorus per unit of volume varies both in saliva and in urine, the radioactivity is calculated as *specific activity* (radioactivity per mg of phosphorus)[1] and is recorded in percentage of the dosage given.

The curve in fig. 1 shows that the specific activity is the same in saliva and urine, and identical for the two persons. During the first 24 hours the excretion is exceedingly large, corresponding to the fact that the P^{32}-concentration of the blood is very large. The radioactivity decreases rapidly during the first 24, then more slowly during the next 24 hours, whereupon the value decreases quite evenly and slowly.

[1] The phosphate analyses were made by Mr. P. FISCHER-JØRGENSEN, cand. pharm. (School of Pharmacy, Dept. of Inorganic Chemistry, Director: Professor Dr. C. FAURHOLT).

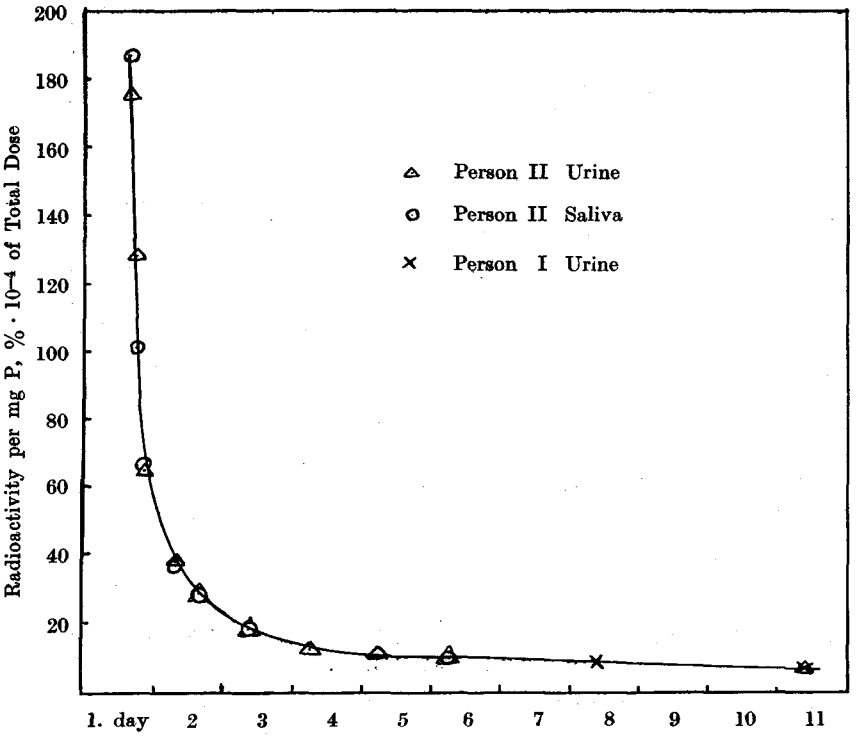

Fig. 1. The specific radioactivity of urine and saliva in persons I and II. Ingestion of radioactive phosphorus 1st day, 10 a. m.

D. In Vitro Experiments with Special Regard to the Exchange Saliva/Enamel Surface.

In vitro experiments with radioactive saliva have been made, partly to investigate whether the results mentioned in the foregoing sections could be reproduced outside the organism, and partly to secure more accurate information on the influence of the acid treatment upon the uptake of P^{32}. There was used unstimulated saliva from person II, originating from the 4th., 8 th. and 11th. day after the ingestion of P^{32}.

The experiments were carried out on 15 freshly extracted sound teeth from persons of different ages. 8 of these teeth were treated with 5 % HNO_3, whereupon they were thoroughly washed. The 8 corroded and 5 non-corroded teeth were embedded in paraffin of high melting point, in small glasses, so that only the crown

was free. 2 teeth were embedded so that the crown was covered with paraffin while the root was free. To each glass were added 4 ml of saliva, so that the teeth were completely covered. Thymol crystals were added to prevent putrefaction. The glasses remained in a thermostat at 37° for 11—24 days, being cautiously shaken now and then.

Table 4.

In vitro experiments on the exchange of phosphorus saliva/enamel surface

Treated with acid				Not treated with acid			
Tooth	Age of person	Days kept	Specific activity of sample: Specific activity of saliva %	Tooth	Age of person	Days kept	Specific activity of sample: Specific activity of saliva %
+ 5	10	24	0.3	+ 6	34	21	0.04
5 +	10	12	0.2	+ 4	12	11	0.03
+ 1	32	24	0.2	4 —	12	23	0.02
3 —	29	21	0.2	5 —	10	24	0.00
3 —	55	21	0.1	— 05[1]	11	14	0.04
— 3	29	13	0.4				
2 +	29	12	0.8				
05 —[1]	11	14	0.4				

[1] Deciduous molars from the same person.

Table 4 gives the results for all samples of surface enamel, i. e. about $^1/_5$ of the total enamel thickness, stating the percentage ratio between the specific activity of the enamel and that of saliva. It will be seen that the corroded enamel surface on the average takes up 10 times as much P^{32} as the uncorroded surface.

Table 5 shows that no measurable radioactivity was found in the inner enamel or in the crown dentin from the teeth the crowns of which had remained surrounded by radioactive saliva. Nor is a measurable radioactivity found in the root dentin (inner and outer) from the tooth[1] the root of which was surrounded by radioactive saliva. The surface of the cementum, however, was found to be slightly radioactive.

[1] By accident, the samples from the second tooth were lost.

Table 5.

In vitro experiments on the exchange of phosphorus saliva/deeper layers of crown, and saliva/deeper layers of root

	Tooth	Days kept	Specific activity of sample: Specific activity of saliva %		
			Inner enamel	Dentin	Outer crown dentin
Root embedded; Crown covered with saliva	— 3	13	0.0		0.0
	2 +	12	0.0	0.0	

			Crown dentin	Root dentin		Cementum
				inner	outer	
Crown embedded; Root covered with saliva	— 4	17	0.0	0.0	0.0	0.2

Discussion.

The scope of the present experiments with human beings was in several respects like that of our earlier investigations (50). In such respects our earlier experiences could be confirmed and strengthened, just as the previous and present results show good agreement with the results of experiments with animals obtained by other investigators. As mentioned above, however, we have in our renewed investigations also followed new paths, and especially tried to elucidate the question of the exchange in devitalized teeth as well the question of remineralization.

The in vivo experiments proved that *there occurs an exchange of phosphorus between saliva and the intact enamel surface.* This was also found in our earlier investigations (50) as well as by SOGNNAES and VOLKER (52, 51) and by BARNUM and ARMSTRONG (35). In vivo, the enamel of both devitalized and vital teeth showed such exchange. The in vitro experiments proved the existence of an exchange between saliva and the surface layer of enamel of the same order of magnitude as in the experiments in vivo. This

indicates that the exchange of phosphorus saliva/enamel surface is not determined by the biological conditions in the mouth cavity.

In case of devitalized teeth, information can be obtained as to whether there occurs a *phosphorus exchange between the enamel and the dentin*, i. e., whether the phosphorus which the enamel surface acquires from the saliva permeates as deeply as to the dentin. In contrast to BARNUM and ARMSTRONG (35) we have been unable to find any such phenomenon.

Considering now the transport of phosphorus from the blood stream (the dental pulp) via the dentin to the enamel, we observe that sound vital teeth in young people (one person + two earlier persons) show a considerably greater *exchange between the dental pulp and the dentin* than that which occurs between the saliva and the intact enamel surface. The dentin of the crown is found to be distinctly less radioactive than the dentin of the root. This is presumably because there is more dentin in proportion to pulp surface in the crown than in the root.

In teeth where saliva was excluded by means of jackets attached with cement, we have been unable, now as previously, to show any measurable radioactivity in the outer (and intermediate) enamel layers. Thus the *exchange dentin/enamel must be of a very small order of magnitude*, but we find no reason to suppose that no such exchange takes place. It must be assumed that we are here faced with a quantitative rather than with a fundamental question.

The cementum shows distinct radioactivity of a somewhat higher magnitude than that of the root dentin. The radioactivity of the cementum is — as might be expected — not of a different magnitude in vital and devitalized teeth.

Since *the root dentin* in the devitalized teeth do not show measurable radioactivity, it seems *impossible to demonstrate any exchange between the cementum and the adjacent dentin.* That the metabolism of the root dentin in vital teeth in the main takes place via the dental pulp is well known and has been confirmed (strongly radioactive root dentin in vital teeth).

In the acid treated enamel surface we found, both in vital and devitalized teeth as well as by in vitro experiments, *a greater radioactivity than in the uncovered intact enamel surface.* In corroded surface enamel the activity is on the average 10 times as great as in the intact surface enamel.

The purpose of treating the enamel surface with HNO_3 was to imitate the incipient decay of the enamel and to investigate whether it is possible by means of radioactive phosphorus to prove the occurence of remineralization or similar reparative processes in superficially demineralized enamel. — If an addition (deposit) occurs in the disintegrated enamel surface, it will manifest itself by high radioactivity in the newly-formed material. It is not correct, however, directly to interpret the relatively high radioactivity which we found in corroded surface enamel as an indication of a *deposit* of new material. The corroded enamel has a considerably increased surface, and this permits of a correspondingly greater *exchange* of phosphorus. It is impossible, without new and thorough investigations, to say whether these two processes can be separated, and it is therfore necessary to postpone a discussion of the remineralization problem from this point of view until such investigations have been made.

We wish to express our sincere thanks to Professor Dr. MANNE SIEGBAHN, the Physics Institute of the Academy of Science, Stockholm, who, through Professor Dr. AUG. KROGH, placed radioactive phosphorus at our disposal. We are greatly indebted to the Professors, Director E. BUDTZ-JØRGENSEN, Dr. AUG. KROGH, and Dr. G. HEVESY for the valuable help which we have received, and we also wish to thank Messrs. HOLM JENSEN, M. D., ZERAHN, cand. mag., and FISCHER-JØRGENSEN, cand. pharm., for many favors, and Messrs. Sv. Å. KØRNING and J. PINDBORG for excellent assistance.

Summary.

The exchange of phosphorus in dental hard tissues was investigated with radioactive phosphorus as indicator.

Experiments were made in vivo as well as in vitro. The in vivo experiments were made with two persons, in the one instance (12 years) on 3 entirely sound teeth, in the other instance (19 years) on 6 devitalized teeth. The in vitro experiments were made with 15 freshly extracted sound teeth which were kept in radioactive saliva at 37°.

It was possible to prove an exchange of phosphorus atoms (phosphate ions) between saliva and intact surface enamel. The order of magnitude was found to be the same in vivo and in vitro.

An exchange was demonstrated to take place between the dental pulp and the dentin, considerably greater than the exchange between saliva and intact enamel surface.

There was found no measurable exchange between enamel and dentin. (No radioactivity in the dentin of devitalized teeth, and no radioactivity in the enamel of vital teeth to which saliva had no access).

No exchange between cementum and root dentin could be demonstrated in devitalized teeth.

Attempts to immitate incipient dental caries were made by treating enamel surfaces with nitric acid. The corroded enamel surface showed an uptake of radioactive phosphorus which was about 10 times that of the intact enamel surface, both in vivo and in vitro. The cause is debatable, and definite conclusions cannot be reached before additional experiments have been made.

Zusammenfassung.

Der Stoffaustausch in den harten Zahngeweben wurde unter Benutzung von radioaktivem Phosphor als Indikator untersucht. Die Versuche wurden sowohl in vivo wie auch in vitro ausgeführt. Für die Versuche in vivo standen zwei Personen zur Verfügung. Bei der einen (Alter: 12 Jahre) wurden 3 völlig gesunde Zähne dazu benutzt, bei der andern (Alter: 19 Jahre) 6 pulpenlose Zähne. Die Versuche in vitro wurden ausgeführt mit 15 frisch extrahierten, gesunden Zähnen, die mit radioaktivem Speichel bei 37° abgestellt wurden.

Zwischen Speichel und intaktem äusseren Schmelz konnte ein Austausch von Phosphoratomen (Phosphationen) nachgewiesen werden, der in vivo und in vitro gleich gross war.

Zwischen Pulpa und Dentin wurde ein Austausch festgestellt, der bedeutend grösser war als der zwischen Speichel und intakter Schmelzoberfläche.

Zwischen Schmelz und Dentin liess sich kein Austausch nachweisen. (Keine Radioaktivität im Dentin pulpaloser Zähne, ebenfalls keine im Schmelz solcher gesunder Zähne, die von Speichelzutritt geschützt waren.)

In wurzelbehandelten Zähnen konnte kein Austausch zwischen Zement und Wurzeldentin nachgewiesen werden.

Durch Ätzung der Schmelzoberflächen mit Salpetersäure wurden Versuche eingeleitet, um die Verhältnisse bei beginnender

Karies nachzunahmen. Die geätzte Schmelzoberfläche zeigte sowohl in vivo wie in vitro eine ca. 10mal so grosse Aufnahme von radioaktivem Phosphor wie die intakte Oberfläche. Die Gründe hierfür werden erörtert. Endgültige Schlüsse lassen sich erst nach Durchführung weiterer Versuche ziehen.

Résumé.

L'échange des substances dans les tissus durs dentaires était examiné en appliquant le radiophosphore comme indicateur.

Des expériences, d'une part in vivo, d'autre part in vitro, étaient faites. Les expériences in vivo étaient faites avec deux personnes, dans l'un cas (12 ans) à 3 dents tout à fait saines, dans l'autre cas (19 ans) à 6 dents sans pulpe. Les éxperiences in vitro étaient faites à 15 dents saines récemment extraites, qui étaient mis à la salive radio-active par 37 degrés.

Il étaient possible de démontrer un échange des atomes de phosphore (ions de phosphate) entre la salive et la surface d'émail intact. L'ordre de grandeur en est le même in vivo et in vitro.

Entre la pulpe et la dentine étaient constaté un échange, qui est beaucoup plus grand que l'échange: la salive — surface d'émail intacte.

Il ne se trouvait pas un échange mesurable entre l'émail et la dentine. (Il n'y avait aucune radio-activité dans la dentine aux dents sans pulpe, et aucune radio-activité dans l'émail aux dents vitales, auxquelles la salive n'avait pas eu accès.)

Un échange entre le cément et la dentine de racine ne pouvait pas être démontré en dents soumis à un traitement radiculaire.

Des expériences sur l'imitation de la carie dentaire commençante étaient faites en traitant des surfaces d'émail avec l'acide nitrique. Une surface d'émail ainsi traitée montrait une absorption de radiophosphore environ 10 fois plus grande que la surface d'émail intacte, tant in vivo que in vitro. La cause en est discutée, mais des conclusions définitives ne peuvent être obtenues, avant que des expériences ultérieures aient été faites.

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