STUDIES ON THE LYMPH DRAINAGE OF THE ACCESSORY NASAL SINUSES.

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In 1916 we began an investigation to determine the course of lymphatic absorption from the antrum and frontal sinus, and, incidentally, from neighboring tissues—the nasal fossae, the palate, the gums, the meninges, and the subcutaneous tissues of the face. Our first series of experiments was completed in 1918, and reported to the American Laryngological, Rhinological and Otological Society.* This was followed by a second series, which has been completed, so that we are now ready to report on the research as a whole.

We have been able to find but little reported work dealing with the lymphatics of the accessory sinuses. According to Da Costa's edition of Gray's Anatomy, which follows the more special work of Sir Frederick Treves and of Delamare, Poirier, and Cunéo, the accessory sinuses drain into the retropharyngeal lymph nodes, which receive tributaries also from the nasal fossae, naso-pharynx, and Eustachian tube, and perhaps from the cavity of the tympanum. They in turn send vessels to the internal jugular group of upper deep cervical nodes, which communicate freely with each other and with the external group, and terminate in the jugular trunk, which on the right side helps to form the right lymphatic duct or empties directly into the junction of the internal jugular and subclavian veins, and on the left side empties directly into the venous junction or into the thoracic duct.

Of the literature available in support of this description, the work of André is the most considerable:

He injected the lymphatics of the antrum in two child cadavers, of 5 and 8 years, and demonstrated many lymph vessels converging to the antral orifice, passing out, and joining the lymphatics of the middle meatus, upper surface of the inferior turbinate, and lower surface of the middle turbinate. Others passed out through the thin "posterior fontanelle" in the internal wall of the antrum to join

*For a full review of the literature bearing on this subject, as well as protocols of all the experimental animals of the first series, and a more extensive collection of photographs, see Mullin, *The Lymph Drainage of the Accessory Nasal Sinuses*, Trans. American Laryngological, Rhinological and Otological Society, 1919.

Fig. 1.

Front view of head and thorax of rabbit.

R. A. S. Rt. anterior submaxillary node. L. A. S.—Left ditto.

R. P. S. Rt. posterior submaxillary node. L. P. S.—Left ditto.

R. I. J. Rt. internal jugular node. L. I. J.—Left ditto

S. G. Submaxillary salivary glands.

P. Pin inserted in the puncture made when injecting the left antrum.

Note.—This picture is semidiagrammatic, the nodes having been darkened in the print. Wherever this has been done, it will be indicated in a foot-note.

those of the middle meatus. Of those passing out through the foramen he writes, "We succeeded in following them in the middle meatus, where they consisted of four to six large collectors, with frequent anastomoses, and having an antero-posterior direction. We saw them continue thus as far as the crease which separates the posterior end of the inferior turbinate from the anterior projection of the Eustachian tube. It is probable then, that in joining the lymphatics of the nasal fossae, they end, like these, by emptying into the pharyngeal nodes and the jugular chain."

Following André, Grünwald injected the antrum of a 60-year-old man, and virtually proved the anatomical lymphatic continuity "of the whole lymph-vascular system of the accessory sinuses between themselves and with the nose, directly in the level of the mucosa and continuously in its course, not through walls." The injection fluid entering the antral mucosa in the region of the hiatus semilunaris, extended to most of the mucosa of the middle meatus and inferior and middle turbinates, also to the ethmoid cells, sphenoidal sinus, and posterior wall of the frontal sinus; passing backward to the pharynx it ended at the projection of the Eustachian tube. No communication was established with the orbit or the gums.

Though demonstrating the anatomical connection, Grünwald deprecates the drawing of clinical conclusions from a single experiment performed under artificial conditions of pressure, upon a dead subject.

J. B. Thomas in a recent article reports seven cases of tuberculosis of the frontal sinus. In one the disease involved the frontal and sphenoidal sinuses, and the autopsy showed tuberculosis of the cervical nodes, also the right apex and bronchial nodes. Another case was complicated by mastoid disease and "glands," location not given. H. A. Lothrop reports eighteen cases of suppuration of the frontal sinus, one of which had also double antrum disease and enlarged cervical lymph nodes. It is significant that among the complications mentioned in these two reports, retropharyngeal abscess does not occur.

G. B. New has lately reported metastasis of malignant tumors of the antrum to the submaxillary, parotid, and cervical nodes.

As already suggested, all the experimental work we have been able to find on the lymphatics of the accessory sinuses, and most of that on the associated regions of the nose and throat, rests upon the method of injections on the cadaver, and therefore, as recognized by the investigators themselves, is not a sure criterion of function in the living subject.

Of the few experiments on living animals which have any relation to our subject, we may mention the work of Cornet on absorption of tubercle bacilli from the nasal mucus membrane of guinea pigs, that of Goodale and Henderson on absorption of inert powdered substances from the surface of the tonsils in guinea pigs, and Grober's injections of the tonsils in rabbits and dogs. Very recently Noyes and Dewey, using dogs, have demonstrated the lymph drainage from the teeth to the submaxillary nodes.

F. R. Sabin has approached the subject of lymphatic anatomy from the embryological point of view, by injections of pig embryos, and her findings go far to explain the disagreements among different investigators as to the lymphatic connections between the various regions of the head, neck and thorax. Such connections exist developmentally, and in all probability idiosyncrasies of individual adult lymphatic anatomy, as well as varying conditions of pressure or infection, may in some cases serve to bridge over from one part of the jugular field to another, in other cases fail to do so. Therefore, when one chooses a limited portion of the field for study, as we have done with the accessory sinuses, one should not expect to find an absolutely distinct and narrowly limited course of absorption therefrom. For a fundamental characteristic of lymph drainage is that it is widely regional and rich in anastomoses.

We have investigated the lymph drainage of the antrum and frontal sinus, and associated regions, by means of a series of experiments on living animals. The work has consisted chiefly of injections and inoculations of the antrum in rabbits and the frontal sinus in cats. The anatomy was worked out on the animals of the series, and also on other normal animals. The antrum in the rabbit and the frontal sinus in the cat are both fairly large as compared with the whole skull, and the anatomical relations are quite similar to those in man. As a rule, direct communication between the sinuses and the nasal fossae is somewhat freer than in the human subject.

The lymph nodes are much less numerous than in man, and their arrangement more constant, but the regional distribution corresponds closely. The upper end of the long internal jugular node corresponds to the retropharyngeal nodes in man, this long node being the analogue of the whole deep cervical chain.

ANTRUM.

The study of the antrum was undertaken first, and began with a series of injections with India ink. This fluid—a suspension of finely divided carbon—was chosen because the pigment granules are

Fig. 2.

Left side of head and thorax of rabbit.

R. A. S. Rt. anterior submaxillary node.

L. A. S. Left posterior submaxillary node.

R. P. S. Rt. posterior submaxillary node.

L. P. S. Left posterior submaxillary node.

R. I. J. Rt. internal jugular node.

L. I. J. Left internal jugular node.

P. Pin in puncture made when injecting left antrum. Some ink discoloration around it.

I. O. Ink in tissues or orbit, extending to edge of conjunctiva.

Note.—Semidiagrammatic as regards nodes. L. I. J., however, has not been retouched.

about the size of cocci, and are absolutely insoluble; it is therefore practically the same in physical characteristics as a dense emulsion of bacteria. The technique consisted simply in entering the antrum with a hypodermic needle, under ether anesthesia, by penetrating the skin of the face and the thin external wall of the superior maxillary bone. The fluid was then injected and the needle quickly withdrawn. If the point of the needle was free in the cavity of the antrum, some of the ink nearly always escaped into the nose and ran out at the nostril. However, we found that ink was quite readily carried away from the nasal fossae by secretion, without being absorbed, while it stagnated in the antrum and was in part taken up by the lymphatics.

After several days the animals were killed with chloroform and autopsied, and in many cases the diagnosis of pigmentation—or, in the inoculated cases, of infection—of nodes and other tissues was confirmed by microscopic sections.

The first rabbit injection (Rabbit 1) gave the most striking result. In this case the point of the needle, after passing through the left antrum, penetrated the mucosa of the inner wall, and about 1 cc. of ink was injected beneath the mucosa against strong resistance, resulting in marked exophthalmos of the left eye. The left nasal fossa was then probed with an applicator. No ink escaped into the nose.

The rabbit was chloroformed after two days. Autopsy showed considerable pigmentation of the subcutaneous tissue over the left antrum, very deep pigmentation of the mucosa of the left antrum, purulent exudate and marked pigmentation of the mucosa of the left nasal fossa, in the region adjacent to the antrum, with fainter extension upward almost to the roof of the superior meatus, laterally to the left ethmoidal cells and across the median line to the middle and lower part of the right nasal fossa, and even to the lining membrane of the right antrum, backward on both sides to the posterior wall of the naso-pharynx, where microscopic sections showed it in large masses within lymph vessels in the diffuse lymphoid tissue of the region, backward on a higher level into the sphenoidal sinus, and forward on both sides almost to the nostrils. No discoloration was detected in the bone or cartilage of the nasal septum, the extension to the right side apparently being around the posterior edge of the septum. Thus the distribution of the injected substance in the nasal fossae and accessory sinuses corresponds quite closely with that observed by Grünwald in the human subject, and illustrates again the complete continuity of the lining membrane.

There was very marked pigmentation of the whole of the left orbit, extending as far as the conjunctiva but not into it, and of the tissue surrounding the sockets of the left molar teeth, but no extension to the oral cavity, the tonsils, or the larynx. There was some pigmentation of the meninges around the optic chiasm and left olfactory nerve.

So far the findings are open to the same criticism which applies to injections on the cadaver, namely that the injection was made under pressure and may have broken through where there is no normal functional communication. Beyond the field of direct extension this criticism is not so valid. There was very deep pigmentation of the submaxillary and internal jugular lymph nodes on both sides, without any discoverable pigmentation of the other tissues of the neck, thoracic wall, or pleura. The left supparotid node was strongly pigmented. The lungs showed numerous small round spots, almost black, especially noticeable on section, and the blood in the heart appeared abnormally dark. Microscopic sections showed carbon in the blood, endothelium, and tissue spaces of both sides of the heart, perhaps slightly more marked in the right side, much carbon in the branches of the pulmonary arteries in the lungs, both free and dotted through the vessel walls, less in the other vessels of the lungs, a good deal in more or less dense focal masses within the lymphatics of the lung tissue, and very small amounts in a bronchial node. There was slight pigmentation of a retrosternal node.

Microscopic sections of the various affected nodes showed carbon granules free in the lymph sinuses, sometimes in considerable masses, and in smaller quantity and finer division within blood vessels and endothelial cells.

The course of absorption here is perfectly clear, from the general left nasal field to the cervical lymph nodes of both sides, the lymph ducts, the great veins, the right heart, and the lungs, whence a residuum filtered through to the left heart and the general circulation. However, owing to the massive injection and the size of the field reached by direct extension, the experiment is not sufficiently limited either in the source of absorption or the degree of effect upon the different cervical lymph nodes. It was therefore necessary to follow it by a series of experiments with the injection more strictly confined to the antrum itself, or to other limited regions.

The reports of the most interesting members of this series follow:

PROTOCOLS—ANTRUM.

Rabbit 2. About $\frac{1}{2}$ cc. ink in left antrum. Some escape from nose.

Autopsy, four days. Much ink in left antrum, considerable amount in overlying tissues. Traces lying free on mucosa of nasal fossae, and mixed with pus in right antrum (proved by microscope). Very little absorption. Very slight pigmentation of left anterior and posterior submaxillary nodes. None elsewhere.

Rabbit 3. Two cc. ink in right antrum. Much escape from nose, 1.5 cc. ink in subcutaneous tissue of left side of face, and submucosa of left side of palate.

Autopsy, three days. Small amount of ink in right antrum and overlying tissues. None in nasal fossae. Large amount in subcutaneous and muscular tissues of left side of face and submucosa of left side of palate. Moderate discoloration of left anterior submaxillary node, very slight of posterior. Deep discoloration of left internal jugular node. Pharynx, larynx, thorax and cranial cavity negative.

Microscopic sections. Tonsils and postauricular nodes, normal. Left posterior submaxillary node, small amount of carbon.

Rabbit 8. About $\frac{1}{2}$ cc. ink in right antrum. Some escape from nose.

Autopsy, one day. Moderate amount of ink in right antrum. Very slight discoloration of right anterior and posterior, and left anterior, submaxillary nodes. Slight discoloration of right internal jugular node. Verified by microscopic sections.

Rabbit 9. A few drops of emulsion of 11-weeks-old culture of human tubercle bacilli in right antrum. Lining mucosa of antrum scratched with needle.

Autopsy, thirty-seven days. In mucosa of right antrum several small yellowish plaques, which in microscopic section showed tuberculosis at a fairly advanced stage of caseation, and loaded with tubercle bacilli. Right anterior and posterior submaxillary nodes, moderately advanced tuberculosis. Right internal jugular node, early tuberculosis with moderate number of bacilli. Left posterior submaxillary node, moderately advanced tuberculosis; left anterior, apparently normal, no bacilli found. Left internal jugular, early tuberculosis. At upper margin of lower lobe of left lung, near the root and immediately beneath the pleura, a whitish rounded elevated mass about 5 mm. in diameter, which in microscopic section proved to be a tuberculous focus in a fairly early stage of caseation, with numerous bacilli. The bronchial nodes on microscopic section showed very early tuberculosis with beginning caseation and numerous bacilli. The meninges appeared somewhat congested, and microscopic sections of meninges and brain showed some

Fig. 3.

Transverse section of head through antra of rabbit.

Transverse section of head through antra of rabbit.

R. A. Rt. antrum, normal (approximately).

L. A. Left antrum, containing ink.

L. E. Left ethmoid cells, containing ink.

Fig. 4.

Transverse section of head through nasopharynx and anterior part of orbits of rabbit.

N. P. Nasopharynx, somewhat pigmented.

O. Areolar tissue of left orbit, containing ink.

T. Tissue surrounding sockets of left molar teeth containing ink.

L. S. A left submaxillary node.

lymphocyte infiltration around the vessels, but no bacilli were found in several sections examined, and no perfectly characteristic tubercles.

Rabbit 11. About $\frac{1}{2}$ cc. fresh pus from antrum of Case P. in right antrum. This patient (Case P.) had a chronic suppuration of the left antrum, and bronchiectasis. Smears of the pus from the antrum showed pneumococci, staphylococci, and a variety of bacilli both Gram-positive and Gram-negative; twenty-four-hour broth culture chiefly pneumos and staphs.

Died, eleven days. Autopsy. Marked inflammation of right antrum, slight of nasal fossae. Slight congestion of submaxillary and internal jugular nodes. Intense hemorrhagic inflammation of trachea and bronchi. Pneumonia of left lung in stage of red hepatization, of right lung in stage of resolution. Moderate nephritis. Spleen small and pale. Smears: Right antrum, pneumos and staphs. Right internal jugular node, pneumos and staphs. Left lung many capsulated pneumos, free and in phagocytes. Trachea same. Right lung same, but less numerous. Heart blood, very rare pneumos, numerous staphs.

DRAINAGE OF THE ANTRUM AND ITS RELATION TO THE LUNG.

In the first series, the lymph drainage of the antrum by way of the cervical lymph vessels and nodes was demonstrated, and the possibility of substances absorbed from the antrum reaching the lung by an exclusively lymph- and blood-vascular route proved. In view of the clinical observation that chronic antrum disease and chronic pulmonary—especially bronchial—disease so often occur together, we were anxious to follow up this line. The former experiments proved that the antrum *can* act as a source of absorption; may therefore, if diseased, be, like tonsils and tooth roots, the ambush of a focal infection which, taken up by the lymphatic division of the circulatory system, can be carried to any other vulnerable tissue—in this case especially the lung. Is this in reality the way in which the chronic antrum-chronic bronchitis cases develop?

We inoculated four more rabbits in the antrum by the method previously described. Two rabbits (RV and RVIII) were given plain emulsion of tubercle bacilli, while two others (RVI and RVII) were given tubercle bacilli plus India ink, in order to compare the development of lesions with absorption pure and simple. No attempt was made to close the foramen from the antrum into the nose. The inoculating fluid was allowed to escape in the natural way of an unobstructed suppurating antrum.

RV was killed after three months, and showed two minute ulcers in the mucosa of the outer wall of the right (injected) antrum. No tubercle bacilli were found in scrapings, and an attempt to remove the membrane for sections was not successful, as it adhered closely. The right submaxillary nodes showed early tuberculosis. The remaining tissues examined in gross and microscopically (jugular nodes, lungs, mesenteric nodes, spleen) were negative.

RVIII, killed at two months, showed a caseous lesion of the left (injected) antrum. The right submaxillary nodes were negative. The left submaxillary and jugular nodes showed early tuberculosis. The lungs showed a number of small conglomerate tuberculous nodules with early caseation. The bronchial nodes showed very early tuberculosis. The spleen, liver and mesenteric nodes showed no tuberculosis.

RVI, killed at two months, showed slight carbon discoloration and well advanced tuberculous lesion of the right antrum. The right submaxillary nodes contained a moderate amount of carbon, and a few small early tubercles. The left submaxillary nodes were negative. The right and left jugular nodes showed traces of carbon, and some extremely early (not unquestionable) tubercles. The lungs contained a small amount of carbon, and numerous good-sized conglomerate tuberculous nodules with caseation. The bronchial nodes showed a moderate amount of carbon, and some very early tubercles. The abdominal viscera were negative.

RVII, killed at three months, showed a small amount of carbon in and over the right antrum, with caseous and nodular tuberculosis of the antral mucosa. The submaxillary and jugular nodes, lungs, and bronchial nodes, showed small amounts of carbon, but no tuberculosis. The spleen and mesenteric nodes were negative.

These findings show once more, both in the carbon discoloration and the development of early tubercles secondary to the primary focus in the antrum region, the immediate course of absorption from the antrum via the cervical nodes. But they also show a relation between the stage of development of the antrum and lung condition on the one hand, the cervical and bronchial node condition on the other hand, which is quite different from that observed in the first series. In the first series, in two separate cases, one of carbon, the other of tuberculosis, we had a conspicuous primary focus in the antrum, a less conspicuous condition in the cervical nodes, still less in the lungs, with the bronchial nodes following. In this series, especially in RVI, also in RVIII, we have not even approximately this relationship. The lesions of cervical, as of

Fig. 5.

Front view of head and neck of cat.
 R. A. S. Rt. ant. submaxillary node.
 L. A. S. Left ant. submaxillary node.
 R. P. S. Rt. post. submaxillary node.
 L. P. S. Left post. submaxillary node.
 R. I. J. Rt. internal jugular node.
 L. I. J. Left internal jugular node.

Note.—Semidiagrammatic as regards pigment in nodes.

Fig. 6.

Sagittal section of head of cat.

L. F. S. Left frontal sinus, with septum in place, opened to show interior. No ink.

R. F. S. Rt. frontal sinus, full of ink.