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Abstract: The birth of "heavier than air" aviation is related to the hang-gliding flights of the German Otto Lilienthal, beginning in the year 1891. This paper relates the biography of Otto Lilienthal until his death due to a plane crash in 1896. He contributed significantly to the first powered flight of the Wright brothers in 1903. Initially paraplegic after the plane crash on August 9th, 1896, Lilienthal was brought to a specialized medical clinic in Berlin where he died August 10th. So far, his death is believed to have been caused by a spinal fracture. This presentation of Otto Lilienthal´s clinical case documented by rare historical evidence makes it more likely that he died due to a contusion of his head and brain with resulting complications (e.g. epidural haematoma), as the other clinical findings were more likely survivable. Embedded in history, Lilienthal´s death remains the tragic starting point of flight testing.

Cover Letter

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Sarah A. Nunneley, M.D., M.S.
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Dear Sally,

with this letter I do want to lead your attention on the medical case of the First Flyer, Otto Lilientahl, who did crash in August 1896 and died the day after in a Berlin clinic. In literature his death is mentioned as connected to a spine fracture, which is not explaining his premortal clinical development. In cooperation with the neurosurgeon Sir Benny Bardrum, Col. RDAF M.C., FS and AAMIMO-colleague from 2002, we did prepare the following presentation, as the evidence for an epidural hematoma is evident. Petra Illig, AME from Akaska was not only envolved to make the paper closer to American English.

The paper is original and has not been published elsewhere, and is not currently under consideration by another journal.

There is no financial or other relationship that might be perceived as leading to a conflict of interest (i.e., affecting author objectivity).

The manuscript has been read and approved by all authors and that all named authors meet the criteria stated in Section 5 above.

I do suggest Stanley Mohler for the historical part of the review and a trauma surgeon for the medical case.

Best Regards,

Viktor Harsch, MD

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Otto Lilienthal´s (1848-1896) Medical Case: Was the First Aviation Fatality caused by an Epidural Hematoma?

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Abstract

The birth of "heavier than air" aviation is related to the hang-gliding flights of the German Otto Lilienthal, beginning in the year 1891. This paper relates the biography of Otto Lilienthal until his death due to a plane crash in 1896. He contributed significantly to the first powered flight of the Wright brothers in 1903. Initially paraplegic after the plane crash on August 9th, 1896, Lilienthal was brought to a specialized medical clinic in Berlin where he died August 10th. So far, his death is believed to have been caused by a spinal fracture. This presentation of Otto Lilienthal´s clinical case documented by rare historical evidence makes it more likely that he died due to a contusion of his head and brain with resulting complications (e.g. epidural haematoma), as the other clinical findings were more likely survivable. Embedded in history, Lilienthal´s death remains the tragic starting point of flight testing.

Biography

Lilienthal's reputation is primarily based on his successful gliding flights between 1891 and 1896, covering a distance of 25 m up to 250 m (80 feet up to 800 feet). Based on his scientific research, he introduced the aerodynamic concepts we still employ for wing construction today. His flight tests inspired the Wright brothers, who brought the airplane to operational status in the early 20th century **(6, 8)**.

Otto Lilienthal was born May 23rd, 1848, in Anklam, Pommeria. He went to grammar school from 1856 until 1864, where he was already busy studying the capability of bird flight. In 1870 he earned his technical degree at the Royal Technical Academy in Berlin **(8)**. A one year voluntary military service as a fusilier in the Franco-Prussian War during the siege of Paris 1870/71 interrupted his research on the possibility of flight **(3, 11)**. In 1873 the Lilienthal brothers became members of the Aeronautical Society of Great Britain. In 1886 he was one of the first flight technicians to become a member of the 1881 founded German Association for Promotion of Airship Navigation ("Deutscher Verein zur Foerderung der Luftschiffahrt") in Berlin. Otto Lilienthal held 23 patents out of which four were in the field of aviation (flying machines as U.S. Patent N° 544816, Flying machine, 1.2.1894/20.8.1895), and began systematic experiments on the physics of air on artificial wings in 1874. Four years later he married Agnes Fischer, the mother of his four children. In 1883, Lilienthal founded his own mechanical engineering company for boilers and steam machines in Berlin (**5**). His main interest remained, however, in researching the possibility of human flight. Afters of observations and experiments in the field of wing aerodynamics, he published his book “Bird Flight as a Basis of Aviation” in 1889 (“Der Vogelflug als Grundlage der Fliegekunst";

English translation by A. W. Isenthal in 1911) and started to construct manned flying machines **(5, 8**).

Otto Lilienthal used his so-called "Derwitzer glider", the world's first successful manned airplane, in the summer of 1891. Numerous flights followed within the next five years. His first glides took place at the windmill hill (Muehlenberg) close to Derwitz. Glides up to 25 meters were performed from an elevation of 5 to 6 m (**5**). While Lilienthal controlled his flight by shifting his body, he could escape from the glider in dangerous situations by releasing the glider and falling out, resulting only in minor injuries due to the low speed and altitude **(8)**.

More effective flights made it necessary to move to a more favorable landscape. While the Wright brothers profited from strong headwinds at the U.S. east coast, Lilienthal operated his gliders in the flat northern German landscape with mainly calm wind conditions. He tried some flights at the edge of a sand pit close to his home in Lichterfelde in 1892. One year later he started his glides from a platform at the "Fliegestation" (flight station) at "Maihoehe", which seemed to be less dangerous than at the sand pit (**Fig. 1)** (**3**).

Figure 1

In the small village Stoelln, west of Berlin, at an elevation of up to 60 m at the Rhinow hills, Lilienthal performed glide flights up to 250 m beginning in 1893 (**1**). Directional control was improved and turns up to 180° were performed at this location (**5**). In 1894, Otto Lilienthal constructed the 15m high so-called "Fliegeberg" (flight hill) which still exists in Berlin-

Lichterfelde. Flights up to 100 m were possible at this central location. Here Lilienthal could experiment with his gliders almost on a daily basis and requiring less travel, compared to the remote Rhinow hills (**3**).

In addition to flight experiments, Otto Lilienthal tried to make the idea of flight more popular by serial production of some of his models. In 1894, he started the production of his so-called "Normal Glider" (Normalapparat). This flying machine, which was protected by a US patent in August, 1895, had a wing span of 6.7 m and a wing surface area of 13.6 m^2. This flyer was built at least 10 times and copies were sold to the USA and many different European countries, such as France, Russia, and England (**5, 8**). A biplane-constructions followed in 1895 **(11) (Fig. 2)**. The same year he was visited by flight technicians from different countries, among them S. P. Langley, secretary of the Smithsonian Institution in Washington D.C., U.S.A. and N. J. Shukowski, an aerodynamics expert from Moscow, Russia. S. P. Langley later provided the Wright brothers information regarding Lilienthal's flight achievements (**3, 13**).

Figure 2

On August 9th, 1896, Lilienthal crashed after an unsuccessful attempt to steer a "Normal Glider" through a heat eddy. He crashed from an altitude of 15 meters and died the following day in a clinic in Berlin (**3)**.

World's first Heavier-than-Air Aviation Accident

The American Robert W. Wood made the last three photographs of Otto Lilienthal in flight on August 2nd, 1896, just one week before his fatal accident at the Gollenberg hill near Stoelln **(Fig. 2)**. Wood reported in the Boston Evening Post after the crash about his meeting with Otto Lilienthal. He met him in company of Lilienthal's fourteen-year-old son at the Lehrter train station in Berlin, and they travelled to the Rhinow hills. At this location, Wood witnessed a serious flight incident, which could have been a forerunner of the accident the following week. Wood reported: "It happened so quickly and I was so excited, at the moment that I did not quite grasp exactly what happened, but the apparatus tipped sideways as if a sudden gust had got under the left wing. For a moment I could see the top of the aeroplane, and then with a powerful throw of his legs he brought the machine once more on an even keel, and sailed away below me across the fields at the bottom, kicking at the tops of the haycocks as he passed over them. When within a foot of the ground he threw his legs forward, and notwithstanding its great velocity the machine stopped instantly, its front turning up allowing the wind to strike under the wings, and he dropped lightly to the earth. I ran after him and found him quite breathless from excitement and the exertion. He said: ´Did you see that? I thought for a moment it was all up with me. I tipped so, then so, and I threw out my legs thus and righted it. I have learned something new; I learn something new each time.´" (**10, 11**). Only one week later Otto Lilienthal was less fortunate and was severely injured in an aviation accident.

The only report of his fatal flight accident was delivered by Lilienthal's glider mechanic, Beylich, who witnessed his plane crash. While falling headwords from an altitude of about 15 m, Lilienthal tried to recover by shifting the center of gravity of the flying apparatus by moving his body to the back. The attempt to produce lift failed and Lilienthal hit the ground

seconds later **(7, 9, 11).** Volunteers assisted Beylich in bringing the severely injured flyer from Gollenberg with a horse carriage to the guest house of August Herms in Stoelln (**1**). A physician, Dr. Niendorf, was called to see the injured flyer at the Stoelln guesthouse at about 2 p.m. There the 48 year old athletic patient was placed on a metal cot. Lilienthal was already paralyzed from the abdomen on down. However, he was not complaining about serious pain and could move his hands with no limitations, indicating an injury of the mid thoracic spine and/or contusion of the thoracic medulla. The physician took care of him and attended Lilienthal's transport in a goods wagon from Neustad-Dosse to Berlin. During transport Lilienthal became unconscious and developed breathing difficulties. From the Lehrter station he was transported in a horse drawn ambulance to the clinic of the leading German neurosurgeon, Ernst von Bergemann (1836-1907), which today is the Charité Hospital on Ziegelstrasse. Otto Lilienthal died in this hospital the same day at about 5.30 p.m. (**7).** Fracture of the spine is mentioned in the clinic's registry as the cause of his death **(1, 4, 11).** The destroyed glider was brought to his factory on Koepenicker Strasse in Berlin. Two photographs are available to give us an impression of the force of the accident **(Fig. 3)**.

Fig. 3

To understand the medical case based upon rare historical documents, it is helpful first to analyze all known aspects of the aviation accident. The airworthy glider was basically crash-protected by a semicircular band made of willow twigs in the front, however this protection was not used in the crashed glider. As we can see in **Fig. 3**, the right wing of his glider was damaged. The rest of the glider seems to have no serious damage from the crash. This indicates that the main force on impact was absorbed partly by the wing-construction,

however resulting in a torque force onto the flyer contained within. During flight, Lilienthal hung vertically in the glider from his forearms. By moving his lower body in all four directions he could alter the pitch and bank by moving the center of gravity of the glider. This is how he changed the direction of the flight. If a dangerous situation emerged, he could easily escape by letting his body fall down to the ground through the hole in the aircraft from which he hung by his forearms. Due to the fact that the velocity and the altitude were low, he never had any severe damage to his body, but only minor injuries (**8**). On the day of the plane crash, Lilienthal wore a flannel shirt, a pair of knickerbockers, a cap, additional protection on the knees, and a pair of solid boots **(1)**. For that time, the pilot did wear adequate protective clothing; however, the fragile structure of the airframe could not support him at the time of the impact.

On impact, Otto Lilienthal´s arms were likely fixed in the sleeves in which he placed his forearms in the glider. Neither arm was broken, as he could move both of them freely on Dr. Niendorf's arrival. However, the severity of the impact left the flyer paraplegic, which indicates the severity of the crash to the pilots spine. Though a head-on collision was not described, Lilienthal became unconscious the following day. There is no mention whether Lilienthal initially complained of headache or numbness. No external injuries were noticed except some skin abrasions, but no localisation was mentioned either (**7**). The official documents indicate a spinal fracture as the cause of death (**4**). Oral history and some written document mention a cervical spine fracture (C3-fracture) as the cause of death, but all this remains doubtful **(1,7, 9).** It can be assumed that the diagnosis of spine fracture was made based upon the clinical findings and physical examination. Although the first x-ray exams in Berlin are documented to have occurred in early 1896, it remains doubtful that a radiological

examination was already introduced into clinical practise just a few months later. It is also not mentioned whether an autopsy was performed on him. **(1,3)**. It can therefore be assumed that the physical diagnosis of an unstable cervical spine injury was misleading as the real cause of death. Relying on the only official document of the "spinal fracture" as cause of death is not very convincing, and is therefore discussed in further detail.

Dr. Niendorf welcomed Lilienthal upon his arrival by shaking his hands, which rules out a severe or symptomatic fracture of the cervical spine at or below the C3 vertebral column, as free hand movements would not have been possible in case of a damage to the cervical medulla just below the level of C5. Likewise, there was no mention initially of breathing abnormalities, indicating that pathology of the cervical nerve segments were not present. However, another injury initially without symptoms which could later compress medullar or brain structures can not be excluded in Lilienthal's case. Otherwise it seems more likely that dyspnea would have been the leading symptom before becoming unconscious. Going back to the medical report, it is mentioned that Otto Lilienthal became somnolent and unconscious hours later during his transport to Berlin, and that his breathing became heavy or irregular. Starting with a Glasgow Coma Scale (GCS) of 15 upon the arrival of Dr. Niendorf, his conditioned worsened during transport the next day, reaching a level that would require urgent ICU treatment and neurosurgical intervention nowadays.

Impairment of the phrenic nerve (C3-5) affects diaphragmatic breathing. In this case the intercostal muscles would have been the only means for ventilation of the lung. Under these circumstances, the injury was not survivable in the 19th century, as active breathing would have been impaired. Additional quadriplegia would have been observed.

This implies that another mechanism of death is more likely: an increase in brain pressure from brain swelling or intracranial bleeding, which affects consciousness of the patient as well as breathing. Otto Lilienthal became somnolent during transport, had late-onset of breathing difficulties, became unconscious, and died several hours later.

Though he was paralyzed from the belly down, the spinal fracture was not the reason for Lilienthal's worsening condition. The alleged cervical spinal fracture is not likely to have caused his death.

The thesis of this paper is that cerebral edema or bleeding resulting from head trauma caused Lilienthal's death, while the spinal fracture was more likely survivable. However, it took another decade before flyers protected their head with a helmet during flight duties.

It seems that the rim of the hole of the glider in which Lilienthal hung is the cause of the injury to the lower thoracic spine, thereby affecting the thoracic medulla. If Lilienthal hung from forearms with the elbows flexed at 90 degrees, and the glider hit the ground in a forward and partly rotating (right wing damage) manner, his lower thoracic spine would have been hyperextended over the rim of the hole since the lower body would have been forced backward relative to the glider. This would have caused an injury to the thoracic spine at the T8-T10 level, giving rise to the symptoms described in the notes of Dr. Niendorf (paraplegia). Having said that, it is relatively easy to postulate that this slight rotational force at the time of impact caused Lilienthal's upper torso, including his head, to hit the frame of the glider off the centerline. This means that the side of the head could have struck the framework of the

glider, possibly on the temporal region. In this region the skull of the head is relatively thin. A relatively mild trauma to this region can cause a fracture of the skull, thereby creating an injury to the meningeal artery, causing an ipsilateral epidural hematoma. These do not necessarily show any sign of trauma to the skin of the head. The symptomatology described in this case is classic for this condition, starting with a trauma to the head not necessarily with an initial unconsciousness, but with a lucid interval of hours. Then either suddenly or more protractedly, the patient will get sleepier, resulting in unconsciousness. Respirations will become more labored, (blood pressure will increase dramatically) and eventually life will cease to exist. All this is due to the (slowly) expanding intracranial but extradural mass (blood).

These postulated injuries fit nicely with all the descriptions of the symptoms of Otto Lilienthal after his plane crash.

Final remarks

Although Albrecht Ludwig Berblinger failed in his attempt in 1811 to be the first man to fly, he can be regarded as one of the significant aviation pioneers who applied the "heavier than air" principle (**2**). Lilienthal perfected the glide flight, but failed in his efforts to apply motor power to his plane constructions. Although he constructed and experimented with several flying machines, among them a flapping wing machine driven by a CO_2 motor, the available 2 HP engine with a weight of 10 kg was to heavy for practical use (**3**). Lilienthal's engineer, Paul Schauer, constructed a 5 kg engine in spring 1896**.** Flight tests at Fliegeberg seemed to have been of some success. However, Lilienthal did nor experiment with propeller driven

gliders. If he would have attached the Schauer engine with a propeller to his glider, he probably would have been the first to achieve sustained, partly controlled, powered flight. Partly recovered original gliders can be found in museums of Moscow, London, Washington D.C., Munich and Wien (**8**).

In addition to these this museum, there are several unique opportunities to find out more about Otto Lilienthal's life and technical contributions to aviation. First of all, the Lilienthal-Museum in his birth town of Anklam, located just south of the island Usedom, with its Peenemuende historical technical information center and museum, is a 2.5 hour drive from Berlin (**11, 18)**. Another smaller museum is located at Gollenberg, close to the city Stoelln (**14).** The International Airport of Berlin-Tegel, connecting the old and new continent, is named after Otto Lilienthal. Also, a German Air Force Airbus A 310, used for Strategic Aeromedical Evacuation, is named after the German flight pioneer **(15)**. The German Society for Aviation and Space Travel Lilienthal-Oberth (DGLR) present its Lilienthal award for outstanding scientific contributions in the field of aviation engineering **(16).** Additionally, the Lilienthal Foundation supports scientific and industrial projects in the field of Aviation and Space travel (**17**).

Acknowledgements

Dr. Bernd Lukasch, Otto-Lilienthal-Museum in Anklam/Germany for his advice regarding the biography of Otto Lilienthal (**11**).

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Figure I: Otto Lilienthal at Derwitz in 1891. Photograph by Carl Kassner.

Courtesy of the Otto Lilienthal Museum Anklam, Mecklenburg-Vorpommern, Germany.

Picture No. OLM F0066LF

Figure II : Otto Lilienthal with his double decker at Gollenberg on August 2nd, 1896.

Photograph by Robert W. Wood. Courtesy of the Otto Lilienthal Museum Anklam,

Mecklenburg-Vorpommern, Germany. Picture No. F0651LF.

Figure III: Destroyed glider at Lilienthal's factory on Koepenicker Street in August 1896.

Photograph by A. Regis. Courtesy of the Otto Lilienthal Museum Anklam, Mecklenburg-

Vorpommern, Germany. Picture No. OLM F0012LF

Figures (separate file for each)

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