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MINI-SYMPOSIUM: TRIBUTE TO DR. JULIUS WOLFF

Biographical Sketch

Julius Wolff, 1836–1902

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Abstract This biographical sketch on Julius Wolff corresponds to a translation of the historic text, Zur Lehre von der Fracturenheilung, available at DOI 10.1007/s11999-010-1240-9; and a translation and abridgement of the historic text, Ueber die Innere Architectur der Knochen und ihre Bedeutung für die Frage vom Knochenwachstum, available at DOI 10.1007/s11999-010-1239-2. (Supplemental materials are available with the online version of CORR.) An accompanying Editorial is available at DOI 10.1007/s11999-010-1238-3.

Julius Wolff was born in March, 1836 in Märkisch Friedland in West Prussia (now Mirosławiec, Poland) [3]. He attended gymnasium in Berlin and then the University of Berlin. Wolff studied medicine at the Friedrich Wilhelm Universität, where he obtained a medical degree in 1860 and wrote his dissertation ("De Artificiali Ossium Productione in Animalibus") under Bernhard Langenbeck (who founded *Langenbecks Archiv für klinische Chirurgie*). He married Anna Weigert in 1869 and the couple had three children, one of whom tragically died at the age of 6 (personal communication, Dr. Georg Bergmann, The Julius Wolff Institute, Berlin as reported by Karola Nick for the Jewish Museum of Frankfurt, Germany). According to Nick there are available 168 private letters indicating his devotion to his family. He wrote poems for the children of his four siblings. According to his wife's reminiscences, he awoke every morning at 5 AM and worked on his research until about 8 AM. He was fond of classical music and literature [4].

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Wolff served with the Prussian campaign against Denmark in 1864, against Austria in 1866, and against France 1870/1871, and received the Iron Cross [5]. He completed his habilitation in 1868 and subsequently lectured at the University ("privatdocent") and opened a private practice and then his own institute: Privatinstitut für orthopädische Erkrankungen. He became professor extraordinaire in 1884. Orthopaedics at the time was beginning to separate as a discipline from surgery, and in 1889 Wilhelm Waldeyer-Hartz (1836–1921), dean of the Charité, petitioned the government to incorporate Wolff's Institute [4]. Various other faculty members (including the pathologist Rudolf Virchow, the surgeon Ernst von Bergmann, the internist Ernst von Leyden, and the pediatrician Eduard Enoch) who stood to benefit from Wolff's research were supportive and in 1890, his institute was combined with the Friedrich Wilhelm Universität as a provisional private clinic with him as director; his institute became the Poliklinik für orthopädische Chirurgie in 1894. In 1899 he received an appointment as Privy Medical Councilor (Geheime Medizinalrat—reflecting outstanding contributions to medicine) in the medical school. The Poliklinik was then fully integrated into Charité in 1902 with a thirty bed unit only a few months before he died, three days after suffering a stroke [4].

In the late 60s Wolff became aware of the work of von Meyer and Culmann in Zurich. Herman von Meyer, an anatomist at the University of Zurich, described the regularity of the architecture of cancellous bone from subject to subject in the same bone [6]. Evidently, Culmann, a professor of engineering at the Swiss Federal Polytechnic Institute, attended a lecture given von Meyer on this architecture and recognized a possible importance of that regularity. Culmann had developed a type of stress analysis, "Graphische Statik" which showed that the

Fig. 1 Portrait of Julius Wolff. (Courtesy of the Julius Wolff Institute, Berlin.)

"trajectories" of principle compressive and tensile stresses crossed at right angles. He recognized the trabeculae in von Meyer's specimens followed similar trajectories to those in solid structures (Culmann's example was a Fairbairn crane). von Meyer's paper [6] included that discussion. To pursue his research into the structure of bone, Wolff developed a technique to make thin sections ("Fournierblätter") of whole bones so he might carefully examine the trabecular patterns (this was decades before the discovery of xrays) [5]. This method was crucial to his observations because it allowed a more detailed sense of trabecular directions in various locations rather than simply on the surface of a single cut section. Wolff suggested von Meyer failed to recognize the trabeculae crossed at right angles and connected to the cortex at right angles, and thus did not realize they were formed along the lines of principle compressive and tensile stresses [9]. (Wolff conveniently ignored the fact that many trabeculae do not cross at right angles and usually do not connect to the inner cortex at right angles; scientists are prone to overlooking evidence contradictory to their theories.) He published his first two papers in 1870 and 1873 [7, 8], and it is those two papers we reproduce here in translation (with the original German texts, available with the online version of CORR.). These two articles became the basis for his opus magnum, *The Law of Bone Transformation* (*Das Gesetz der Transformation der Knochen*) published in 1892 [9]. (We are indeed fortunate that this entire volume was translated into English in 1986 by Maquet and Furlong [10].) In that work Wolff made three major observations: (1) trabecular architecture is regular in a given bone from individual to individual; (2) many trabeculae cross at right angles; (3) when a bone is fractured or deformed and the trabeculae would not be at right angles, they reorient over time so they are again at right angles [1]. The first of these three was not original with Wolff nor was the second (Wolff acknowledge Jeffries Wyman, in 1857, had recognized trabeculae crossed at right angles and even if von Meyer had not explicitly commented on the crossing at right angles, the connection with the principal tensile and compressive stresses was apparent and implied from the illustration of the stresses in a Fairbairn crane). The third observation was original with Wolff. He searched numerous museums and dissection rooms to find a wide array of pathological specimens to document the reorientation of trabeculae. This remodeling, in a sense, documented the active nature of bone adaptation, and according to a specific "law" which he termed a "mathematical law." Wolff, however, never defined that law in any mathematical sense, and perhaps the clearest statement of "Wolff's Law" came at the end of the short first chapter:

> "The law of bone remodeling is that mathematical law according to which observed alterations in the internal architecture and external form of bone occur as a consequence of the change in shape and/or stressing of bone." (Translation mine, not that of Maquet and Furlong [10].) ("Es ist demnach unter dem Gesetze der Transformation der Knochen dasjenige Gesetz zu verstehen, nach welchem im Gefolge primärer Abänderungen der Form Inanspruch-nahme, oder auch bloß der Inanspruchnahme der Knochen, bestimmte, nach mathematischen Regeln eintetrende Umwandlungen der innerer Architectur und ebenso bestimmte, denselben mathematischen Regeln folgenden secondäre Umwandlungen der äusseren Form der betreffenden Knochen sich vollziehen.")

Wolff briefly considered the tissue mechanisms by which remodeling might occur, and in particular that related to the active turnover of bone recognized by von Volkmann. He anticipated the role of cytokines and growth factors ("It is possible that some molecules from the debris of the product of inflammation are used to form the product of the remodeling process" [10]) and the role of what we now call the "regional acceleratory phenomena" described by Frost [2] ("The seat of the remodeling process is, besides the fracture site, everywhere in the fragments of the fractured bone and, in some circumstances, everywhere in the adjacent bones" [10]). Some of Wolff's deductions are all the more remarkable when one realizes his observations were made prior to the discovery of xrays and modern techniques of tissue and cell biology. However, Wolff overlooked the fact that the concept of tensile and compressive stresses applies to solid

structures while he was considering the overall organization of a nonsolid structure (trabeculae with intervening spaces). While he briefly discussed tissue changes, he ignored exploring the role of cells, a peculiar oversight given his acquaintance with Virchow.

However, Wolff essentially established the concept of bone adaptation occurring in response to mechanical stress. If the nascent ideas had existed in the literature prior to the two articles we reproduce here, Wolff unquestionably pursued them and made them (and ultimately his name) a part of today's orthopaedic lexicon.

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