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OBITUARY

Bengt Saltin 1935–2014

Professor Bengt Saltin was arguably one of the most influential human physiologists of his generation. Using physical exercise as an exposure variable, he spent more than five decades addressing health and disease in general and specifically in the skeletal and heart musculature from an integrative physiological perspective. An underlying objective was the understanding of how the human body functioned, and what were its limitations when exposed to extreme physical stress and detraining? His approaches to reach this ambitious goal ranged from basic (mechanistic) laboratory studies to clinical physiological studies and eventually to applied field studies.

Although largely identified with exercise physiology and sport science, Bengt Saltin was also interested in human variation and adaptability to different environmental settings, especially high altitude. Many of his field activities were of the genre commonly associated with studies of human adaptability following in the tradition exemplified in the classic volume edited by Paul T. Baker and J.S. Weiner, *The Biology of Human Adaptability* (1966), which was a primary resource for a generation of aspiring human biologists.

Bengt Saltin was born June 3, 1935 in the town of Ålsten close to the Swedish capital, Stockholm. During his school years, the young Saltin wanted to be a forester; however, his mother insisted that he study medicine. Many years into his career when he was an established and world-renowned professor, Bengt Saltin revealed that a lengthy hospitalisation due to a fractured leg during his youth motivated him to study hard for his secondary school exams. This was apparently successful as he qualified for medical school in Stockholm.

As a medical student at the Karolinska Institute (KI), Bengt Saltin became interested in work physiology, a research area with strong traditions in Scandinavia. His initial research in the exercise physiology laboratory began in 1959 and resulted in his first scientific publication in 1960 in *Acta Physiologica Scandinavica* (now *Acta Physiologica*). The paper addressed intermittent and continuous running (Christensen et al., 1960), and was co-authored by his mentor, Erik Hohwü-Christensen (1904–1996), a Dane who was a highly renowned physiologist and professor at the Stockholm University College of Physical Education and Sports (now the Swedish School of Sport and Health Sciences, GIH). Bengt Saltin graduated from medical school in 1962 and subsequently received a doctoral degree in 1964 with a thesis entitled ‘‘Aerobic work capacity and circulation at exercise in man’’. He was mentored by the excellent team of Professor Hohwü-Christensen and Dr. Per-Olof Åstrand.

Bengt Saltin’s doctoral research also included a field study of the aerobic fitness of northern Scandinavian reindeer herders, the nomadic Lapps (Sami) in 1960. The Sami had high aerobic capacity between 18 to 30 years, which subsequently declined over the next two decades. The results were published in 1961, but Saltin cited these observations throughout his career as an example of *culturally determined detraining* interacting with age (Andersen et al., 1961).

A subsequent clinical research opportunity further strengthened his interests in physical training and the detrimental effects of physical inactivity. Bengt Saltin and a colleague, C. Gunnar Blomqvist (1931–2011), were invited to the University of Texas, Southwestern Medical Center at Dallas in 1965 to participate in a National Institutes of Health project entitled ‘‘Response and Adaptation to Exercise’’. The two young Swedes participated in a sub-project, the ‘‘Dallas Bed Rest and Training Study’’, along with among others Jere H. Mitchell. After complete physiological evaluations (cardiovascular, pulmonary, and electrolyte and blood work), five healthy young men were exposed to three weeks of bed rest

and then to eight weeks of training, primarily running. As expected, cardiac output and aerobic capacity declined dramatically after the interval of bed rest, but the loss of function was completely recovered following the eight weeks of intensive training (Saltin et al., 1968; Snell et al., 2014), providing Bengt Saltin with another example of the detrimental effects of physical inactivity and the importance of regular activity in the restoration and maintenance of cardiovascular function. The functional capacity of this small sample was subsequently re-evaluated 30 years later showing that three weeks of bed rest in the same subjects at 20 years of age (1966) had greater impact on physical work capacity than three decades of aging (McGuire et al., 2001). The Dallas experience turned out to be a breakthrough for Saltin. He was invited to take up a faculty position in applied physiology at the KI.

Soon after returning to KI, Saltin and colleagues had the opportunity to research altitude physiology and exercise in Mexico as a consequence of the decision to award the 1968 Olympic Games to Mexico City, situated at 2,250 meters above sea level (Blomqvist et al., 1969). Related to the altitude environment, Bengt Saltin and colleagues did a detailed laboratory study on an elite athlete in 1967 – the distance runner Kipchoge Keino, who was born and reared in rural Kenya at an altitude similar to that of Mexico City. Keino had a remarkable maximal oxygen uptake ($82\,ml O_2\,min^{-1}\,kg^{-1}$) and went on to become an Olympic champion the following year in Mexico City (Saltin & Åstrand, 1967).

Although retaining his strong interest in applied physiological field studies, Saltin shifted to doing more research in a laboratory setting in the late 1960s and 1970s. His research specifically focused on skeletal muscle physiology and he used the biopsy needle technique (after Bergström) to study the biochemistry and morphology of skeletal muscle tissue. A significant person in this decision was Philip Gollnick (1934–91) of Washington State University, with whom Saltin would publish several important papers on skeletal muscle physiology (Gollnick & Saltin, 1982). In 1973, Professor Hohwü-Christensen convinced Bengt Saltin to accept a Professorship in human physiology at the August Krogh Institute of the University of Copenhagen in Denmark. This marked the beginning of almost 40 years in Copenhagen with few interruptions. Bengt Saltin's first 17 years at the August Krogh Institute were extremely productive. His group published 112 peer-reviewed papers dealing with the effects of exercise-training protocols and dietary substrates on skeletal muscle metabolism, muscle fibre types, specific skeletal muscle metabolic or hormonal diseases, and limitations of oxygen delivery to active muscle (Raven et al., 2014).

This productive interval was followed by a return to KI (1990–1993). During this brief interval and more than two decades after his first encounter with Kipchoge Keino, Saltin finally made it to Kenya in 1990 with a group of Swedish elite runners whom he would study and compare with an equivalent group of Kenyan runners in a makeshift laboratory in Eldoret, a town located in the western Kenyan highlands, the heartland of elite runners of mainly Kalenjin origin. The study was repeated in 1991 at the August Krogh Institute, this time using Danish elite runners as a control group. The driving question was the following: Was Kenyan running success due to a physiological advantage associated with a superior metabolism? The question was pursued in depth with a group of Scandinavian researchers. Results of skeletal muscle biopsies suggested only subtle differences when comparing Kenyans and Scandinavian runners. Kenyan runners, however, had a superior running economy, i.e. used less oxygen at a given sub-maximal running speed even in comparisons of Kenyan and Scandinavian runners having equal maximum oxygen uptake. To this day, these observations are the most convincing in explaining the success of the Kenyan runners (Saltin et al., 1995a,b)

After this brief stint at KI, Bengt Saltin returned to Copenhagen as director of the Copenhagen Muscle Research Centre (CMRC) that was funded by the Danish National Research Foundation (DNRF) for a 10-year period (1994–2003). The objective of the centre was to investigate the function, regulation, adaptation and pathology of skeletal muscle. Saltin's by now legendary enthusiasm, indefatigability and leadership were fundamental in creating an environment of unique entrepreneurship of young and established scientists alike. At its height, the CMRC was second to none in productivity; during the 1994–2003 interval funded by the DNRF, 514 peer-reviewed papers along with 143 book chapters and symposia proceedings were published by those working in the laboratory. In addition, 42 PhD theses were written and successfully defended (Raven et al., 2014).

During its 20 years of existence, and especially while Bengt Saltin was director, the CMRC was one of the most influential human biology laboratories in the world, perhaps surpassing the famous Harvard Fatigue Laboratory (1927–1947). During the height of the CMRC years, field expeditions were planned and carried out in Bolivia and Greenland. The former compared Danish lowlanders with native highland Aymara at a field station at 5200 meters in the Andes. One of many questions that were addressed was the so-called ''lactate paradox'' which was refuted (van Hall, 2009; Zacho et al., 1999). The latter used Greenland Inuit as a model of habitual upper body work associated with kayak rowing and the tanning of seal skin in the context of the influence of long term physical activity exposure on fat oxidation among other functions. Danish subjects were used as controls with and without long term exposure to upper body physical activity. Overall, physical activity did not influence fat oxidation in the Danes so that the marked differences expressed as the respiratory exchange ratio were thought to be due to differences in diet intake (Saltin, 2013). His interests also extended to animals under different environmental and stress conditions including horses (Asheim et al., 1970), dogs (Costin et al., 1971) as well as racing camels (Saltin & Rose, 1994), and in turn expanding his understanding of integrative physiology of mammals in general.

Bengt Saltin's contributions have been recognised by both the scientific and non-scientific communities. He became a member of the Royal Danish Academy of Sciences in 1984. Among many awards, Saltin was the recipient of the highly prestigious Novo Nordisk Prize (1999), the Marie and August Krogh Award from the Danish Medical Society (2001), and the International Olympic Committee Prize in Sports

Sciences (2002). He was the recipient of Honorary Degrees (doctor honoris causa) from 12 universities in Europe and North America. Other honours included the 1st degree Royal Danish Order of Chivalry (1995) and the King Carl XVI Gustaf Gold Medal (2002). He was also a founding member and the first president of the European College of Sports Science (ECSS), 1995–1997. More recently, he was a member of the World Anti-Doping Agency's (WADA) Health Medical and Research Committee, 1999–2004.

Among the public, Bengt Saltin became known as the ''doping hunter'' given his efforts in the fight against doping abuse in athletes. His involvement was based on medical rather than moral grounds, as he was concerned about the health of the athletes. At the 2006 Winter Olympic Games (Turin), where he served as Chairman of the Medical Committee of the International Ski Federation, Saltin received death threats from angry fans when he introduced a temporary ban of athletes on site until their blood haematocrit values were back to normal. Along the same line, he engaged in heated discussions in the written and electronic media with Norwegian skiers and sports officials in 2013 when he pointed out that the great Nordic skiers of the 1990s had had abnormal blood values and, by inference, must have been using blood doping to enhance their performances. At the same time, Saltin was generous in sharing his knowledge and insights on public health and physical activity with laymen. He knew the importance of sharing his knowledge as a civil servant.

To his colleagues, Bengt Saltin was highly respected and admired. Although a giant within his field of science, he remained friendly, welcoming and modest. He encouraged his students to read novels and books not related to their work in order to increase their creativity and to think ''outside the box''. He too was a great literature lover and also enjoyed classical music and the theatre. At the same time, he was very humble about his own role and aware of the fact that he was ''standing on the shoulders of giants'', especially the pioneers in the nexus of physical education and medicine such as August Krogh (1874–1949) and Johannes Lindhard (1870–1947).

In remarks at one of his last public appearances at the ECSS in Barcelona in 2013, Saltin first quoted August Krogh: ''There is no value in publishing a finding, which is in conflict with present thinking; the value comes with finding an explanation for the difference'', and then his mentor Erik Hohwü-Christensen: ''When you write an article or present your data at a meeting, you should refer to other researchers' work as you yourself want your own research to be quoted and discussed''. These remarks highlight the value Bengt Saltin placed on a serious and ambitious scientific environment that was the foundation of his scientific legacy. We are privileged and grateful to have worked with (DLC) and known (RMM) Bengt Saltin over several decades. He will remain a giant on whose shoulders we will be standing.

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