CHAPTER 1

SKELETAL MUSCLE PLASTICITY – HISTORY, FACTS
AND CONCEPTS

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1. INTRODUCTION

In 1873, Louis Ranvier characterized “white” and “red” muscles of the rabbit and ray as “tetanic-fast” and “tonic-slow”, respectively (Ranvier, 1873). More recently, functional specialization of muscles and muscle fibers has become a major topic of interest. The muscular system is unique in its architectural design and complexity. As such, each skeletal muscle within an organism is distinct and even homologous muscles in different species and strains have been shown to differ. Contributing to this diversity is the design of muscle as a composite tissue with a large variety of fiber phenotypes distributed in varying proportions in each muscle. The phenotypic properties of muscle fibers are determined by endogenous, species-specific programs which can be modulated by a variety of exogenous influences, making muscle a highly adaptive tissue. This adaptive potential marked an important evolutionary achievement because it improves survival under altered environmental conditions.

The change in paradigm from functionally distinct muscles and fiber types that are essentially static structures to that of an ever-changing, dynamic model has taken a long time since Ranvier’s characterization of two functionally distinct types of muscle in rabbit and ray (Ranvier, 1873). The initial concept of a few distinct fiber types which emerged from studies combining histochemical with physiological methods, has been increasingly modified by more refined analytical methods, such as immunohistochemistry, microbiochemistry, and molecular biology. Thus, the categorization of fiber types has given way to the notion that terminally differentiated, postmitotic muscle fibers are versatile entities. In this regard, the nerve cross-union experiment performed over four decades ago by Buller, Eccles and Eccles (1960) has become a landmark study for its demonstration of muscle
plasticity. They showed that the acutely denervated slow-twitch soleus muscle of the cat turned faster when it was reinnervated by nerve fibers normally supplying the fast-twitch flexor digitorum longus (FDL) muscle. Conversely, the fast FDL muscle converted into a slower contracting muscle after being reinnervated with the nerve normally supplying the slow soleus muscle. These findings brought to light the phenotypic influence innervation exerts on muscle, and more importantly, demonstrated the functional malleability of fully differentiated mammalian skeletal muscles. The moulding influence of innervation on developing and adult vertebrate muscles was a discovery with an impact similar to the discovery of the specific effects hormones and growth factors exert on cell and tissue differentiation. Since the landmark study of Buller, Eccles and Eccles (1960), numerous studies have increased our understanding of the cellular and molecular mechanisms underlying the processes of myogenesis, muscle fiber differentiation, specialization, and transformation. Although skeletal muscle is a dynamic tissue, the classification of muscle fiber types has played an important role in most of these studies. The development of different types of muscle fibers and their modulation are tightly connected to the evolution of the concept of muscle plasticity and will, therefore, be dealt with in the following paragraphs.

1.1 Muscle Fiber Types

Early attempts at classifying specific fiber types were based solely on light microscopic morphology (Grützner, 1883; Knoll, 1891; Krüger, 1952). A breakthrough, however, came with the introduction of enzyme histochemical methods (Padykula and Herman, 1955; Ogata, 1958a; 1958b; 1958c; Dubowitz and Pearse, 1960; Engel, 1962). Several approaches combining histochemical, biochemical, and physiological methods ultimately led to the delineation of functionally and metabolically distinct fiber types (Guth and Samaha, 1969; Brooke and Kaiser, 1970; Barnard et al., 1971; Burke et al., 1971; Peter et al., 1972; Close, 1972). Based on enzyme histochemistry, two major classifications schemes evolved. One is entirely based on myofibrillar adenosine triphosphatase (mATPase) histochemistry and separates fibers into slow type I and fast type II, including subtypes IIA, IIDX, and IIB (Guth and Samaha, 1969; Brooke and Kaiser, 1970). According to microbiochemical and immunohistochemical analyses, the mATPase profiles of these fiber types correspond to specific myosin isoforms (Staron and Pette, 1986; Pette and Staron, 1990; Gorza, 1990; Häääläinen and Pette, 1993). The other classification scheme distinguishes between fast-twitch glycolytic (FG), fast-twitch oxidative-glycolytic (FOG), and slow-twitch oxidative (SO) fibers by combining mATPase histochemistry with histochemical assays for enzyme activities specific to aerobic and anaerobic energy metabolism (Barnard et al., 1971).

Although both methods are still in use, their resolution is relatively low in comparison to immunohistochemistry, single fiber biochemistry, and the latest methodological achievements such as real-time RT-PCR and microarray techniques.