INTRODUCTION: The composition and organization of cartilaginous tissue determine its mechanical properties, which in turn dictate its physiological function. It has been hypothesized that the inhomogeneous zonal architecture of articular cartilage is optimized for its load bearing capabilities. An understanding of articular cartilage structure-function relations is therefore important to better elucidate both disease processes and its regeneration through engineering therapies. The objective of this study is to test the hypothesis that the superficial tangential zone plays a critical role in determining the dynamic properties of articular cartilage.

METHODS: Osteochondral cores (∅6mm) were harvested from the medial and lateral trochlear ridges of the femoropatellar groove of six 4-month-old porcine knee joints within 3h of sacrifice for mechanical testing, biochemical and histological analysis. On each respective day of testing the samples were transferred to a confined compression chamber and attached to a standard materials testing machine with a 20N pancake load cell (Zwick Roell 2005; Germany). A preload of 0.05N was applied to ensure contact between the articular surface and the porous indenter (30µm porosity). Cores were kept hydrated through immersion in a PBS bath at room temperature. Static compressive strains were applied in sequential increments of 10% to a maximum of 30% over 500 seconds and the equilibrium stress was recorded after each relaxation period of 1800 seconds. A 1% amplitude sinusoidal strain was superimposed after each static strain increment at a frequency of 1Hz. The aggregate modulus and dynamic modulus were determined at each strain level. After a relaxation period the superficial/middle region (S/M) of the modulus and dynamic modulus was determined at each strain level.

RESULTS: The aggregate moduli of the osteochondral cores (Fig. 1A) significantly increased (p<0.05) at all strain levels after removal of the superficial tangential zone/middle zone (STZ+M) from 0.76 ± 0.05, 0.8 ± 0.04, 0.81 ± 0.04 to 1.09 ± 0.1, 1.03 ± 0.05, 0.99 ± 0.07 at 10%, 20% and 30% strain respectively. In contrast, the dynamic modulus (Fig. 1A) significantly decreased (p<0.05) at 10%, 20% and 30% strain respectively. In confined compression, characterized by one dimensional motion, fluid movements in cartilage are governed by the hydraulic permeability of the solid matrix. As the permeability of articular cartilage is low, large fluid pressures are generated within the tissue during loading, which in turn determine the dynamic properties of the tissue. Safranin O staining and biochemical analysis revealed a significant increase in sGAG content with depth, with no significant difference in hydroxyproline content with depth. Biochemical analysis (Fig. 2) revealed a complex spatial distribution of collagen through the depth of the tissue, with the superficial and deep regions staining intensely for collagen and more moderate staining in the middle zone.

DISCUSSION: In confined compression, characterized by one dimensional motion, fluid movements in cartilage are governed by the hydraulic permeability of the solid matrix. As the permeability of articular cartilage is low, large fluid pressures are generated within the tissue during loading, which in turn determine the dynamic properties of the tissue. Safranin O staining and biochemical analysis revealed a significant increase (p<0.003) in sGAG content with depth from the articular surface. This correlated with a significant increase in the aggregate modulus (Hₐ) of the tissue upon removal of the STZ+M zone which is in agreement with the literature. However, while removal of the STZ+M leads to an increased compressive modulus of the remaining tissue, a significant reduction in the dynamic modulus is also observed. One explanation for this reduction may be that the superficial tangential zone acts as a low permeability barrier to fluid flow. This suggestion is supported by the finding that the ratio of peak stress to equilibrium stress for intact tissues is larger compared to those with their STZ+M removed, suggesting increased pressurization in intact osteochondral cores resulting from the low permeability of the tissues STZ.

SIGNIFICANCE: A biomechanical failure of the collagen network in the superficial tangential zone of articular cartilage is postulated by many to play a key role in the development of osteoarthritis with advancing age. In this study we demonstrated that although this layer is less stiff than the remainder of the tissue, it plays a key role in determining the dynamic material properties of the tissue.