COULD MECHANICALLY INDUCED OSTEOCYTE SIGNALLING REGULATE RESORPTION AND FORMATION IN CORTICAL BONE REMODELING?

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INTRODUCTION
Trabecular and compact bone are continuously remodeled by bone resorbing osteoclasts and bone forming osteoblasts, combined in Basic Multicellular Units (BMU). Remodeling of cortical bone involves osteoclastic excavation of circular tunnels (cutting cone) and osteoblastic filling with new bone (closing cone). The resulting new bone structure is called osteon. Most osteons run parallel to the principal loading direction, indicating that effects of mechanical loads might regulate BMU behavior. It is not unlikely that such a process relies on osteocytes in the bone matrix serving as mechanosensors, with the osteocytic canalicular network for mechano-transduction of signals to the BMU’s (Burger, 1999). Smit & Burger (2000) showed, using an FEA model of the cutting cone, that strains at the cone’s end are reduced, while those around the closing cone are increased, relative to those away from the cone. This might provide the link between mechanics and remodeling.

We tested this hypothesis, using a computer-simulation model that earlier related trabecular morphogenesis and remodeling to mechanical load transfer (Huiskes, 2000; Ruimerman, 2001). Our basic assumptions are (a) that subnormal osteocyte signaling (due to micro-cracks or mechanical disuse) stimulates osteoclastic resorption and that (b) superno rmal osteocyte signaling, from increased bone strains, stimulates osteoblastic formation.

METHODS
The initial configuration consists of a small piece of compact bone with an initial cutting cone (200 µm in width) that is aligned with the external loading direction (Fig. 1A,B). Osteocytes are positioned in the tissue at a density of 1250 mm⁻². Depending on the local strain-energy density experienced, they send a stimulus signal to the internal cone surface. Where the total stimulus received exceeds a threshold level, osteoblasts are recruited to form bone. Osteoclasts positioned in the cutting cone continuously resorb bone in the direction of the lowest stimulus.

RESULTS
The osteocytic sensation in response to mechanical loading (Fig. 1C) was found to be consistently low at the tip of the cutting cone. Hence the osteoclasts continued to resorb bone in that direction, in line with the original orientation. The osteocytic sensation was high at the tunnel wall. In response osteoblastic bone formation was initiated and progressed to close the cone. In the course of time, the cutting cone progressed through the bone, forming an osteon aligned with the external load orientation (Fig. 1D).

DISCUSSION
The results explain a cellular level, mechanically driven regulation process to be capable of directing osteoclast resorption in the mechanical loading orientation of the bone. It explains that osteoblast formation closely follows the cutting cone. How the process starts or ends remains unanswered. These results unify a theory for cortical (Smit & Burger, 2000) with one for trabecular remodeling (Huiskes, 2000).

REFERENCES