SECTION IV

LETTER TO THE EDITOR

Electrical Osteogenesis: An Analysis

Dear Sir:

Many investigators have studied the growth promoting effects of electric currents on osseous systems from 10^{-13} to 10^{-4} amperes (a).[1–3, 5–17, 20, 21, 23–26] In this communication we wish to discuss the experimental conditions which are associated with an osteogenic response (OR) in this interval, and the mechanisms involved therein.

Table 1 lists an extensive series of studies which describe attempts to produce an OR at the site of implanted electrodes. Where possible, the applied voltage and currents, and the total energy dissipated, are given. The reports have been grouped roughly in order of increasing energy dissipated.

The data in Table 1 show that an OR has been observed at currents of 0.2 $\mu\mu$a and 5,000 $\mu\mu$a, and at currents of 3–20 μa. On the other hand, currents of 0.7–4 μa have produced no OR, and currents above 50 μa have produced necrosis. The data therefore suggest that different mechanisms produced the ORs in the low and high current range.

In the high range, currents of about 3–20 μa, when applied sufficiently long that the total energy dissipated was greater than about 7 joules, generally elicited an OR. Currents of 0.7–4 μa and less than 7 joules, generally failed to produce an OR, while currents above 50 μa (for 10–14 days) produced necrosis. The assignment of upper and lower limits of current and energy (in the high range) which can elicit an OR is admittedly crude, but appears to have certain advantages. It clearly categorizes the major reports dealing with ORs, regardless of type, technique of observation, or electrode material.

Electrical osteogenesis in the high range exhibits a threshold, an efficacious region, and blends directly into necrosis. The entire spectrum occurs within a current interval of less than 50 μa. We therefore suggest that injury or tissue irritation resulting from the electrical current is the underlying physical mechanism.

The existence of an OR in bone subject to chronic or acute injury is well known.[22] A variety of nonspecific stimuli (mechanical, thermal, chemical) are transduced by the animal into a biological signal which initiates cellular proliferation and bone production. It appears that the most parsimonious explanation of the OR in the 3–20 μa interval is that the applied current is simply another form of nonspecific stimuli capable of eliciting an OR. The stimulus may be electrolysis[4, 18] of tissue fluids, although there is some contrary evidence.[17]

The OR observed in the low range[3, 10] cannot reasonably be attributed to injury from electrical current, and may be a direct cellular effect such as that postulated to arise from the piezoelectric currents of bone.[19]

Sincerely yours,

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TABLE 1. Reported Attempts to Produce Electrical Osteogenesis at Implanted Electrodes in Mammals. Occurrence (non-occurence) of an Osteogenic Response is Indicated by a Plus (minus) Sign.

Ref.	*Animal*	*Bone*	*Time (days)*	*Voltage (volts)*	*Current (μa)*	*Energy (joules)*	*Response*	*Electrode Material*
10	Rabbit	Femur	14	—	0.0000002	—	(+)	Teflon
3	Rat	Humerus	3–28	—	0.005	—	(+)	Ag, Pt
2	Dog	Femur	14–21	0.35	0.7	0.3– 0.4	(−)	Pt
8	Rabbit	Femur	10	—	1.0	—	(−)	Stainless
6	Mice	Femur	14	1.35	3*	4.9	(−)	Stainless
11	Rabbit	Femur	21	1.3	3	7.1	(−)	Pt
14	Rabbit	Tibia	21	—	0.2–4.0**	—	(−)	Stainless
1	Rabbit	Radius	10–14	—	4–6	—	(−)	Pt, Au
2	Dog	Femur	14–21	1.4	2–3	4.2– 6.3	(+)	Pt
21	Dog	Femur	21	1.4	3	7.6	(+)	Pt
20	Rabbit	Femur	21	1.4	3*	7.6	(+)	Pt
26	Dog	Ear	56	1.4	2.5	16.9	(+)	—
15	Rabbit	Femur	45–195	0.150	8.5**	4.9–21.5	(+)	Pt
23	Rabbit	Humerus	21	0.5**	25.0**	22.7	(+)	Pt
17	Human	Tibia	125	0.55	3.9	23	(+)	Pt
9	Rabbit	Fibula	18	—	10	—	(+)	Stainless
24	Sheep	Various	42	—	10	—	(+)	Pt
14	Rabbit	Tibia	21	—	10–20**	—	(+)	Stainless
8	Rabbit	Femur	10	—	5–20	—	(+)	Stainless
1	Rabbit	Radius	10–14	—	15–20	—	(+)	Pt, Au
25	Rabbit	Tibia	31–77	—	5	—	(+)	—
16	Rabbit	Tibia	21–42	—	2.5–40	—	(+)	Pt
12	Rabbit	Femur	21	2.8	—	—	(+)	Pt
5	Human	Various	84	—	10–20	—	(+)	Stainless
13	Rabbit	Calvarium	21	—	10–50	—	(+)	Pt
7	Human	Spine	35–112	—	20	—	(+)	Ti
1	Rabbit	Radius	10–14	—	> 100	—	Necrosis	Pt, Au
8	Rabbit	Femur	10	—	50–100	—	Necrosis	Stainless

* Estimated, based on ref. 3.
** Average.

and

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