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Zinc Versus Magnesium as Biodegradable Metals for Temporary Implants

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Opening Remarks

Extensive research efforts are ongoing to develop materials that can be used as temporary implants in the human body to perform multiple functions depending on the nature of ailment. Among the metals, zinc and magnesium based materials have garnered significant attention in recent years to serve as temporary implants. This article aims to provide a snapshot of their merits and demerits and accordingly the challenges faced by material scientists.

Driving force for Temporary Implants

There are broadly two types of implants that are used in body: permanent implants and temporary implants. Permanent implants refer to implants that are intended to stay in the body for the lifetime such as the one used for hip and knee replacement and for artificial tooth and its fixation. Then there are temporary implants which are not required in the body after a certain period of time when the injury is healed. This is applicable for orthopaedic fixation purposes (plates and screws) and in cardiovascular (stents) application. The use of temporary implants helps in:

- Avoiding revision surgery for the patient.
- Minimizing medical cost for patient.
- Minimizing patient trauma inflicted during second surgery.
- Saves doctor's time.
- Avoid long-term toxicity effects if a permanent implant material is used instead.

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Commonly used implant materials used in past as both temporary and permanent implant applications are:[1]

- Titanium based materials.
- Steels.
- Co-Cr based alloys.
- Tantalum.
- Nitinol.[2]

In view of disadvantages associated with using permanent implants for temporary functionality required by human body, extensive research is being carried out to develop magnesium and zinc based materials in recent years. To note that for a material to serve as temporary implant it must ensure the following:[1-3]

- Biocompatible with acceptable or zero cytotoxicity.
- No chronic deleterious effect.
- To maintain mechanical integrity during healing time.
- Minimal stress shielding effect.
- Acceptable degradation time synchronized closely with healing time.
- Body should be able to metabolize or excrete corrosion products arising from temporary implants.

Biological Role of Zinc and Magnesium in Human Body

Both zinc and magnesium are nutritionally essential elements for human body and hence non-toxic. Human body is capable to metabolize them and excrete the excess of them, if need to be. Some of the significant roles that these two elements play in the human body are summarized in Table 1 and are instrumental for researchers to use them for making temporary implants. To note that daily requirement of zinc and its serum concentration in human body is an order of magnitude lower when compared magnesium. Moreover, excess amount of magnesium does not affect bone development as against zinc. This suggests that body exhibits more tolerance to magnesium than for excess zinc in physiological environment.

Table 1: Importance of Zinc and Magnesium to human body

	Zinc[1]	**Magnesium[2, 3]**
Function in Human Body	1. Stimulates beneficial osteogenesis in bone. 2. A component of 300 enzymes. 3. A component of almost 1200 proteins. 4. Required for optimal nucleic acid and protein metabolism. 5. Required for cell growth, division and function. 6. Mostly resides in skeletal muscle and bone (86%). 7. Assists in physiological systems including immune, sexual and neurosensory. 8. Daily requirement: ~15 mg/day. 9. Serum concentration: 0.012-0.017 $mmolL^{-1}$.[4] 10. At high concentration hinders bone development and damage vital organs.[1, 4]	1. Promote the growth of new bone tissues. 2. Assists in synthesis of proteins. 3. Activates a variety of enzymes. 4. Regulates the activities of neuromu -scularand central nervous system. 5. Involved in more than 300 chemical reactions in the body. 6. Assist in good cardiovascular health. 7. Mostly stored in bones. 8. Daily requirement varies from 250-400 mg/day. 9. Serum concentration: 0.73-1.06 $mmolL^{-1}$.[4] 10. At high concentration does not affect bone development.[4]

Physical, Mechanical and Corrosion Compatibility of Magnesium and Zinc in Human Body

To serve the function properly, it is important that the materials that are considered for temporary implants such as in orthopaedic fixation must have similar physical properties, superior mechanical properties to an extent when compared to bone and desirable rate of degradation. Some of these compatibilities and mismatches are summarized in Table 2.

Table 2: Properties comparison of magnesium and zinc based materials.[1-4]

Property	Magnesium	Zinc	Cortical Bone	Remarks
Melting Point	650°C	420°C	NA	Energy consumption in processing zinc and zinc -based materials is lower when compared to magnesium.
Density	1.74 g/cc	7.13 g/cc	~ 1.7 g/cc (a function of age, sex and location)	Magnesium is closer to cortical bone and zinc implants will be compara -tively very heavy.
Elastic Modulus	41-45 GPa	94-110 GPa	10-30 GPa	Magnesium based mate -rials will besuperior to avoid stress shielding and implant loosening when compared to zinc.
Tensile Properties Range[4]	σ_{YS} = 149-293 MPa UTS = 199-350 MPa (Extruded form)	σ_{YS} = 126-389 MPa UTS = 167-520 MPa (Extruded form)	σ_{YS} = 104.9-114.3 MPa UTS = 35-283 MPa	Alloys of both zinc and magnesium are equally compatible.
Compressive Properties Range[4]	CYS: 90-258 MPa (Extruded form)	CYS = 99-457 MPa (Extruded form)	UCS = 167 MPa	Alloys of both zinc and magnesium are equally compatible.
Corrosion rate (mm/year)[4]	In vitro: 0.45-12.56 In vivo: 0.36-1.58	In vitro: 0.16-1.66 In vivo: 0.13-0.26	NA	Zinc based materials exhibit marginal advantage *in-vivo*.

In view of the properties described in Table 2, it is evident that both magnesium based materials and zinc based materials have their own merits and demerits and at this stage it is difficult to differentiate between the two. Focussed application-based in-vivo studies are required to see their response in dynamic in-vivo conditions.

Concluding Remarks

Both magnesium and zinc based alloys are mechanically compatible from strength perspective for load bearing application with magnesium exhibiting advantage from density and stress shielding perspectives (closer density and elastic modulus to that of cortical bone). Both zinc and magnesium based alloys provided they are judiciously designed and free of toxic elements are biocompatible and biodegradable. From degradation perspective, zinc has advantage while from body tolerance perspective magnesium has advantage as its daily requirement by human body is significantly higher than that of zinc. Having said this, their relative advantage as temporary implant will largely depend on their systemic effect under dynamic *in-vivo* conditions for which further work is still required.

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