Sharing Session

Université Laval, Canada and Biomaterials

Hendra Hermawan

Assistant Professor, Department of Mining, Metallurgical and Materials Engineering
Université Laval, Canada
hendra.hermawan@gmn.ulaval.ca

Outline

Part 1: Université Laval

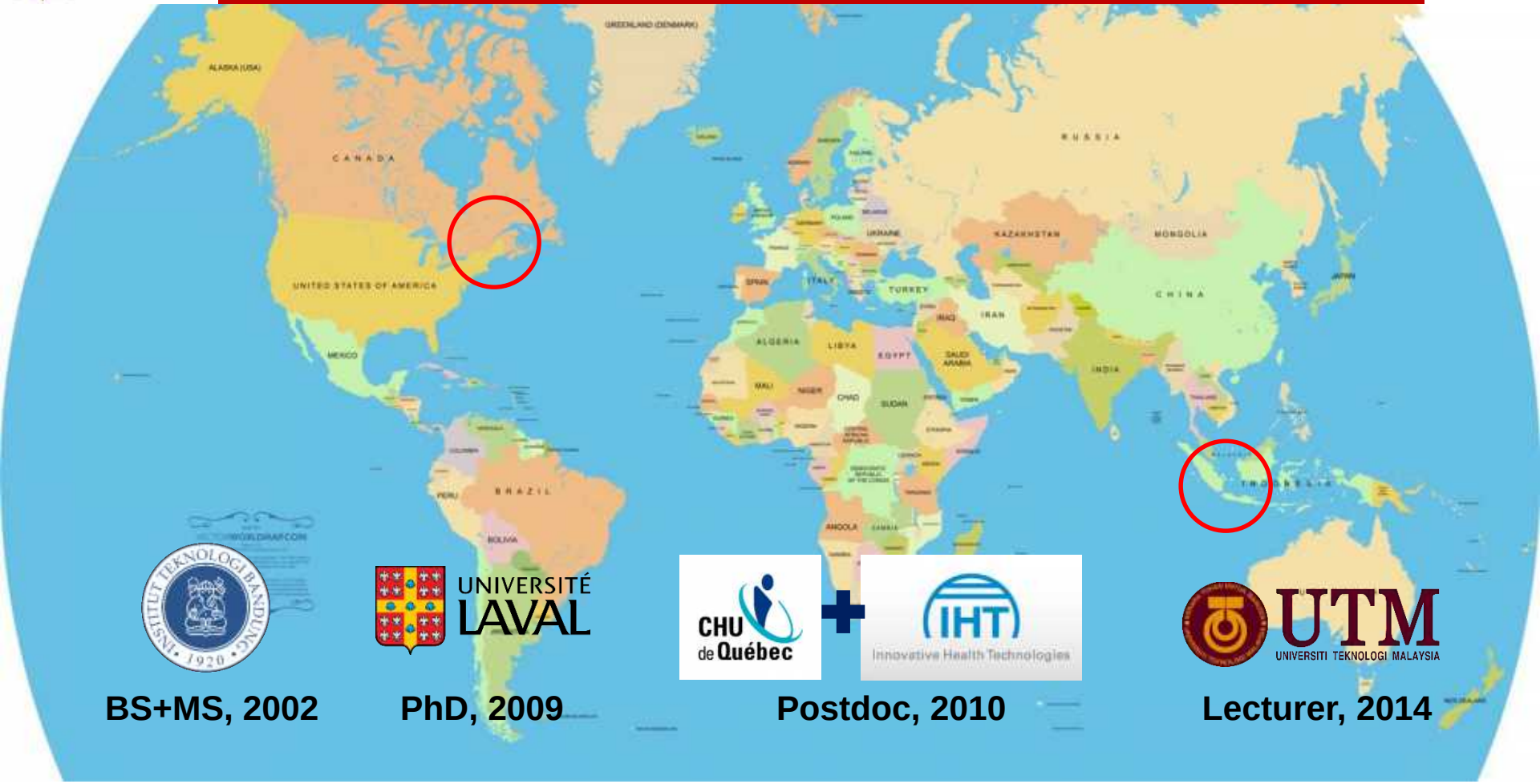
- ❑ Me, past and present
- ❑ UL, Quebec City and Canada
- ❑ Research activities and its management
- ❑ UL and UTM
- ❑ Academic challenges in Canada

Part 2: Biomaterials*

- ❑ Metallic biomaterials
- ❑ Biodegradable metals

***To facilitate a fruitful discussion**, please read a brief introduction to metallic biomaterials:
http://iomm.org.my/materials-mind/scientific-article-3-introduction-to-metals-for-medical-devices

My trajectory



BS+MS, 2002 — **PhD, 2009** — **Postdoc, 2010** — **Lecturer, 2014**

Engineering Council

Chartered Engineer
2013

NACE INTERNATIONAL

Cathodic Protection
2013

GAMRY INSTRUMENTS + Materials Research Company

Electrochemical Impedance Spectroscopy
2016

Previously with UTM

UNIVERSITÉ LAVAL

UTM

MyUTM | Feedback & Support | Map and Location | Main Campus : Johor Bahru | Kuala Lumpur Campus | Contact

Hendra Hermawan, Ph.D., C.Eng.

(octobre 2010 – juillet 2014)

Profile
Resume

Research
Team
Collaborators

Teaching
Courses
Guest lectures

Publication
Books and book chapters
Journal papers
Conference proceeding

Research team

About me

Recent Posts

New accepted paper in J Orthopedic Translation

New accepted paper in MSE-C

New accepted paper in JBMR-B

Convocation day

new accepted paper in JBMR-B

Research interest:

- Novel biodegradable materials
- Electrochemical degradation studies
- In vitro cell-material interactions
- In vivo degradation monitoring

Citation metrics*

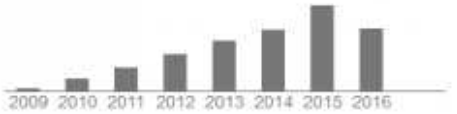
1

Hendra Hermawan

Assistant Professor, Laval University
Biomaterials, corrosion, biodegradable metals
Verified email at ulaval.ca - Homepage
My profile is public

Google Scholar

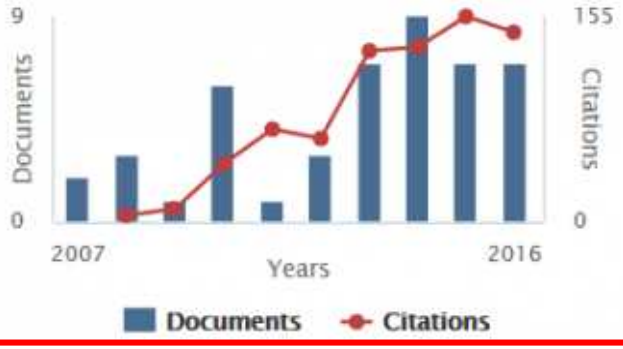
Citation indices	All	Since 2011
Citations	1130	1060
h-index	15	15
i10-index	16	16



2

Hermawan, Hendra
Universite Laval, CHU de Quebec Research Center, Quebec, Canada
Author ID: 56500756700

Documents: 46
Citations: 751 total citations by 474 documents
h-index: 12
Co-authors: 56
Subject area: Engineering , Materials Science View More

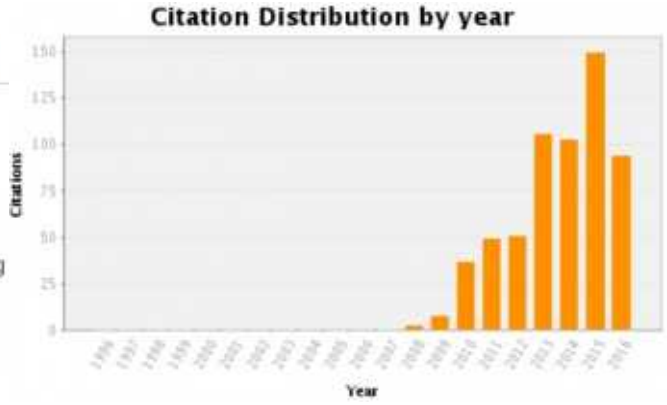


***Check your Scopus profile:** https://www.scopus.com/search/form/authorFreeLookup.uri*

3

Hermawan, Hendra Get A Badge ResearcherID Labs

ResearcherID: G-5892-2010
Other Names: H. Hermawan; Hermawan, H.
E-mail: hendra.hermawan@gmn.ulaval.ca
URL: http://www.researcherid.com/rid/G-5892-2010
Subject: Materials Science, Metallurgy & Metallurgical Engineering
Keywords: biodegradable metals; corrosion; biomaterials
ORCID: http://orcid.org/0000-0002-5596-9949

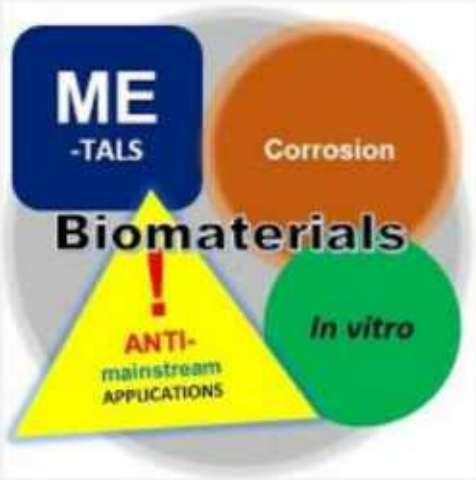


Total Articles in Publication List: 33
Articles With Citation Data: 33
Sum of the Times Cited: 602
Average Citations per Article: 18.24
h-index: 11
Last Updated: 07/02/2016 19:18 GMT

THOMSON REUTERS

*As per 02/07/2016

https://sites.google.com/site/hendrahermawan



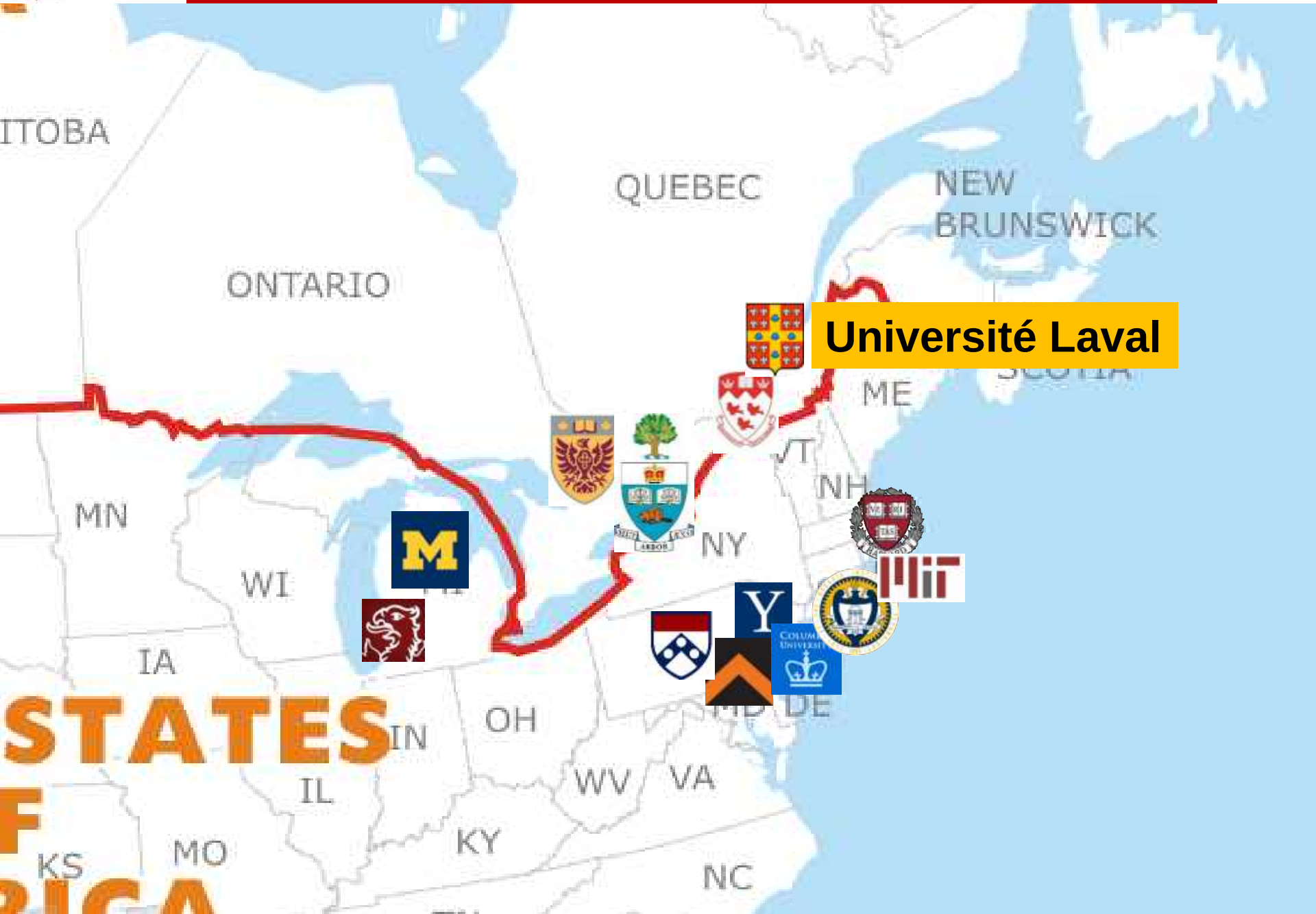
Research groups: Canada Research Chair Tier I on Biomaterials and bioengineering for the innovation in surgery. LINK; Advanced Materials Research Center (CERMA). LINK

Students: Sébastien Champagne (MS), Corrosion study of novel biomedical alloys; Devi Paramitha (PhD), *In vitro* simulated 3D construct for testing of biodegradable implants; Adhitya Trenggono (PhD), Functionalization of porous metals; Reza Alavi (PhD), Mechanical integrity of porous biomaterials; Su Yingchao (PhD, CSC exchange), Conversion coating on porous metals.

Collaborators*: Diego Mantovani (pub), Gabriele RA Froemming (pub), Mohammed Rafiq (pub), Hadi Nur (pub), Izman Sudin (pub), Djoko Hadiprayitno (pub), Ferdiansyah Mahyudin (pub), Deni Noviana (pub), Syafiqah Saidin (pub).

*proven by joint publication (pub)

Where is UL?


ITOBA
QUEBEC
NEW BRUNSWICK
ONTARIO
Université Laval
ME
VT
NH
MN
NY
WI
IA
STATES
IN
OH
IL
WV
VA
KY
KS
MO
NC
DE

The big family of UL

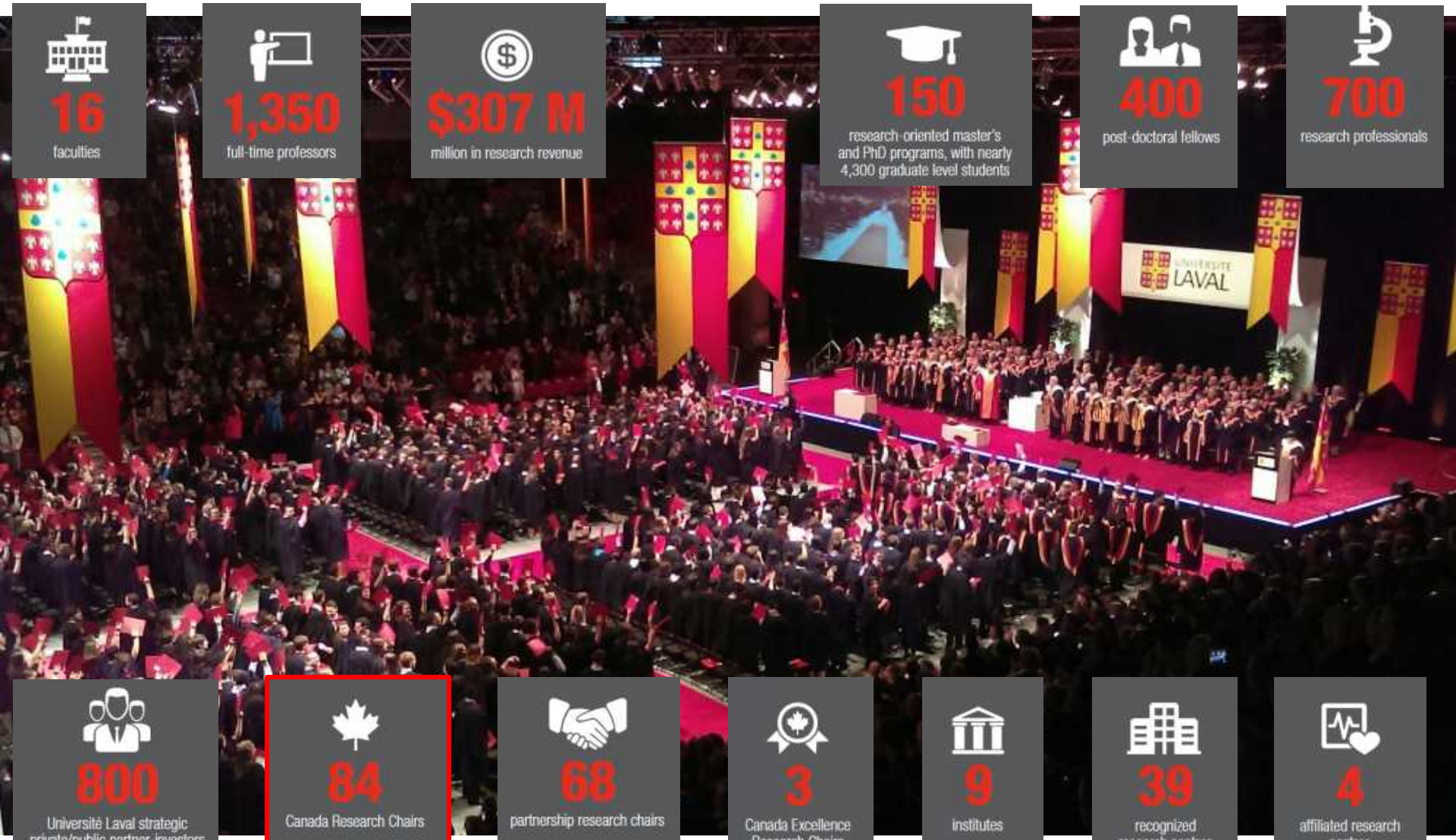
16 faculties covering all fields of study, making it a comprehensive university:

- Faculty of Agriculture and Food Sciences
- Faculty of Arts and Human Sciences
- Faculty of Business Administration
- Faculty of Dentistry
- Faculty of Education
- Faculty of Forestry, Geography and Geomatics
- Faculty of Law
- Faculty of Medicine
- Faculty of Music
- Faculty of Nursing
- Faculty of Pharmacy
- Faculty of Philosophy
- Faculty of Planning, Architecture, Arts and Design
- Faculty of Science and Engineering
- Faculty of Social Sciences
- Faculty of Theology and Religious Studies

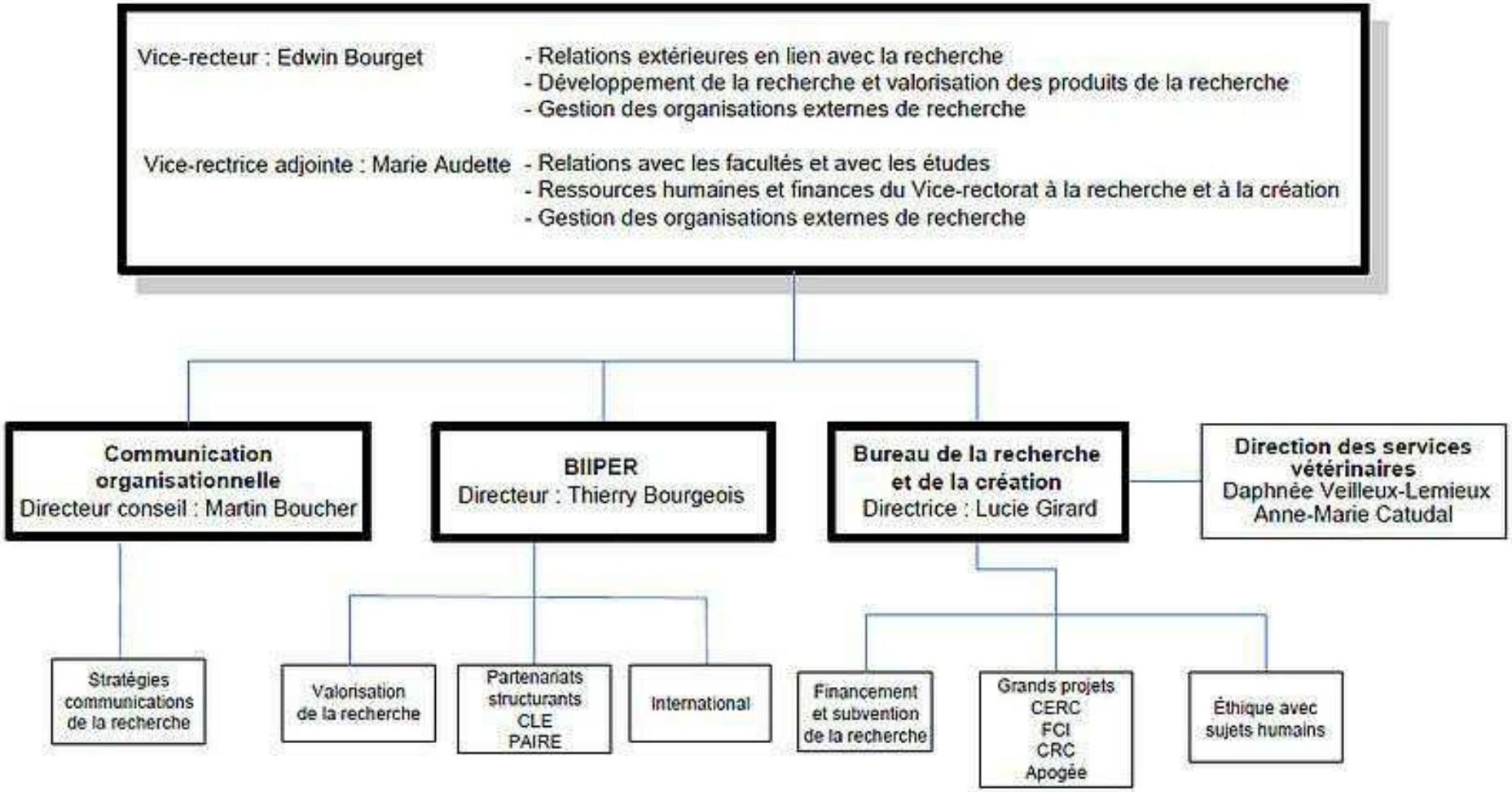
The force of UL

Université Laval teaching and professional resources, chairs, centres and partners (2013)

Source



Vice-rectorat à la recherche et à la création (VRRC)



Source

Dedicated research support team*

- **Équipes des facultés:**
  - Conseillers de première ligne

    Provide all necessary support for a succesful funding application: notify professors for every funding opportunity, provide advice and details, liase with funding agencies via VRRC, verify eligibility and conformity of an application before final submission, including proof read.

- **Équipes du VRRC:**
  - En soutien aux facultés et aux chercheurs
  - Rôle varie selon que les facultés sont
    - **Décentralisées: *Faculté des sciences et de génie***
    - **Non décentralisées**

**majority is former employee of funding agencies*

Research funding agencies

- **The 3 federal councils (health, science/engineering, social/humanities):**

CIHR IRSC | NSERC CRSNG | SSHRC CRSH

Discovery grant, infrastructure, industrial collaboration, chairs, etc.

- **Provincial government (10 provinces, 3 territories):**

Fonds de recherche Nature et technologies Québec | Fonds de recherche Santé Québec | Ontario Research Fund | British Columbia | etc…

Establishment of new professor, univ-college-SME fund, etc.

- **Foundations and philanthropies:**

Heart & Stroke Foundation | INNOVATION.CA (Canada Foundation for Innovation / Fondation canadienne pour l'innovation) | Asia Pacific Foundation of Canada / Fondation Asie Pacifique du Canada (An independent think-tank on Canada's relations with Asia) | The Kidney Foundation of Canada | etc…

Leadership grant, ~250k-20M equipment, etc.

- **Canada-international:**

Mitacs | IDRC | CRDI | AWB | USF (Academics without Borders / Universitaires sans frontières) | International Scholarships (scholarships.gc.ca) | etc…

Globalink fund, inbound/outbound students mobility, etc.

**Each logo is linked to its website*

Research activity

Assistant Professor: Teaching function
Dept. of Mining, Metallurgical & Materials Engineering
Laval University. LINK

Researcher: Research function
Axis of Regenerative Medicine
CHU de Québec Research Center. LINK

Canada Research Chair Tier-1: Biomaterials and Bioengineering for the Innovation in Surgery
Chair holder: Diego Mantovani. Fellow: Hendra Hermawan. Associates: Danielle Pezzoli, Carlo Paternoster. Postdocts: Ranna Tolouei, Agung Purnama. LINK

Research group at university level unifying interdepartmental professors:
Gaétan Laroche, Michèle Auger, Élodie Boisselier, Josée Brisson, Marc-André Fortin, Jesse Greener, Hendra Hermawan, Freddy Kleitz, Mario Leclerc, Diego Mantovani, Jean-François Morin, Roxane Pouliot, Bernard Riedl, Anna Ritcey, Denis Rodrigue. LINK

Research group at provincial level unifying interuniversity professors:
Université Laval, Université de Sherbrooke, UQTR, UQAM, CNRC Boucherville, INRS-Énergie, Université Concordia, Université de Montréal, UQAR, Université McGill, École des technologies supérieures, Collège militaire royal du Canada, Cégep Garneau, Cégep de Sherbrooke, Cégep de Thetford, Institut national d'optique. LINK

Research network at national level unifying interuniversity professors:
Université Laval, University of British Columbia, University of Alberta, University of Toronto, Dalhousie University. LINK

Among 4 UL affiliated research centers

http://www.crchudequebec.ulaval.ca

CHU de Québec Research Center

5 hospitals

The Center | The Research | The Services | The Training

- Research Areas
  - Endocrinology and nephrology
  - Infectious and immune diseases
  - Neuroscience
  - Oncology
  - Regenerative Medecine
  - Reproduction, mother and youth health
  - Population Health and Optimal Health Practices
- Clinical and evaluative research
- Researchers
- Scientific Publications

Tuesday 26 Jul

Professeur Manuel Prieto

Conférence

Amyloid-like fibers and the role of lipids: Structure and dynamics ...

Calendar >

JOBS

Professionnel(le) de recherche

Serge Dumont

List >

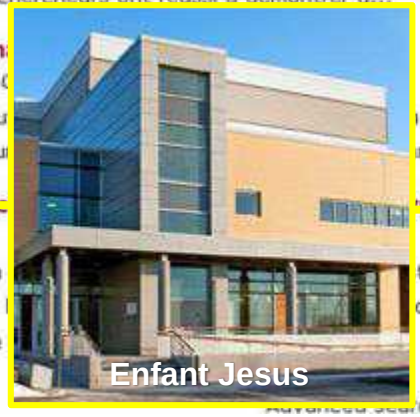
PHONEBOOK

Last name

First name

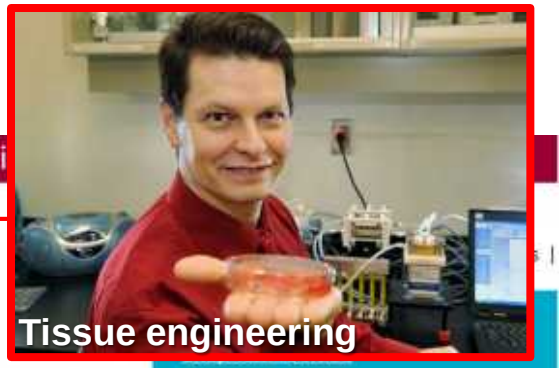
Research area

Saint-François d'Assise Hospital



Regenerative Medecine

http://www.crchudequebec.ulaval.ca



The Center | The Research | The Services | The Trai

Tuesday 26 Jul

Professeur Manuel Prieto

Conférence

Amyloid-like fibers and the role of lipids: Structure and dynamics ...

Calendar >

JOBS

Stagiaire postdoctoral - Programme POCAO

Michel Alary

List >

PH

Last name

First name

Research a

Service

Site

Regenerative medecine

Regular researchers

- Auger, François A.
- Berthod, François
- Boisselier, Élodie
- Bolduc, Stéphane
- Fortin, Marc-André
- Fradette, Julie
- Germain, Lucie
- Gros-Louis, François
- Guérin, Sylvain
- Hermawan, Hendra
- Landreville, Solange
- Laroche, Gaétan
- Mantovani, Diego
- Moulin, Véronique
- Pernet, Vincent
- Pouliot, Roxane
- Proulx, Stéphanie
- Rochette, Patrick J.
- Salesse, Christian
- Zhang, Ze

Associate researchers

- Khuong, Hélène Thida
- Labbé, Raymond
- Maciel, Yvan
- Ruel, Jean

Emeritus researchers

- Desnoyers, Serge
- Dion, Yves-Marie
- Lamontagne, Jean
- Laughrea, Patricia-Ann
- Lopez-Valle, Carlos-Antonio

Address

1401, 18e Rue, H609

All active clinical studies

Research directions:

G. Laroche, D. Mantovani, H. Hermawan

- **Surface modification**
  - Plasma coating of polymers on metals
  - Metal ion implantation
- **Vascular tissue engineering**
  - Polymers scaffold for blood vessel
  - Soft tissue biomechanics
- **Inert metallic biomaterials**
  - Surface treatment of SS, Ti, Co alloys
  - New process for semi-finished metal products
- **Biodegradable metals**
  - New alloys development
  - New applications

PhD Metallurgy/Materials (GMN/GML)

Source

Selection criteria:
Excellence candidature (academic transcript BS, MS, reference letters, CV, publications, etc.)

Competence linguistic:
Candidate must show capability in communicating either in French or English (TOEFL >500)

Research direction:
Pre-approval from potential supervisor

Apply for admission

Research domain:
Métallurgie physique et science des matériaux, technologie et aluminium, biomatériaux et bio-ingénierie, ingénierie de surface, imagerie médicale

Obligatory credits:

GML-8000 Examen de doctorat	6
GMN-8001 Séminaire de doctorat I	1
GMN-8002 Séminaire de doctorat II	1
GMN-8003 Séminaire de doctorat III	1
Elective courses	9
Research activities	78
Total minimum credit	**96**

Cost of studying at UL

Tuition Fees 2015-2016*	Master's Degree	Doctoral Degree	Doctoral Degree with Exemption[1]
1 course (3 credits)	$1,638.51	$1,477.65	$ 297.15
1 full-time semester (15 credits)	$8,157.18	$7,352.88	$1,450.38

[1]All foreign PhD students are eligible for this exemption.

1 academic year (30 credits)	$16,314.36	$14,705.76	$2,900.76
Medical and hospital insurance	$1,044/yr.	$1,044/yr.	$1,044/yr.

UL sports center

UL students housing

Application Fee[2]	$79	$79	$79
Application for Quebec Acceptance Certificate	$110	$110	$110
Study permit	$150	$150	$150
Food and Lodging	$9,200	$9,200	$9,200
Academic and personal expenses (books, clothes, transportation, etc.)	$3,500	$3,500	$3,500
Total to budget for	$30,397.36	$28,788.76	$16,983.76

Source

PhD GMN/GML at FSG UL

Source

▪ S1-S2: Welcome grant (for foreign students, $1,000/season)	$ 2,000
▪ S3-S9: Support grant ($500/season)	$ 3,500
▪ S1-S4: Seminar 1 (1 time)	$ 500
▪ S1-S5: Predoc exam (1 time)	$ 500
▪ S1-S9: Publication (1 time)	$ 500
▪ S1-S12: Conference (1 time)	$ 500
▪ S1-S14: Thesis submission (1 time)	$ 1,000
*S = season **Total support/student**	**$ 8,500**

*On top of scholarship received by students from other sources (government, NGO or supervisor).

Academic challenges

https://jobs.uic.edu/job-board/job-details?jobID=66284

UIC UNIVERSITY OF ILLINOIS AT CHICAGO

UNIVERSITY OF ILLINOIS Hospital & Health Sciences System

FIND JOBS LOGIN CIVIL SERVICE POSITION

Job Details

Title:	Assistant/ Associate/ Full Professor - Mechanical Industrial
Department:	Engineering/ Mechanical and Industrial Engineering
Category:	Faculty
Location:	Chicago
Close Date:	12/01/2016

AcademicKeys
UNLOCKING ACADEMIC CAREERS

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Engineering

Search for University Jobs in Engineering

Chemical and Materials Engineering
Concordia University

Date Posted
Apr. 19, 2016

Job Title
Chemical and Materials Engineering

Department
Chemical and Materials Engineering

Institution
Concordia University
Montreal, QC
Canada

nature jobs newsletter The career magazine for scientists

SANOFI - INSTITUT PASTEUR 2016 AWARDS
€ 400 000
FOR BIOMEDICAL RESEARCH

CALL FOR NOMINATIONS
SUBMIT YOUR NOMINATION BEFORE
TUESDAY 14TH JUNE 2016

McGill

Undergraduate Students Graduate Students Research People Safety Employer Info Job Opportunities

Faculty
Rosinos Dimitrakopoulos
Ferri Hassani
Hani Mitri
Mustafa Kumral
Agus Pulung Sasmito
Administrative Staff

Agus Pulung Sasmito

Assistant Professor

Education

Contact

Frank Dawson Adams Building, Room 115

Group website: Mine Ventilation, Energy and Environment

+ Research interests
+ Undergraduate courses offered
+ Graduate courses offered
+ Publications

Recent science jobs

- Clinical Research Opportunity : Seattle, WA, United States
  Fred Hutchinson Cancer Research Center
- Faculty Position, Clinical Research Division : Seattle, WA, United States
  Fred Hutchinson Cancer Research Center
- Postdoctoral Research Associate
  University of Illinois
- Postdoctoral Research Assistant
  University of Dundee
- Research Science Faculty
  Stanford University
- Full-time Postdoctoral Scientist

s and addresses of three (3) refer

Dr. David Taylor, Chair
Department of Chemical and Biological Engineering
University of Ottawa
david.taylor@uottawa.ca

All qualified candidates are invited to apply; however, preference will be given to Canadian citizens and permanent residents.
is an equal opportunity employer. We strongly encourage applications from women, Aboriginal peoples, persons with disabilit
visible minorities. If you are invited to continue the selection process, please notify us of any particular adaptive measures yo
contacting the Office of the Associate Vice-President, Faculty Affairs at 613-562-5958. Any information you send us will be ha
complete confidence.

The University of Ottawa is proud of its 160-year tradition of bilingualism. Through its Official Languages and Bilingualism Ins
provides training to staff members and to their spouses in their second official language. At the time of tenure, professors are
ability to function in a bilingual setting.

Academic challenges

1. Win the competition:

- *Sending applications for getting interviewed*
- *Beating all competitors:* ***PhD++***
- *5 years contract (tenure-track)*
- *Assistant Professor* ★

2. Get the tenure:

- *Fulfilling all requirements within the given time*
- *Teaching, research*, internal participation*
- **external funding, graduate students, publications*
- *Associate Professor* ★★

3. Go international:

- *Excellence in teaching, research, external* participation*
- **world leader in the field, international reputation and network*
- *Full Professor* ★★★★

UL-UTM collaboration

The latest

Colloids and Surfaces B: Biointerfaces
Volume 145, 1 September 2016, Pages 130–139

Immobilization of antibacterial chlorhexidine on stainless steel using crosslinking polydopamine film: Towards infection resistant medical devices

Nurizzati Mohd Daud[a], Ihda Fithriyana Saeful Bahri[a], Nik Ahmad Nizam Nik Malek[b], Hendra Hermawan[c], Syafiqah Saidin[a,b]

[a] Biomedical Science Laboratory, Faculty of Biosciences and Medical Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia

[b] Department of Biotechnology and Medical Engineering, Faculty of Biosciences and Medical Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia

[c] Department of Mining, Metallurgical and Materials Engineering & CHU de Québec Research Center, Laval University, Quebec City, G1V 0A6, Canada

The first

Materials Science and Engineering: C
Volume 33, Issue 8, 1 December 2013, Pages 4715–4724

Polydopamine as an intermediate layer for silver and hydroxyapatite immobilisation on metallic biomaterials surface

Syafiqah Saidin[a], Pascale Chevallier[b], Mohammed Rafiq Abdul Kadir[a], Hendra Hermawan[a], Diego Mantovani[b]

More…

Materials & Design
Volume 85, 15 November 2015, Pages 431–437

Influence of thermal treatment on microstructure, mechanical and degradation properties of Zn–3Mg alloy as potential biodegradable implant material

M.S. Dambatta[a], S. Izman[a], D. Kurniawan[a], Saeed Farahany[a], Bashir Yahaya[a], H. Hermawan[b]

SCIENTIFIC REPORTS
Scientific Reports **5**, Article number: 11194 (2015)
doi:10.1038/srep11194

The highest

Controlling the degradation kinetics of porous iron by poly(lactic-co-glycolic acid) infiltration for use as temporary medical implants

Abdul Hakim Md Yusop, Nurizzati Mohd Daud, Hadi Nur, Mohammed Rafiq Abdul Kadir & Hendra Hermawan

Journal of Biomedical Materials Research
PART B APPLIED BIOMATERIALS

More…

Original Research Report

Degradation behavior of biodegradable Fe35Mn alloy stents

N. B. Sing[1], A. Mostavan[2], E. Hamzah[3], D. Mantovani[2,*] and H. Hermawan[1,2,*]

Version of Record online: 21 JUN 2014
DOI: 10.1002/jbm.b.33242

Issue

Journal of Biomedical Materials Research Part B: Applied Biomaterials
Volume 103, Issue 3, pages 572–577, April 2015

More…

Materials Science and Engineering: C
Volume 51, 1 June 2015, Pages 294–299

Structure–property relationships of iron–hydroxyapatite ceramic matrix nanocomposite fabricated using mechanosynthesis method

Jamillah Amer Nordin[a], Djoko Hadi Prajitno[b], Syafiqah Saidin[a], Hadi Nur[c,d], Hendra Hermawan[a]

More…

UL-UTM collaboration

GENERAL COOPERATION AGREEMENT

(Memorandum of Understanding)

BETWEEN

Université Laval (Québec, Québec, Canada)

AND

Universiti Teknologi Malaysia (Johor Bahru, Johor, Malaysia)

WHEREAS Université Laval and Universiti Teknologi Malaysia wish to collaborate through different teaching and research programs in order to improve the qualifications of the teaching staff and students of both institutions;

WHEREAS both institutions wish to develop, through this collaboration, their teaching and research resources in their fields of competence;

WHEREAS both universities have a genuine interest in the promotion of such international collaboration on the basis of equality and mutual assistance;

Université Laval, on the one hand, and Universiti Teknologi Malaysia, on the other, agrees to the following:

Article 1 - FIELDS OF COOPERATION

The general cooperation agreement includes all programs of mutual interest in the two institutions.

Article 2 - MODES OF COOPERATION

2.1 A separate agreement shall be required for each cooperative program. The following activities are considered:

- exchanges of professors;
- exchanges of students;







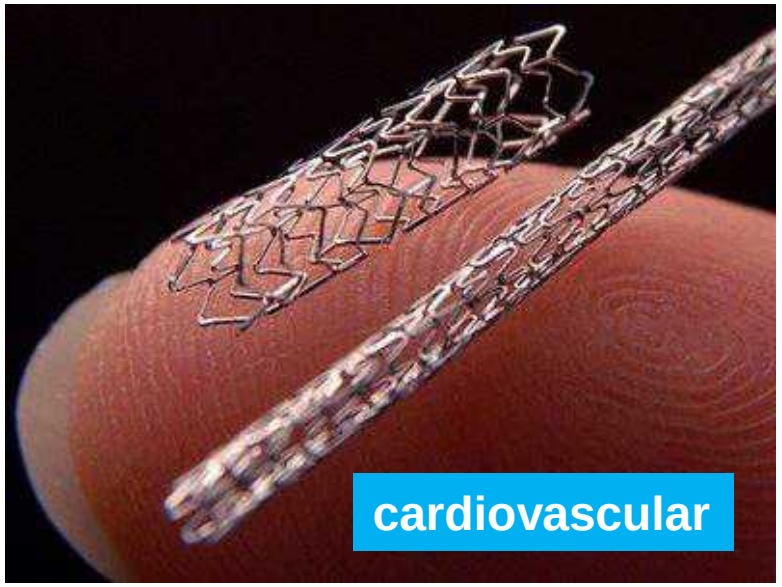





Discussion

Next … Part 2: Metallic biomaterials from inert to biodegradable

Biomaterials



Type of biomaterials

Table 1.3 Materials commonly used for biomedical applications

Materials	Advantages	Disadvantages	Applications
Metals: stainless steel, Ti alloys, Co-Cr alloys, Mg alloys, etc.	Though, strong, ductile	Non bioactive	Load bearing implants; dental implants, joint replacement, cardiovascular stents, etc.
Ceramics: zirconia, alumina, bioglass, calcium phosphate, etc.	Bioactive, inert,	Brittle, not resilient	Orthopaedic and dental implants
Polymers: nylon, polylactide, polyethylene, polyesters, etc.	Bioactive, resilient	Not strong	Blood vessel grafts, sutures, hip sockets, etc.
Composites: amalgam, fiber-reinforced bone cement, etc.	Tailor made	Relatively difficult to make	Bone cement, dental resin

Hermawan H. Biodegradable Metals: From Concept to Applications. Springer, 2012

Metallic biomaterials

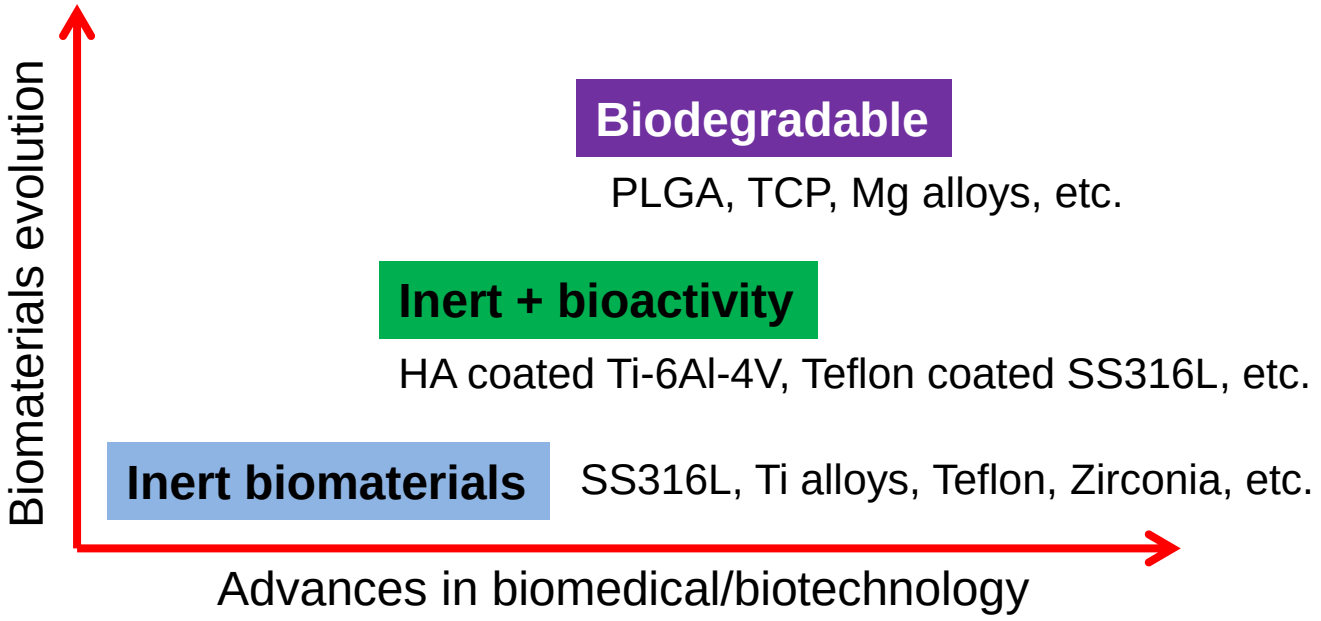
Table 1.2 Implants division and type of metals used

Division	Implants	Type of metal
Orthopaedic	• Bone fixation (plate, screw, pin)	SS316L; Ti; Ti-6Al-4V
	• Spinal fixation	SS316L; Ti; Ti-6Al-4V; Ti-6Al-7Nb
	• Artificial joints	Co-Cr-Mo; T-6Al-4V; Ti-6Al-7Nb
Craniofacial	Plate and screw	SS316L; Co-Cr-Mo; Ti; Ti-6Al-4V
Cardiovascular	• Artificial valve	Ti-6Al-4V
	• Stent	SS316L; Co-Cr-Mo; Ti
	• Pace maker case	Ti; Ti-6Al-4V
	• Stent graft	SS316L
Otorhinology	• Artificial eardrum	SS316L
	• Artificial inner ear (electrode)	Pt
Dentistry	• Filling	Ag-Sn(-Cu) amalgam, Au
	• Inlay, crown, bridge	Au-Cu-Ag; Au-Cu-Ag-Pt-Pd; Ti; Co-Cr
	• Orthodontic wire	SS316L; Co-Cr-Mo; Ti-Ni; Ti-Mo
	• Dental implant	Ti; Ti-6Al-4V; Ti-6Al-7Nb; Au

Hermawan H. Biodegradable Metals: From Concept to Applications. Springer, 2012

Biomaterials evolution

Paradigm shift:



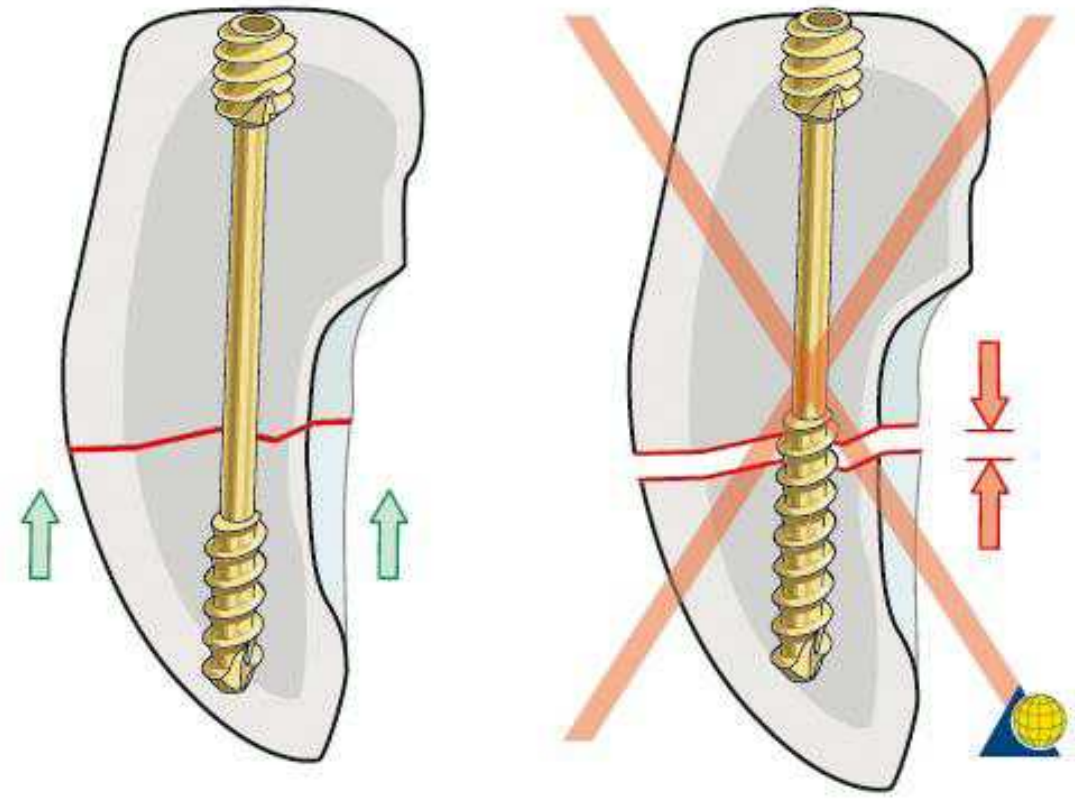
Hermawan H. Biodegradable Metals: From Concept to Applications. Springer, 2012

If after healing the screws disappear …

http://www.orthomed.co.uk

- ❑ We don’t need a second surgery
- ❑ We can avoid the stress shielding problem
- ❑ Bone returns to its normal biomechanics condition

How shall they perform?



https://www2.aofoundation.org/wps/portal/surgery

- Provide a temporary **mechanical** support
- **Degrade** progressively
- Do not cause problem of **toxicity** (but +biofunctionnalities)

Idealization for hard tissue

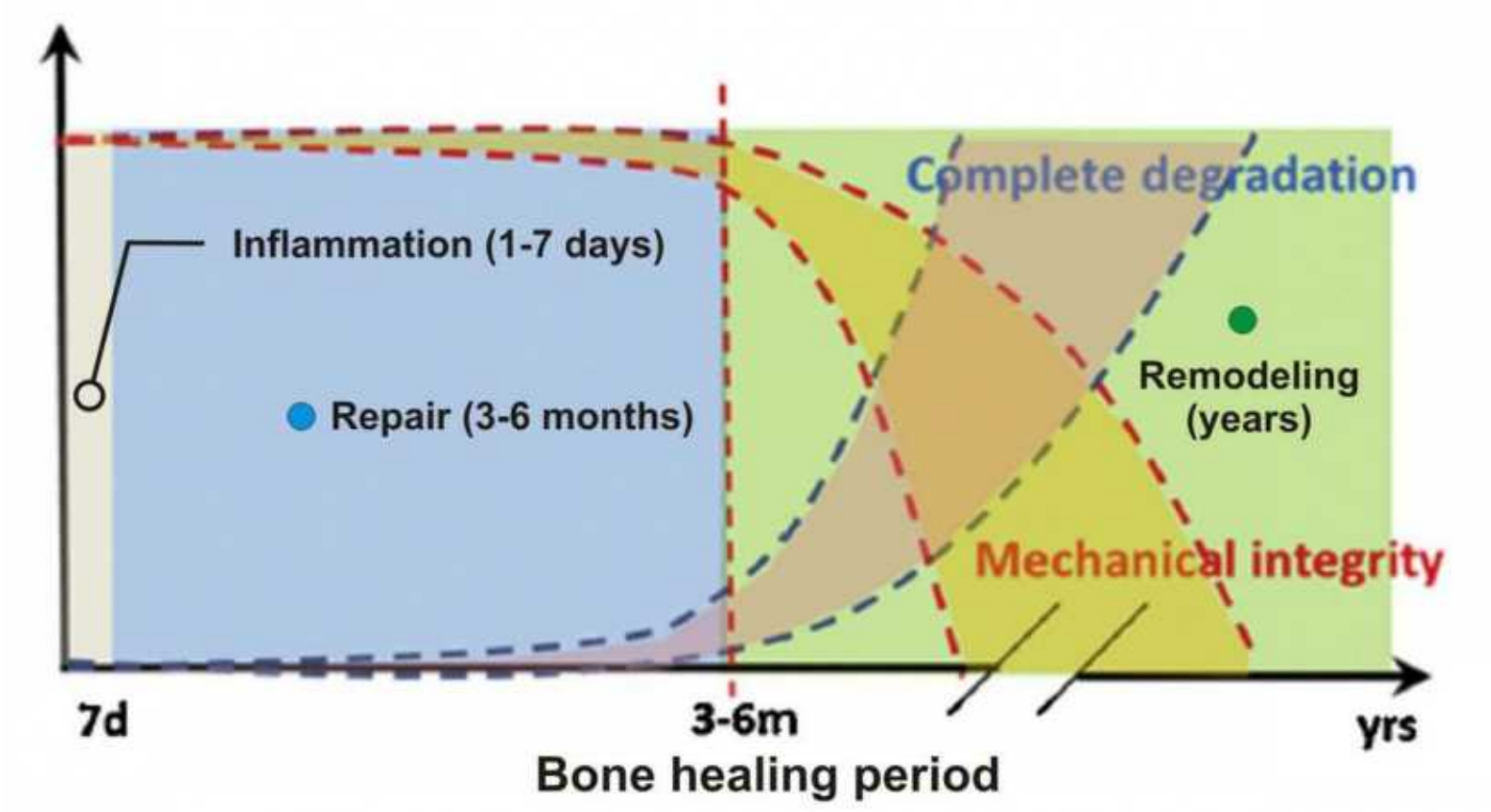


Fig. 6.5: Schematic diagram showing ideal behavior of biodegradable metal implants for bone fracture fixation. Degradation rate stays low during the first 3-6 months and increases thereafter, and mechanical integrity stays relatively constant during the same period and progressively deteriorate thereafter.

Biomaterials and Medical Devices: A Perspective from an Emerging Country, Springer, 2016.

Biodegradable metals: Definition

Materials Science and Engineering R

journal homepage: www.elsevier.com/locate/mser

Biodegradable metals

Y.F. Zheng [a,b,*], X.N. Gu [c], F. Witte [d]

[a] State Key Laboratory for Turbulence and Complex System and Department of Materials Science and Engineering, College of En
Beijing 100871, China
[b] Shenzhen Key Laboratory of Human Tissue Regeneration and Repair, Shenzhen Institute, Peking University, Shenzhen 5180
[c] Key Laboratory for Biomechanics and Mechanobiology of Ministry of Education, School of Biological Science and Medical Eng
Beijing 100191, China
[d] Julius Wolff Institute and Center for Musculoskeletal Surgery, Berlin-Brandenburg Center for Regenerative Therapies, Charité
Augustenburger Platz 1, 13353 Berlin, Germany

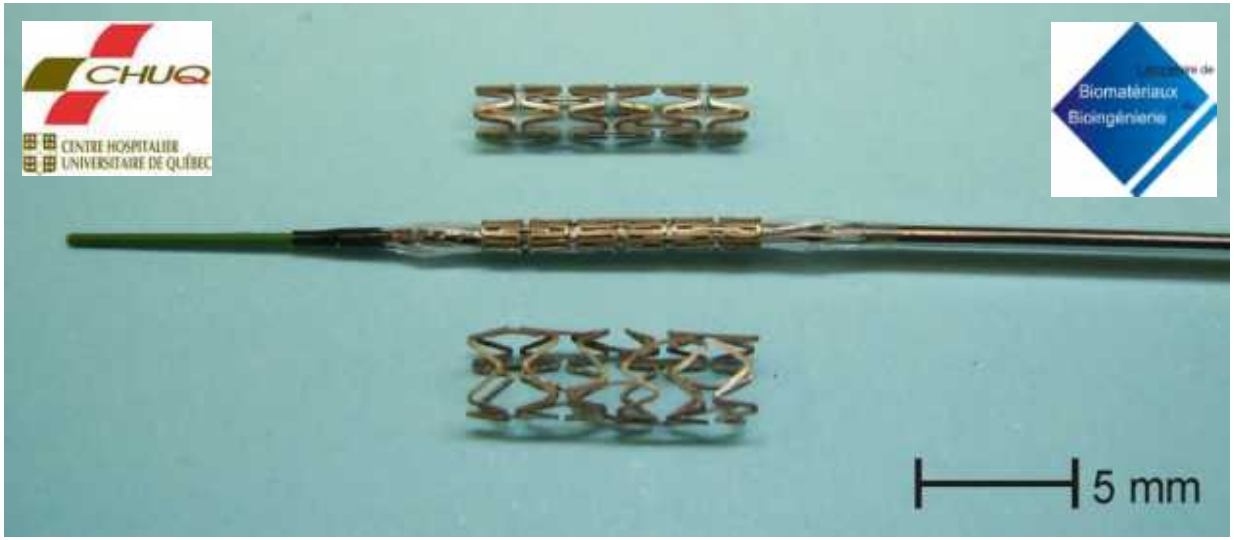
The definition of BMs can be given as follows: BMs are metals expected to corrode gradually *in vivo*, with an appropriate host response elicited by released corrosion products, then dissolve completely upon fulfilling the mission to assist with tissue healing with no implant residues. Therefore, the major component of BM

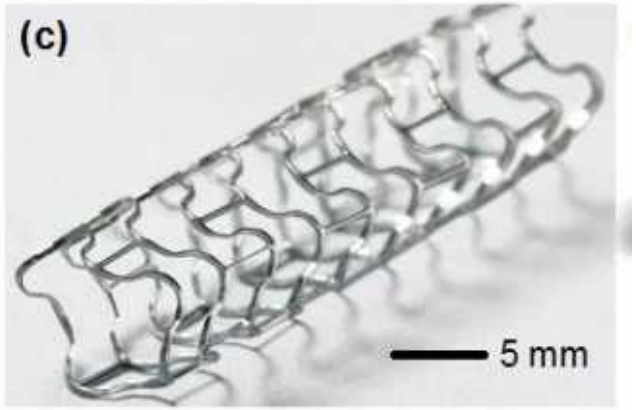
stent thrombosis. During stent degradation, endothelial and smooth muscle cells will be exposed to loca
unknown physiological consequences. Here, we investigated the effects of elevated magnesium concer
and smooth muscle cell (HCAEC, HCASMC) growth and gene expression. In the course of 24 h after in
(1 or 10 mM) intracellular magnesium level in HCASMC raised from 0.55 ± 0.25 mM (1 mM) to 1.38 ± 0.
detected in HCAEC. Accordingly, a DNA microarray-based study identified 69 magnesium regulated tra
regulated transcripts in HCASMC. Notably, a significant regulation of various growth factors and extrace
contrast, viability and proliferation of HCAEC were increased at concentrations of up to 25 mM magnes
proliferation appeared to be unaffected. Taken together, our data indicate that magnesium halts smooth
endothelial cell proliferation, which might translate into a beneficial effect in the setting of stent associa

Product prototypes

MAGNEZIX

Compression Screw 3.2
Bioabsorbable





AMS Biotronik

Biodegradable metals: Elements

Protein / Protéines 19 g	
Vitamin A / Vitamine A	0 %
Vitamin C / Vitamine C	2 %
Calcium / Calcium	25 %
Iron / Fer √	50 %
Phosphorus / Phosphore	25 %
Magnesium / Magnésium √	30 %
Zinc / Zinc √	15 %

Biodegradable metals: Properties

Metal	Mechanical properties				Degradation rate* (mm/year)
	E (GPa)	YS (MPa)	UTS (MPa)	ε (%)	
Pure magnesium (annealed)	45	30	100	7	8
Mg-Al (AZ31, extruded)		175	250	14	2.0
Mg-RE (WE43, extruded)		180	280	10	4.34
Mg-1Ca (extruded)		135	240	10	1.4
Mg-1Zn (rolled)		160	240	7	1.52
Pure iron (annealed)	200	150	200	40	0.2
Pure iron (electroformed annealed)		270	290	18	0.75
Fe-35Mn (PM annealed)		230	430	30	0.44
Fe-10Mn-1Pd (forged)		850	1450	10	0.42
Fe-30Mn-6Si (cast)		180	430	17	0.3
Pure zinc	100	-	20	0.3	0.5
Zn-1Mg (cast)		-	150	2	0.20
Zn-1Mg (extruded)		170	250	11	0.12
Zn-3Mg (ECAP)**		205	220	6	0.28

Biomaterials and Medical Devices: A Perspective from an Emerging Country, Springer, 2016.

Magnesium and its alloys

Consideration

- **Toxicity:**

  High daily allowance level: 700 mg

  Essential element: enzyme activator, protein co-regulator

- **Degradability:**

  Degraded in physiological condition via corrosion:

  $$Mg + 2H_2O \rightarrow Mg(OH)_2 + H_2$$

  Challenge: high degradation rate, hydrogen gas formation

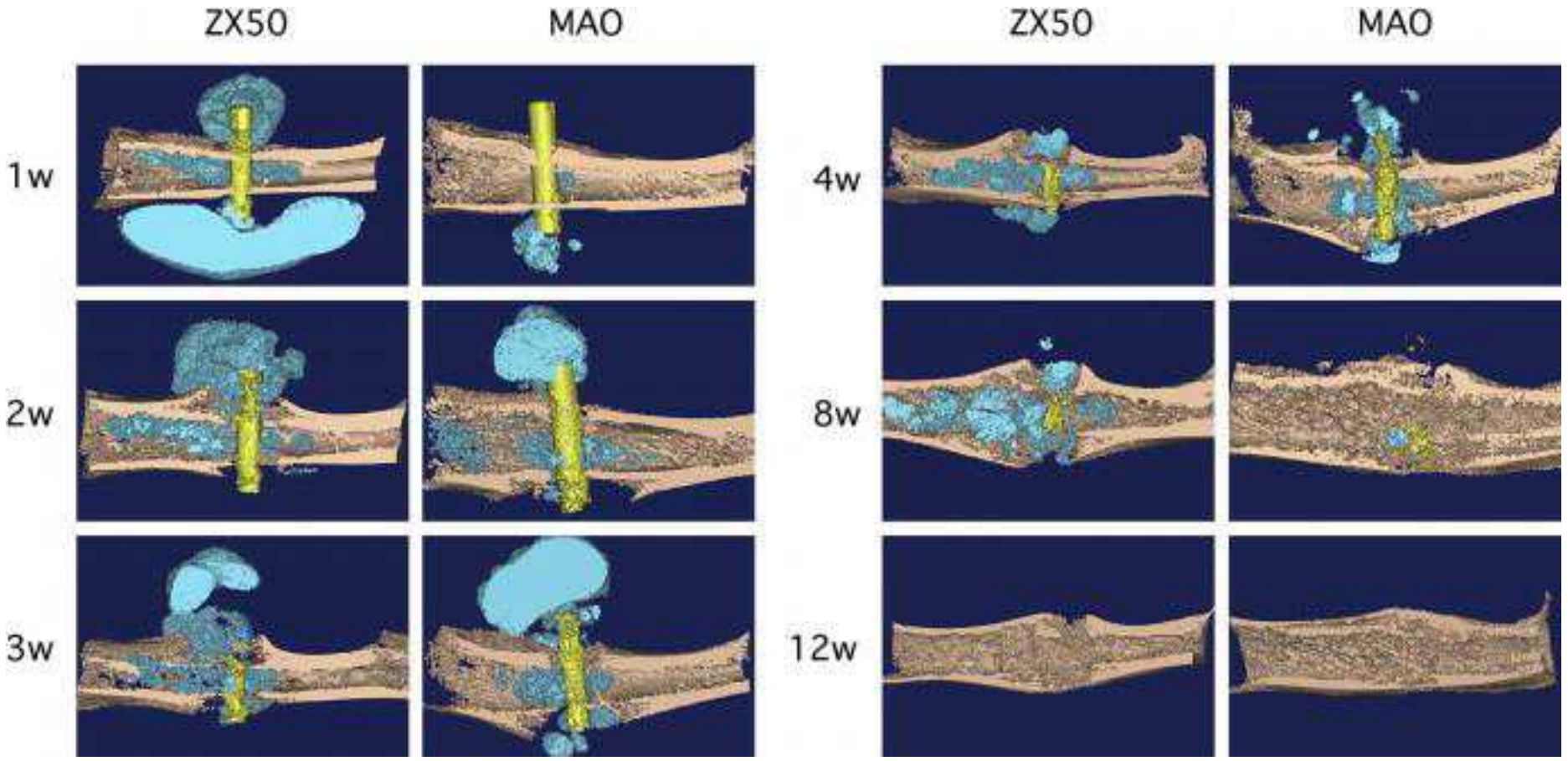
- **Mechanical property:**

  Light weight: 1.74 g/cm^3

  Low elastic modulus: 45 GPa near to that of bone (~30 GPa)

  Challenge: low strength and ductility

Mg alloy pin



µCT Mimics® 3D reconstructions of the implant site for ZX50 and MAO implants; gas bubbles are visible in light blue.

Fischerauer SF, et al. In vivo degradation performance of micro-arc-oxidized magnesium implants: A micro-CT study in rats. Acta Biomater 9 (2013) 5411.

Mg alloy screw

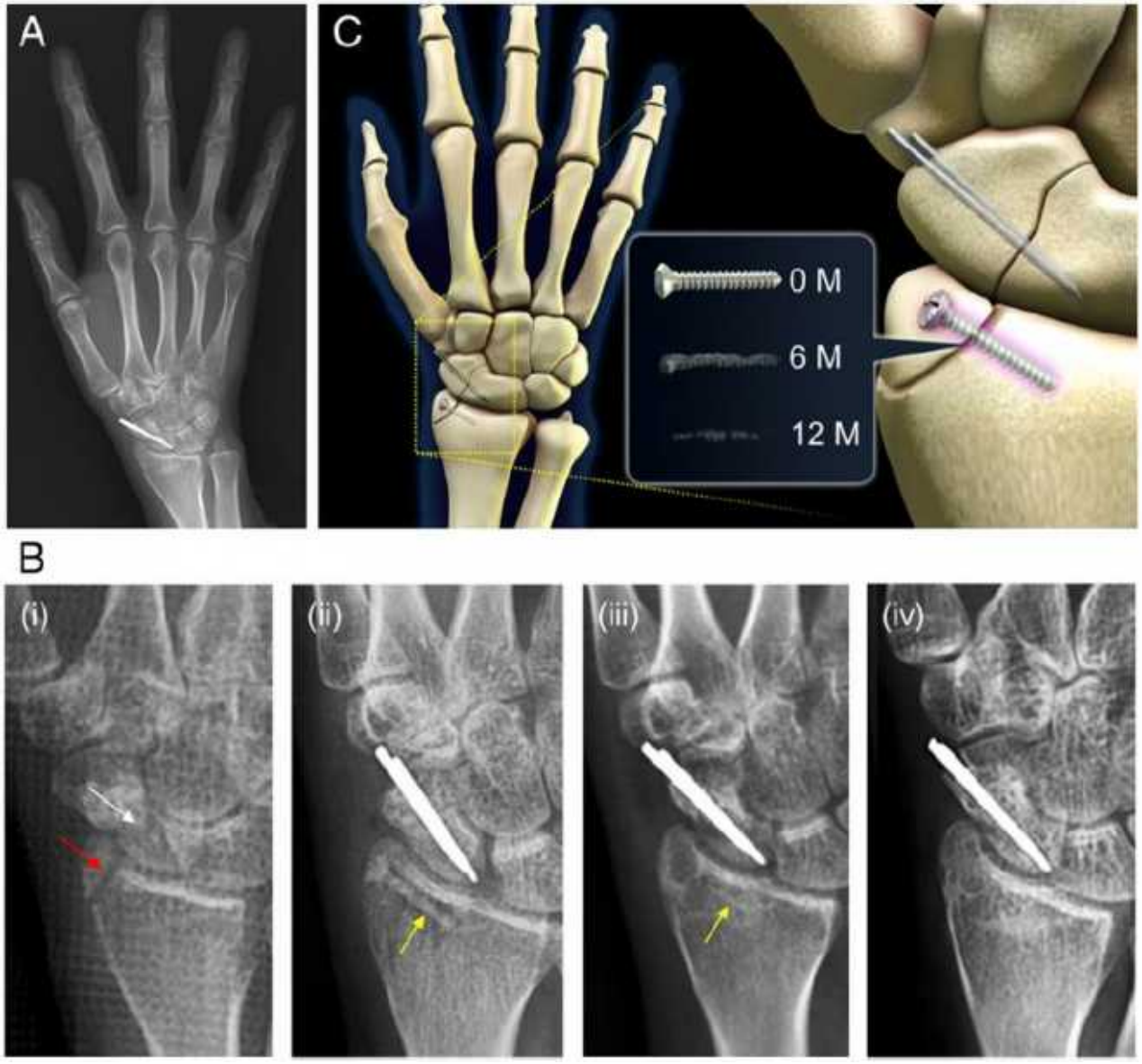


Fig. 4: Fig. 4. Clinical observation of complete degradation and bone healing of Mg alloy (Mg-5wt%Ca-1wt%Zn) screw over a 1-y period.

*"Controlled degradation of **Mg-5Ca-1Zn** alloy results in the formation of **biomimicking calcification matrix** at the degrading interface to initiate the **bone formation** process. This process facilitates early bone healing and allows the **complete replacement** of biodegradable Mg implant by the new bone within 1 y of implantation, as demonstrated in **53 cases** of successful long-term clinical study."*

Lee J-W, et al. Long-term clinical study and multiscale analysis of in vivo biodegradation mechanism of Mg alloy. PNAS 113 (2016) 716–721.

Iron and its alloys

Consideration

- **Toxicity:**

  Essential element: oxygen transport, component of metalloprotein

  Medium daily allowance level: 20 mg

  Challenge: excessive presence causes liver toxicity

- **Degradability:**

  Degraded in physiological condition via corrosion:

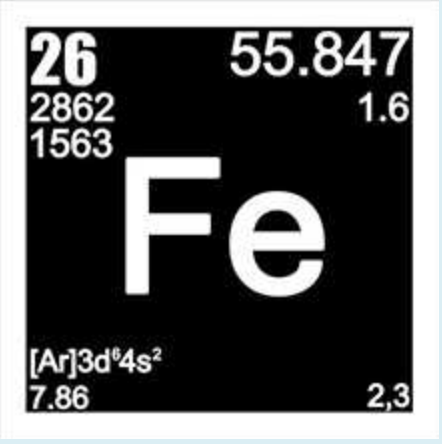
  $$2Fe + O_2 + 2H_2O \rightarrow 2Fe(OH)_2$$

  Challenge: low degradation rate

- **Mechanical property:**

  High strength and ductility

  High elastic modulus: 200 GPa

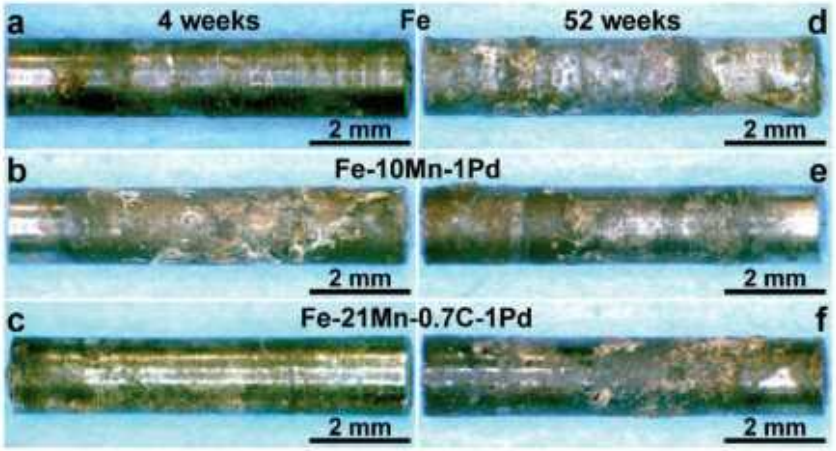


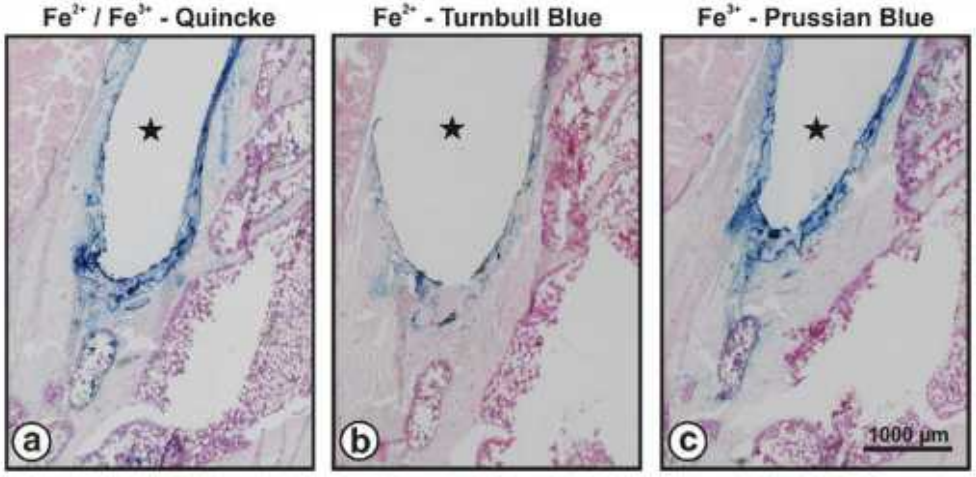
Iron alloy for pin

Biodegradable Fe-based alloys for use in osteosynthesis: Outcome of an in vivo study after 52 weeks

Tanja Kraus [a], Frank Moszner [b], Stefan Fischerauer [c], Michael Fiedler [c], Elisabeth Martinelli [c], Johannes Eichler [c], Frank Witte [d], Elmar Willbold [e], Michael Schinhammer [b], Martin Meischel [f], Peter J. Uggowitzer [b], Jörg F. Löffler [b], Annelie Weinberg [c,*]

[a] Department of Paediatric Orthopaedics, Medical University Graz, 8036 Graz, Austria
[b] Laboratory of Metal Physics and Technology, Department of Materials, ETH Zurich, 8093 Zurich, Switzerland
[c] Department of Orthopaedics, Medical University Graz, 8036 Graz, Austria
[d] Julius Wolff Institut, Charité—Universitätsmedizin Berlin, Augustenburgerplatz 1, 13353 Berlin, Germany





Low oxygen content in the vicinity of the implants
+ dense degradation products = slow in vivo corrosion

Well integrated, degradation processes caused no obvious harm to the neighboring tissues.

Because of the relatively slow degradation of the alloys, their suitability for bulk temporary implants such as those in osteosynthesis applications appears questionable.

Acta Biomaterialia 10 (2014) 3346–3353.

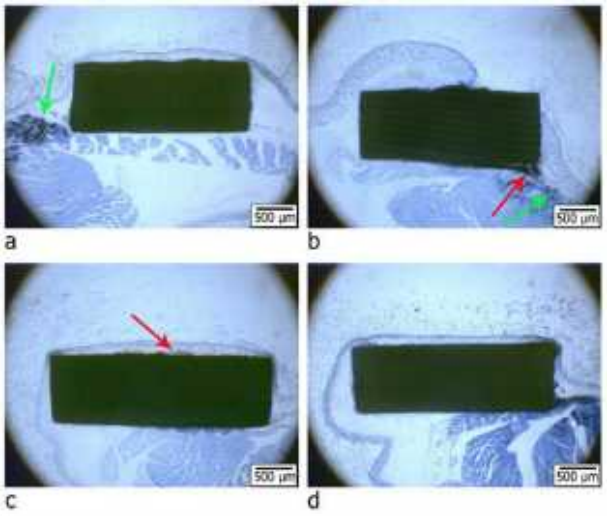
Iron alloy for stent

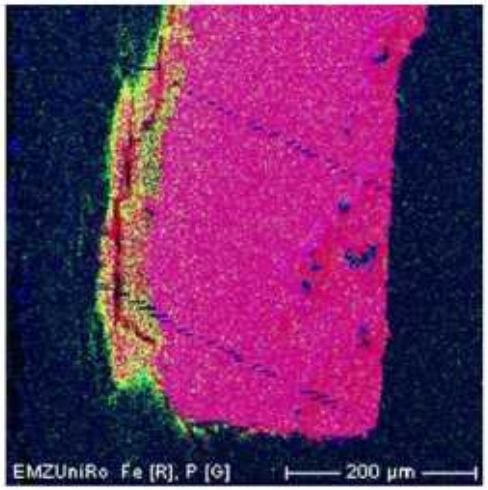
Biomaterials

In vitro and *in vivo* corrosion properties of new iron–manganese alloys designed for cardiovascular applications

Andreas Drynda,[1*] Thomas Hassel,[2*] Friedrich Wilhelm Bach,[2] Matthias Peuster[3]

[1]Department of Orthopaedics, Otto-von-Guericke University of Magdeburg, Magdeburg, Germany
[2]Institute of Materials Science, Leibniz University Hannover, An der Universität 2, 30823 Garbsen, Germany
[3]Jilin Heart Hospital, Department of Congenital and Pediatric Cardiology, Changchun, 130117 Jilin, China





- **In vitro:** Fe-0.5Mn, Fe-2.7Mn, Fe-6.9Mn alloys exhibit good mechanical and corrosion features + suitable biocompatibility.
- **In vivo:** even after 9 months no significant corrosion was detectable.
- **Reason:** formation of passive layers (FeMn phosphates)

Strategies to prevent or dissolve those layers need to be developed to expedite the *in vivo* corrosion of FeMn alloys.

J Biomed Mater Res Part B 103B (2015) 649–660.

Iron composites

Contents lists available at ScienceDirect

Materials Science and Engineering C

journal homepage: www.elsevier.com/locate/msec

Materials Science and Engineering C 36 (2014) 336–344.

In vitro and *in vivo* degradation evaluation of novel iron-bioceramic composites for bone implant applications

M.F. Ulum [a,b], A. Arafat [a,c,1], D. Noviana [b], A.H. Yusop [a], A.K. Nasution [a,d], M.R. Abdul Kadir [a], H. Hermawan [a,*]

[a] Faculty of Biosciences and Medical Engineering, Universiti Teknologi Malaysia, Johor Bahru, Malaysia
[b] Faculty of Veterinary Medicine, Bogor Agricultural University, Bogor, Indonesia
[c] Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, Johor Bahru, Malaysia
[d] Faculty of Engineering, Muhammadiyah University of Riau, Pekan Baru, Indonesia

→ Bioactivity toward bone was improved, but corrosion rate was not accelerated.

www.nature.com/scientificreports

Scientific Reports 5 (2015) 11194. DOI: 10.1038/srep11194.

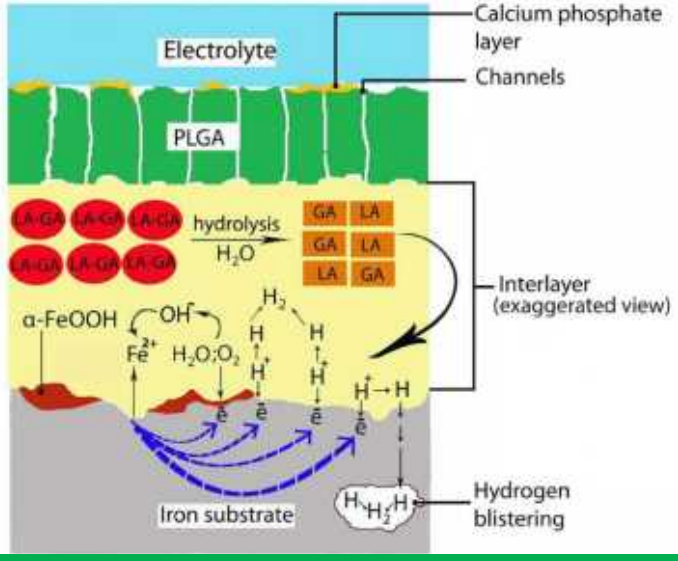
SCIENTIFIC REPORTS

OPEN

Controlling the degradation kinetics of porous iron by poly(lactic-*co*-glycolic acid) infiltration for use as temporary medical implants

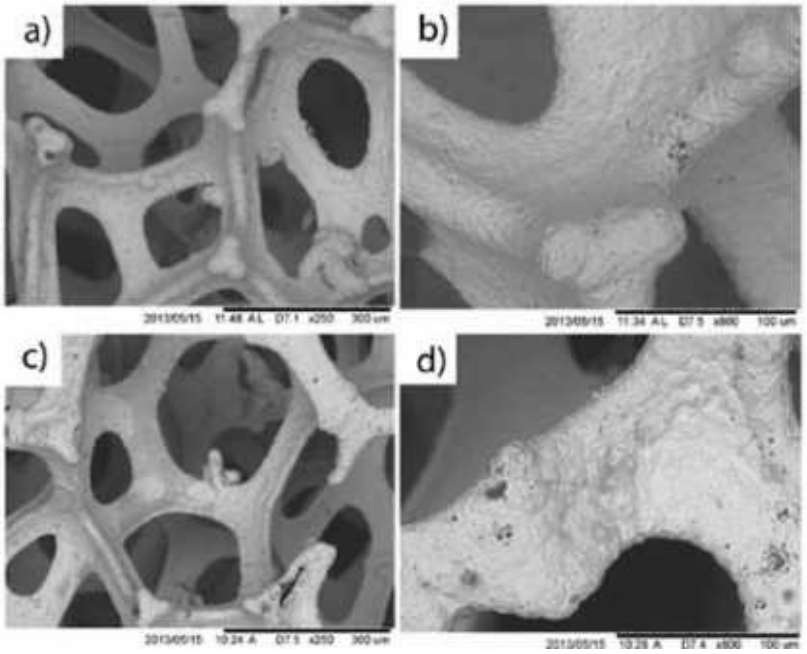
Received: 26 February 2015
Accepted: 15 May 2015
Published: 09 June 2015

Abdul Hakim Md Yusop[1], Nurizzati Mohd Daud[1], Hadi Nur[2], Mohammed Rafiq Abdul Kadir[1] & Hendra Hermawan[1,3]



→ PLGA controls corrosion rate, faster corrosion was achieved.

Iron foam for scaffolds



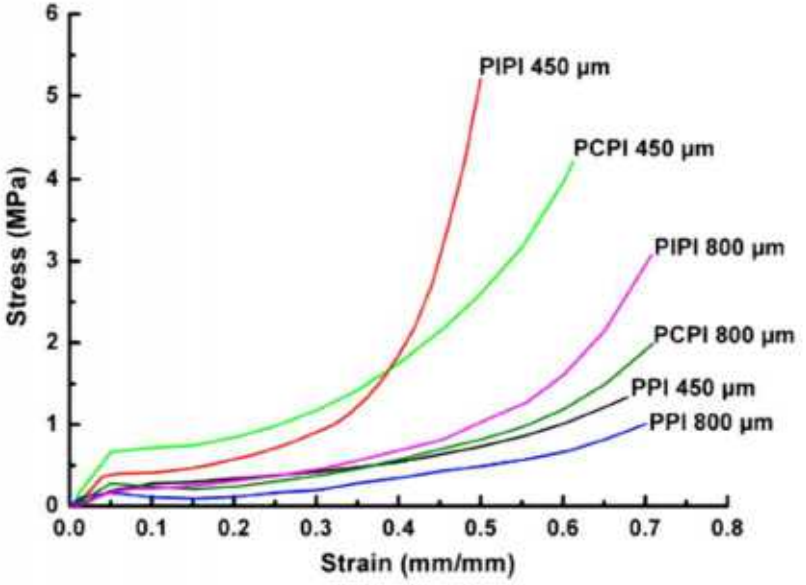


Figure 4. Compressive stress-strain curves of PPI, PCPI and PIPI samples.

Yusop AHM, et al. Controlling the degradation kinetics of porous iron by poly(lactic-co-glycolic acid) infiltration for use as temporary medical implants. Scientific Reports 5 (2015) 11194.

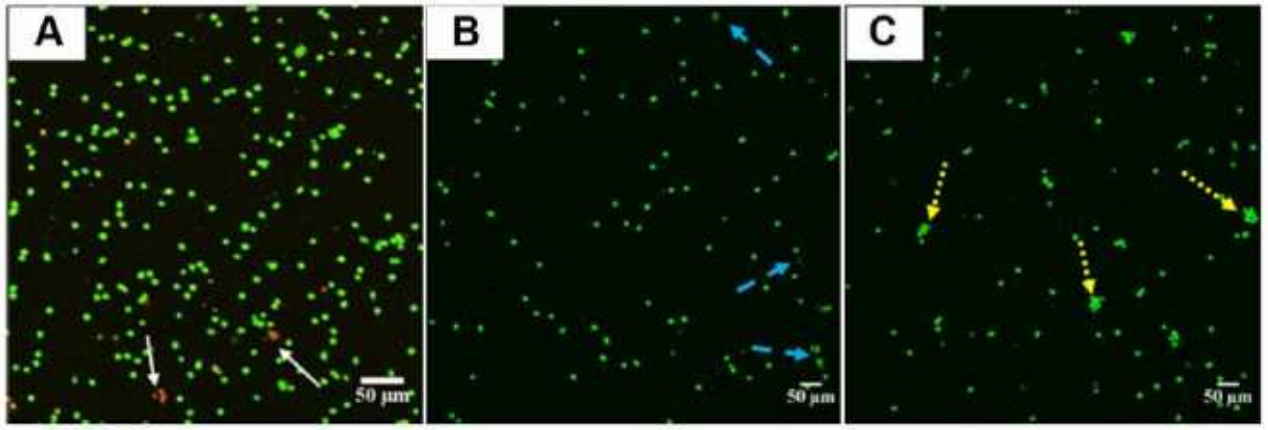


Figure 5 Human skin fibroblast cells detached from: (A) pure-Fe, (B) HA/PCL-Fe, (C) HA-Fe samples.

Daud NM, et al. Degradation and in vitro cell–material interaction studies on hydroxyapatite-coated biodegradable porous iron for hard tissue scaffolds. J Ortho Trans 2 (2014) 177.

Zinc and its alloys

Consideration

- **Toxicity:**

  Essential element: trace elements in many enzymes

  Medium daily allowance level: 15 mg

  Challenge: excessive presence causes neurotoxicity

- **Degradability:**

  Degraded in physiological condition via corrosion:

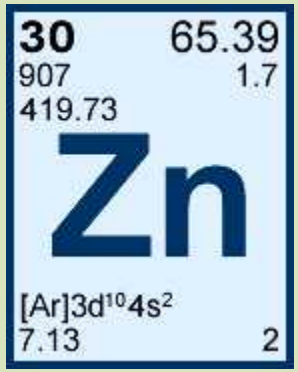
  $$2Zn + O_2 + 2H_2O \rightarrow 2Zn(OH)_2$$

  Challenge: modulate degradation rate?

- **Mechanical property:**

  Elastic modulus: 100 GPa

  Challenge: low strength and ductility



Mechanical property enhancement via extrusion

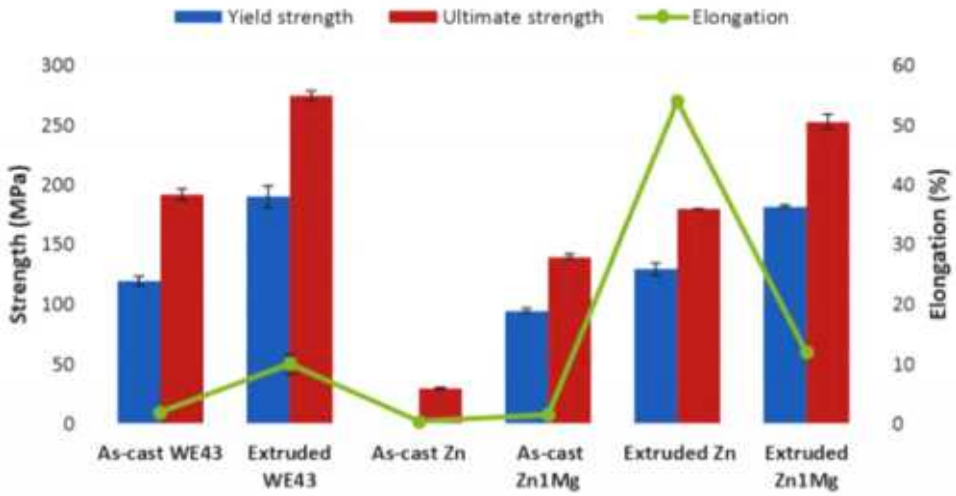


FIGURE 8. Tensile properties of as-cast and extruded WE43, pure Zn and Zn–1Mg. Only ultimate strength was available because as-cast Zn specimen cracked before plastic deformation. [Color figure can be

Gong H, et al. In vitro biodegradation behavior, mechanical properties and cytotoxicity of biodegradable Zn–Mg alloy. J Biomed Mater Res Part B 103B (2015) 1632.

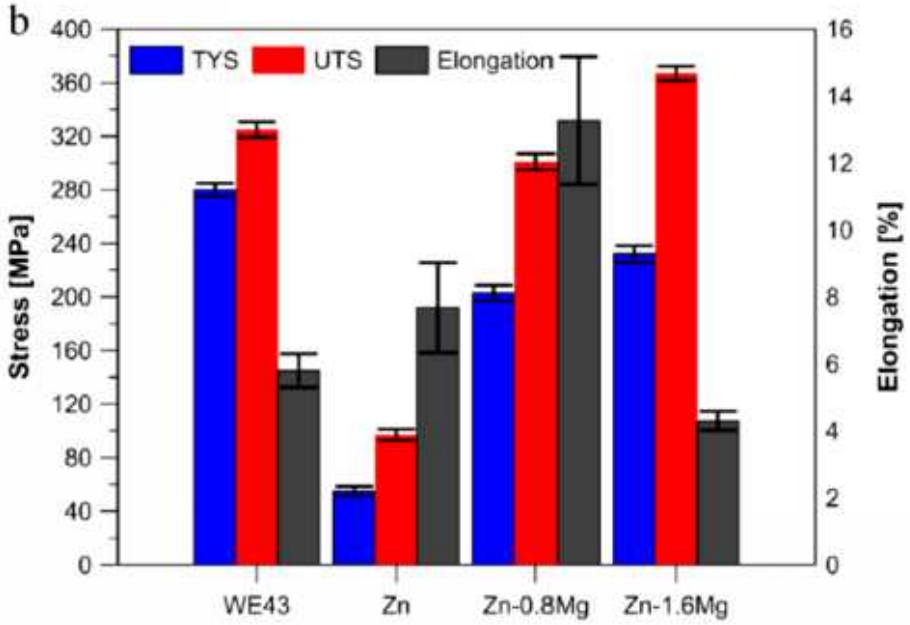
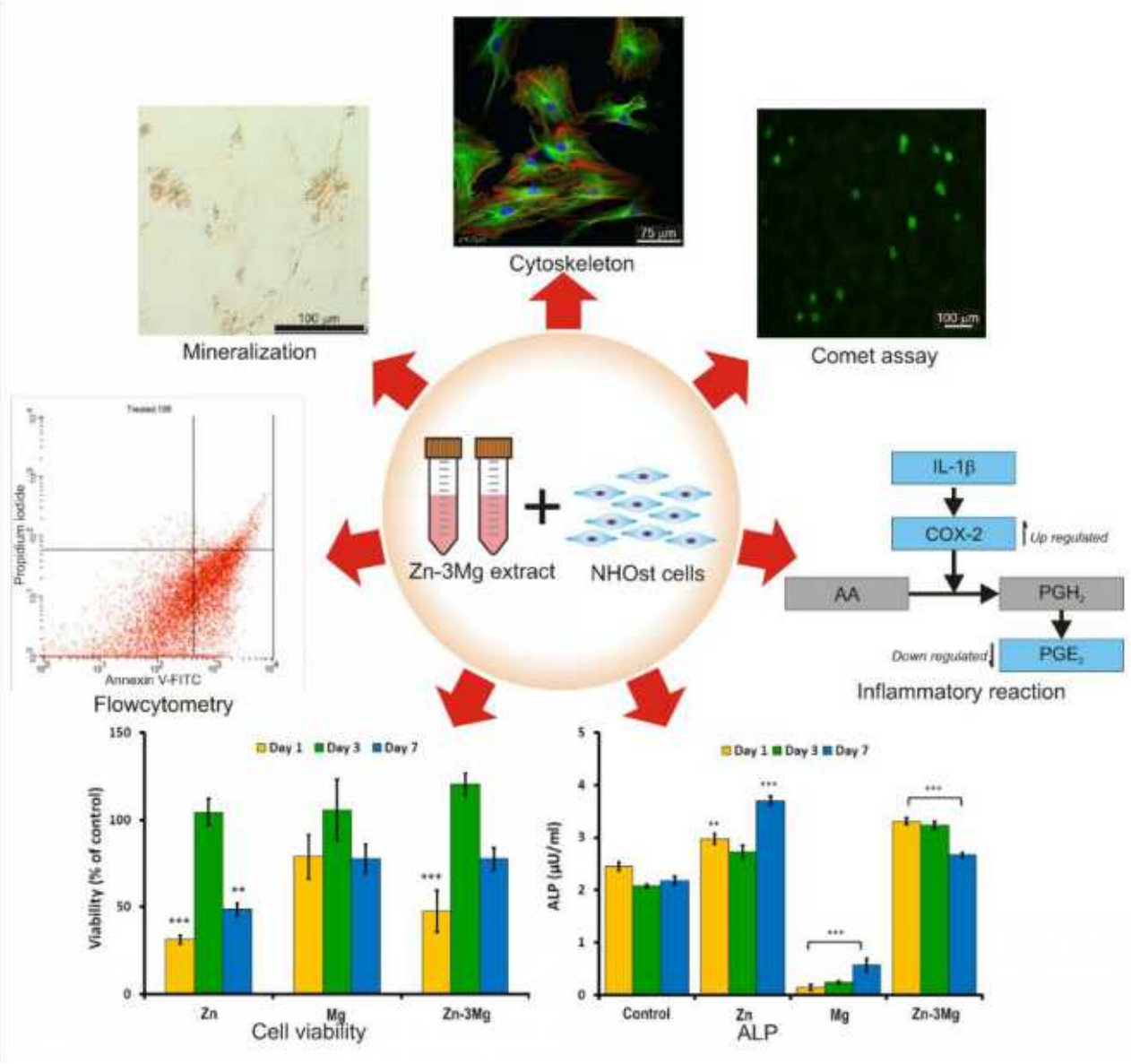


Fig. 3. Mechanical properties of the alloys: a) Vickers hardness (HV 5) and compressive yield strength (CYS), and b) tensile yield strength (TYS), ultimate tensile strength (UTS) and elongation (E).

Kubásek J, et al. Structure, mechanical characteristics and in vitro degradation, cytotoxicity, genotoxicity and mutagenicity of novel biodegradable Zn–Mg alloys. Mater Sci Eng C 58 (2016) 24.

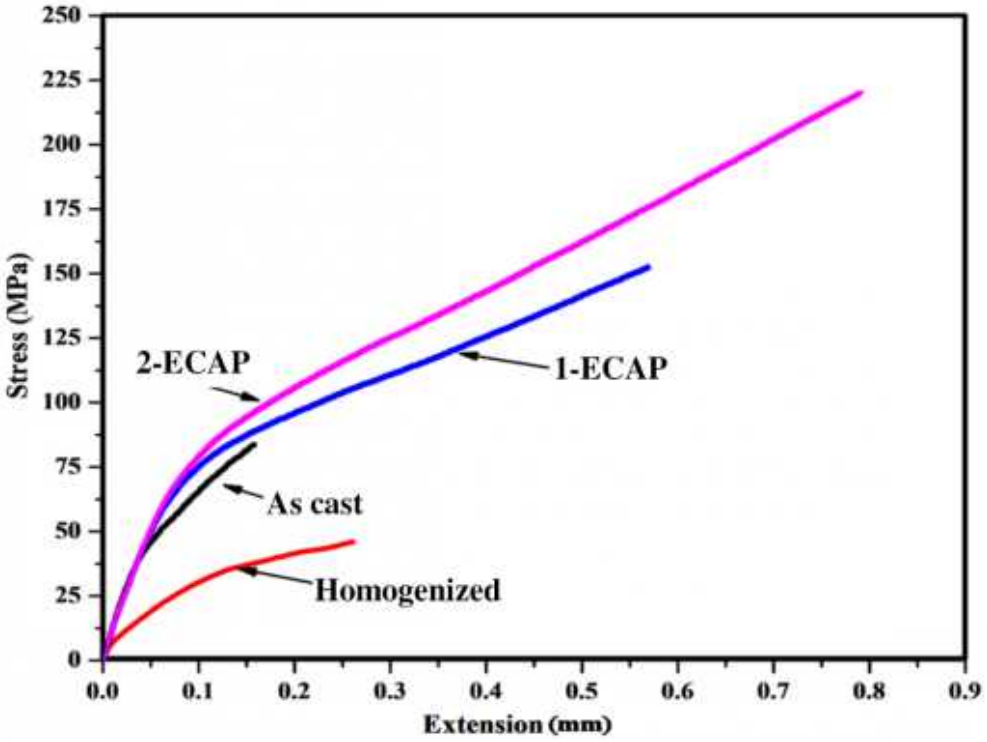
Toxicity of Zn-3Mg alloy

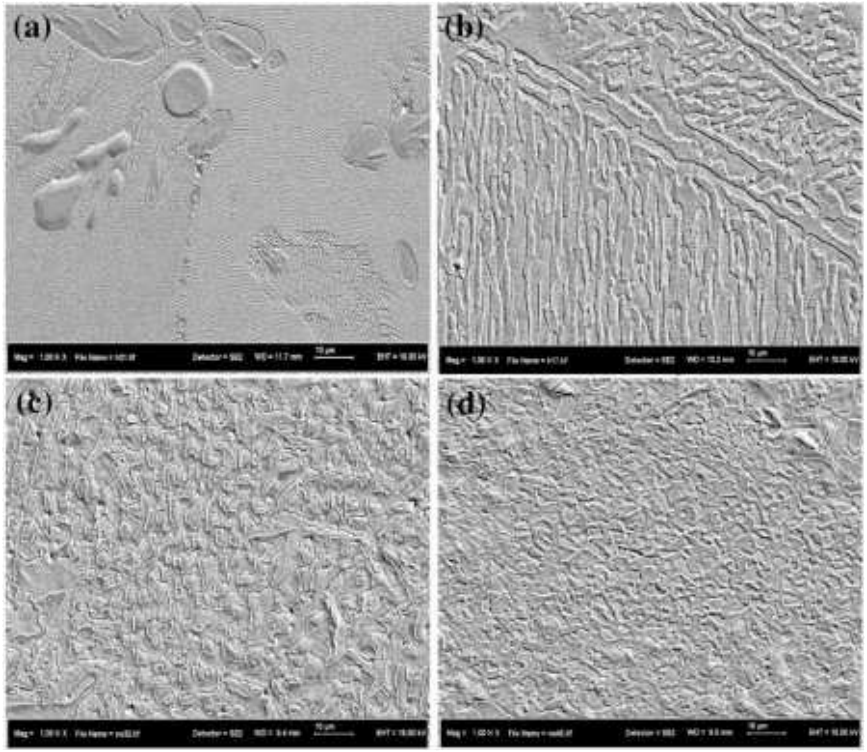


Murni NS, et al. Cytotoxicity evaluation of biodegradable Zn-3Mg alloy toward normal human osteoblast cells. Mater Sci Eng C 49 (2015) 560.

Zn-3Mg alloys

Mechanical property enhancement via ECAP





Zn-3Mg alloy

Condition	Tensile strength (MPa)	Yield strength (MPa)	Elongation (%)	Young's modulus (GPa)
As cast	84 ± 9	65 ± 9	1.3 ± 0.3	132 ± 4
Homogenized	46 ± 1	36 ± 3	2.1 ± 0.1	84 ± 3
1-ECAP	153 ± 4	137 ± 2	4.6 ± 0.5	205 ± 9
2-ECAP	220 ± 3	205 ± 4	6.3 ± 0.9	210 ± 8

Dambatta MS. PhD thesis. University of Technology Malaysia. 2015

Biodegradable metals: Facts and figures

- Web of Science core collection: publications on biodegradable metals for biomedical applications
  - **Up to 2005 <50**
  - **Over the past 10 years >2,000**
- Researchers in academia and industries see their potential to revolutionize the medical products.
- They are working on developing new standards (ISO, ASTM) in collaboration with the FDA.
- The development is fostered by the advancing knowledge in MSE, corrosion and metal technology, **AND ...**
- Enthusiastic ~120 researchers who gathers each year for a full week meeting in secluded place discussing the field.

Biodegradable metals: Map

Map of biodegradable metals related research groups in 2012, based on publications indexed in Scopus.

Recent papers

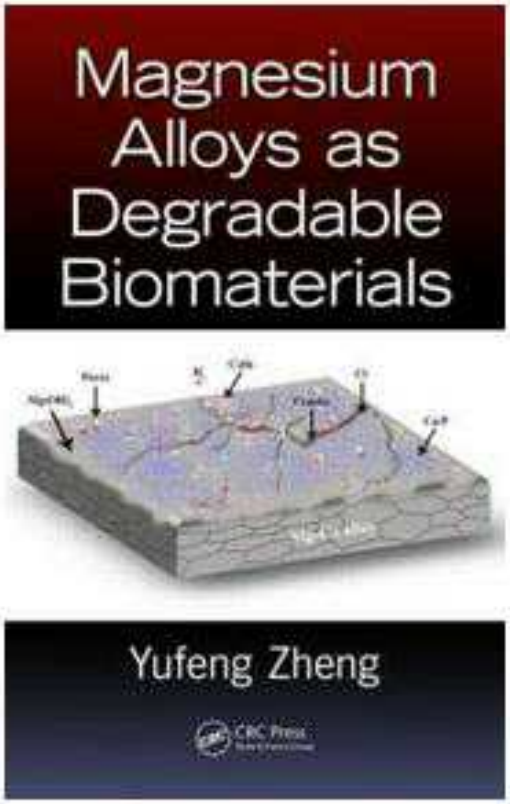
Recent selected research papers:

- Long-term clinical study and multiscale analysis of in vivo biodegradation mechanism of Mg alloy. (*Proceedings of the National Academy of Sciences*, January 2016). LINK
- Controlling the degradation kinetics of porous iron by poly(lactic-co-glycolic acid) infiltration for use as temporary medical implants. (*Scientific Reports*, June 2015). LINK
- Development of biodegradable Zn-1X binary alloys with nutrient alloying elements Mg, Ca and Sr. (*Scientific Reports*, May 2015). LINK

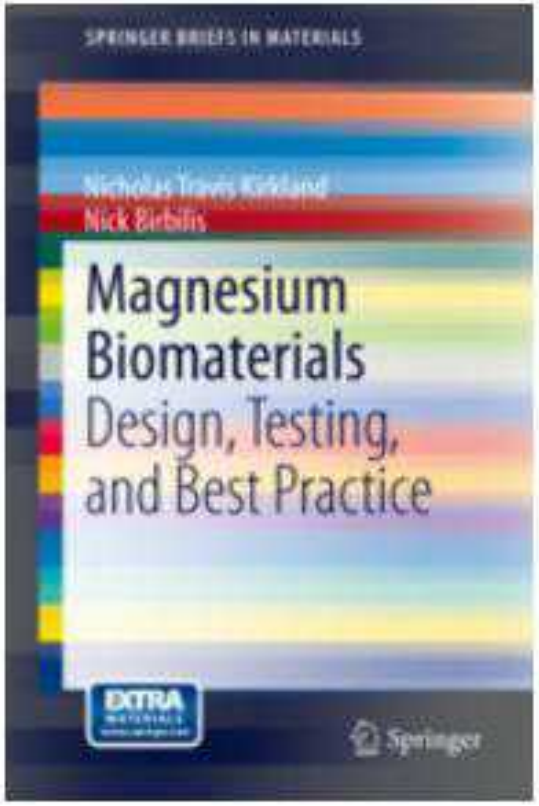
Recent selected review papers:

- Iron and iron-based alloys for temporary cardiovascular applications. (*Materials in Medicine*, February 2015). LINK
- Recent advances on the development of magnesium alloys for biodegradable implants. (*Acta Biomaterialia*, November 2014). LINK
- Biodegradable metals. (*Materials Science and Engineering R*, March 2014). LINK

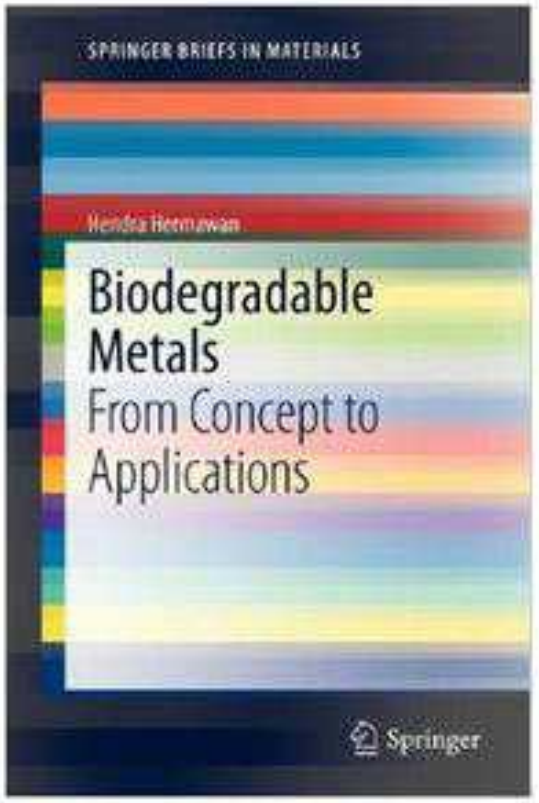
Books



2015
LINK



2014
LINK



2012
LINK

ASTM standard (draft)

Date: June 15, 2015
Tech Contact: John Disegi, disegi.john@synthes.com
Work Item #: WK46455
Ballot Action: Standard Guide for Metallurgical Characterization of Absorbable Metallic Materials for Medical Implants
Rationale: New guide to support the standardization of future specifications for absorbable metallic materials for medical implants.

Standard Guide for Metallurgical Characterization of Absorbable Metallic Materials for Medical Implants

1. Scope

1.1 This guidance document provides metallurgical characterization information that may be beneficial in the evaluation of absorbable metallic materials intended for medical implant applications. This guide is primarily intended for absorbable metallic materials. A few relevant standards for finished implant devices are included for information purposes.

1.2 The purpose of this guide is to provide appropriate test methods and relevant medical product standards that can be used to develop future standards for new or modified absorbable metallic materials.

1.3 This guide is not intended to cover other major classes of materials such as polymers, ceramics, composites, and tissue engineered materials.

1.4 This standard guide is focused on the chemical, physical, microstructural, and mechanical properties plus inspection guidelines for wrought and cast metallic materials that are used for medical implants designed to absorb in the body over a period of time. It does not include safety and biocompatibility requirements since safety and biocompatibility testing is typically done on materials fabricated into a final form to include all possible effects of fabrication and sterilization techniques.

1.5 Compliance with materials specifications developed in accordance with this standard may not necessarily result in a material suitable for its intended purpose. Additional testing specific to the intended use may be required.

2. Referenced Documents

2.1 ***ASTM Standards:***

A262 Practices for Detecting Susceptibility to Intergranular Attack in Austenitic Stainless Steels
A342 Test Methods for Permeability of Weakly Magnetic Materials
A480/A480M Specification for General Requirements for Flat Rolled Stainless and Heat-Resisting Steel Plate Sheet, and Strip
A484/A484M Specification for General Requirements for Stainless Steel Bars, Billets, and Forgings
A555/A555M Specification for General Requirements for Stainless Steel Wire and Wire Rods
A751 Test Methods, Practices, and Terminology for Chemical Analysis of Steel Products

Commercial products

K-MET
BIORESORBABLE METAL

http://kmat.nayana.kr

K-MET Clinical result

Commercial products

SYNTELLIX

http://www.syntellix.de

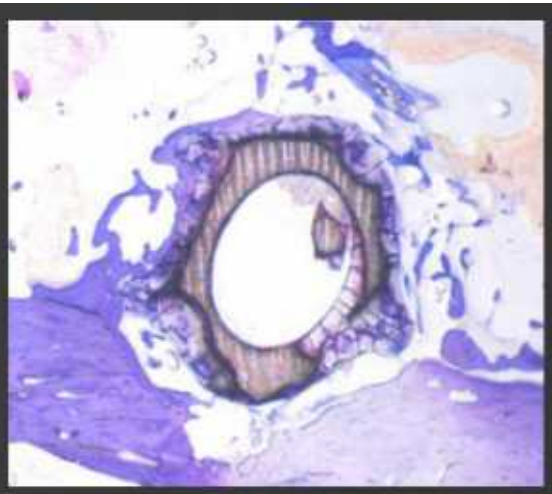
MAGNEZIX

Compression Screw 3.2

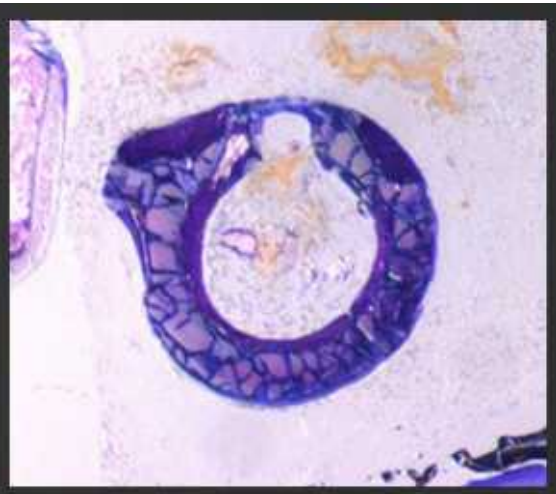
The first resorbable metallic implant in the world.

Magnezix Clinical result

Histological image of implanted MAGNEZIX® Compression Screw after a few days.



Conversion has started of an implanted MAGNEZIX® Compression Screw after several months



Transformation of a MAGNEZIX® Compression Screw into calcium phosphate after 12 months with clear bone adsorption.

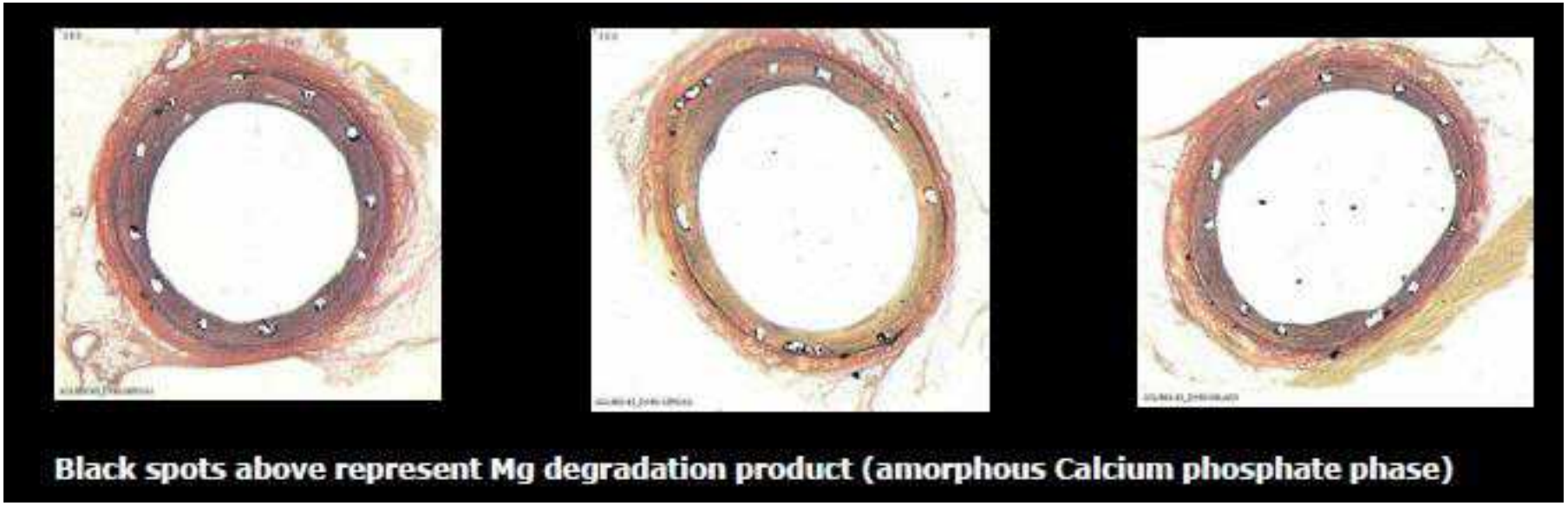
Commercial products

BIOTRONIK
excellence for life

http://www.biotronik.com

DREAMS
(DRug Eluting Absorbable Metal Scaffold)

DREAMS Clinical result



Acknowledgment

https://sites.google.com/site/hendrahermawan




Research team:

- Sébastien Champagne, MS student
- Devi Paramitha, PhD student
- Reza Alavi, PhD student
- Agung Purnama, postdoc

Collaborators:

- Prof. Stephane Bolduc, Hôpital CHUL
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