

# Osseointegration and Dental Implant Research — Contributions from the University of Toronto

A systematic search of bibliographic databases for scientific publications on osseointegration and dental implant research will yield 400–500 research papers originating from investigators working at the University of Toronto faculty of dentistry. The exact number depends on how strictly one defines the 2 terms. Identifying when these investigators started focusing on osseointegration and dental implant research is more difficult. After 40 years, the mechanism by which alloplastic biomaterials can integrate with bone is still not fully understood, and ongoing research directed at elucidating the phenomenon builds on multidisciplinary studies. Research in basic sciences has always been a strong focus in Toronto, well before Dr. P.I. Brånemark and his team in Göteborg, Sweden, published their groundbreaking research showing that titanium implants, which could be effectively anchored in jaw bones, resulted in a predictable and successful long-term clinical outcome. Dr. Brånemark later coined the term for the observed integration of titanium into bone as “osseointegration.”

## A Paradigm Shift in Implant Dentistry

Very early, professor emeritus George A. Zarb recognized the potential of this new technology in the field of dental implants — it would bring about a paradigm shift in the treatment of edentulousness. In fact, his research

team was the first outside Sweden to replicate and verify the clinical results obtained by the Brånemark team.<sup>1</sup> A vast number of patients in North America are indebted to professor Zarb for organizing the Toronto Osseointegration Conference in Clinical Dentistry in May 1982, thereby bringing the new technology to the attention of the academic communities. This singular initiative rendered the use of implant interventions for edentulousness available to the general public much earlier than usual for new treatment modalities, which often take years to be implemented.

Professor Robert Pilliar headed another research group that brought about early innovations in the field of titanium implants and remains active today. Initially, at the Ontario Research Foundation, the focus of Pilliar’s research was on orthopedic implants, but following his appointment to the faculty of dentistry at the University of Toronto in 1978, his program expanded to include oral applications of his porous implant technology. The close cooperation between biomedical implant engineers and dental researchers is an excellent example of how research from interdisciplinary biomedical and engineering fields can benefit patients with missing soft and hard oral tissues.

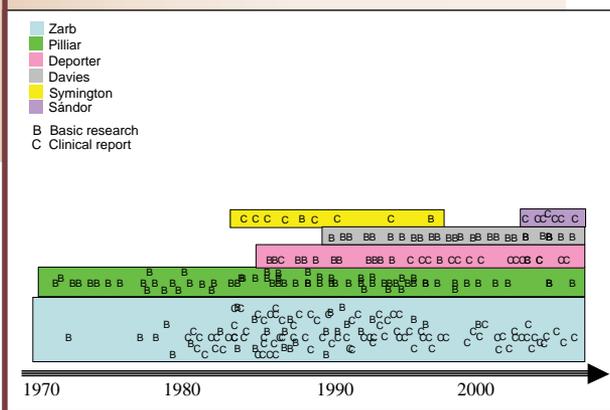
## Translating Research into Treatment

Research programs that have resulted in patented implant designs have evolved into spin-off initiatives. For example, when professors Robert Pilliar, Douglas Deporter and Philip Watson developed a porous coated dental implant, their patent was licensed to Innova Corporation (Toronto, Ont.), who named their product the Endopore implant system. At about the same time, the osteal implant system was



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**Figure 1:** Research papers with a focus on osseointegration and oral implants originating from 6 research teams based at the University of Toronto faculty of dentistry.

patented by the University of Toronto Innovations Foundation. Developed by 2 maxillofacial surgeons, Drs. John Symington and Robin Listrom, this system was used mostly in Ontario and has not attracted interest in international markets to date.

Other individuals and research groups emerged later on, with efforts to capitalize on biotechnological advances in the basic sciences as well as clinical research. One key individual is professor John E. Davies, whose focus is bioengineering research. Arriving from the United Kingdom in about 1990, Dr. Davies has made important contributions to the understanding of the interactions between biomaterials and body tissues, especially bone. In addition to multiple research papers, he has published 2 textbooks on bone-material interfaces and bone tissue engineering — both are considered influential within these fields.

Professor George Sándor, the most recent addition to this impressive research environment, shares his time between the faculty of dentistry and Mount Sinai Hospital. Most of professor Sándor's studies emphasize clinical trials of oral implants and implant site augmentation and are often carried out in cooperation with researchers in other countries, especially Finland.

### Impressive Volume of Research from Toronto

The output of these 6 research groups is illustrated in **Fig. 1**. In addition to those mentioned above, many investigators in both the basic and clinical sciences have contributed to the collection of papers on osseointegration and implant research. With apologies to colleagues who are not named, some who have written multiple papers within the related fields of osseointegration are Jim

Anderson, Cameron Clokie, Richard Ellen, Chris McCulloch, Michael Pharoah, Dennis Smith, Jaro Sodek, Howard Tenenbaum, Ronaldo Todescan and many, many more.

It is clear from **Fig. 1** that the focus and strengths of the individual research groups are unique to each principal investigator, but all complement the theme. Much of the research work of the Pilliar and Davies groups is focused on basic research, whereas the other groups include a mix of both basic and clinical research with an emphasis on the latter. For example, the research that led to the development of the Endopore implant, which was more or less entirely developed at the faculty of dentistry in Toronto, is a model for how a new implant technology, should be developed. A grant from the Medical Research Council in the early 1980s enabled a research program that started with an idea. The idea was first tested in laboratory experiments, then in animal studies and pilot studies in humans before progressing to full-scale prospective cohort studies. Several long-term follow-up studies of the implant system have since been published. It is a great concern in the field today that all too often new implant products are introduced onto the market without following this rigorous process, often taking advantage of the lax regulatory systems in Canada and elsewhere.

In terms of publication, no group has approximated the volume that originated from professor emeritus George A. Zarb's group of investigators. This work centred around the activities of the Implant Prosthodontic Unit, which was inaugurated 25 years ago. More than 150 basic research and clinical papers, editorials and commentaries with a focus on oral implants can be identified. Their authors include Nick Attard, Ross Bryant, Aaron Fenton, Adrienne Schmitt and many others. Moreover, an argument can be made that these papers have had a much bigger impact on the practising dental community than any previous group in this field, as the Zarb group strategically placed its papers in journals targeted toward clinicians, while most other investigators published mainly in more basic science journals.

Unfortunately, no bibliographic indices can support this claim, unlike the research community where the impact of a particular study can be estimated by the extent to which subsequent authors refer to it. The most well known so-called "citation index" was developed and maintained by the ISI Web of Science (<http://isiwebofknowledge.com>). A paper that is cited more than 100 times is customarily termed a "classic." The 15 most

**Table 1** The most frequently cited papers by University of Toronto faculty of dentistry investigators published in the major scientific dental journals<sup>a</sup>

Article	Times cited
Cameron HU, Pilliar RM, Macnab I. The effect of movement on the bonding of porous metal to bone. <i>J Biomed Mater Res</i> 1973; 7(4):301-11	232
Pilliar RM, Lee JM, Maniopoulos C. Observations on the effect of movement on bone ingrowth into porous-surfaced implants. <i>Clin Orthop Relat Res</i> 1986; 208:108-13	177
Smith DE, Zarb GA. Criteria for success of osseointegrated endosseous implants. <i>J Prosthet Dent</i> 1989; 62(5):567-72	165
Zarb GA, Schmitt A. The longitudinal clinical effectiveness of osseointegrated dental implants: the Toronto study. Part III: Problems and complications encountered. <i>J Prosthet Dent</i> 1990; 64(2):185-940	161
Bobyn JD, Pilliar RM, Cameron HU, Weatherly GC. The optimum pore size for the fixation of porous-surfaced metal implants by the ingrowth of bone. <i>Clin Orthop Relat Res</i> 1980; 150:263-70	139
Apse P, Ellen RP, Overall CM, Zarb GA. Microbiota and crevicular fluid collagenase activity in the osseointegrated dental implant sulcus: a comparison of sites in edentulous and partially edentulous patients. <i>J Periodontal Res</i> 1989; 24(2):96-105	123
Davies JE. In vitro modeling of the bone/implant interface. <i>Anat Rec</i> 1996; 245(2):426-45	120
Cameron HU, Macnab I, Pilliar RM. Evaluation of biodegradable ceramic. <i>J Biomed Mater Res</i> 1977; 11(2):179-86	117
Pilliar RM. Porous-surfaced metallic implants for orthopedic applications. <i>J Biomed Mater Res</i> 1987; 21(A1 Suppl):1-33	115
Cameron HU, Pilliar RM, Macnab I. The rate of bone ingrowth into porous metal. <i>J Biomed Mater Res</i> 1976; 10(2):295-302	114
Davies JE. Mechanisms of endosseous integration. <i>Int J Prosthodont</i> 1998; 11(5):391-401	110
Filiaggi MJ, Coombs NA, Pilliar RM. Characterization of the interface in the plasma-sprayed HA coating/Ti-6Al-4V implant system. <i>J Biomed Mater Res</i> 1991; 25(10):1211-29	108
Welsh RP, Pilliar RM, Macnab I. Surgical implants. The role of surface porosity in fixation to bone and acrylic. <i>J Bone Joint Surg Am</i> 1971; 53(5):963-77	106
Davies JE, Lowenberg B, Shiga A. The bone titanium interface in vitro. <i>J Biomed Mater Res</i> 1990; 24(10):1289-306	105
Zarb GA, Schmitt A. The longitudinal clinical effectiveness of osseointegrated dental implants: the Toronto study. Part I: Surgical results. <i>J Prosthet Dent</i> 1990; 63(4):451-7	104

<sup>a</sup>The major scientific dental journals, as defined by ISI Web of Science, has changed over the years; thus, some often-cited papers are not included in this database, e.g., Albrektsson and others.<sup>2</sup>

cited implant research papers originating from the Toronto faculty of dentistry investigators are presented in **Table 1**. Only 1 other university in Canada can boast being cited this often for implant research papers (University of Montreal).

Much criticism can be raised against the use of such citation indices. Perhaps the most important being that a new scientific report, even if the research is excellent and the results significant, will necessarily require some time before it is recognized as such. Thus, a citation index is perhaps more a measure of the quality of past history

of research than current research. Time will tell whether the papers published in the last 5 years will eventually be recognized by the research communities to the same extent as the classic papers.

#### Where Do We Go from Here?

When dental implants were introduced as a new technology some 30 years ago, we did not have answers to the clinical questions of the day, such as: does the technology work? (effectiveness); how does the technology work? (process of intervention or delivery); does it matter to patients? (salience);

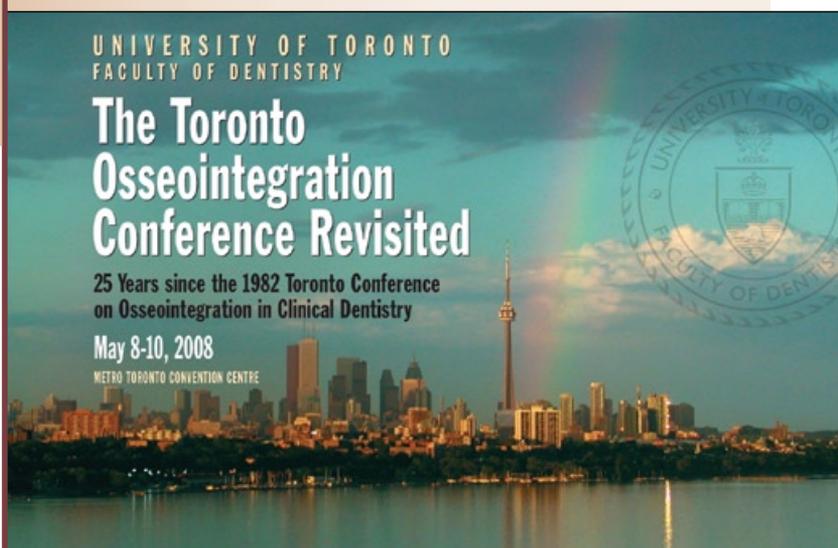


Figure 2: Flyer for the 25th anniversary conference

will it do more good than harm? (safety); will the patient accept the new intervention? (acceptability); is it worth paying for the intervention? (cost effectiveness); is this the right intervention for particular patients? (appropriateness) and are users, providers and other stakeholders satisfied with the intervention? These clinical questions of relevance have been pursued by the Zarb group. The other researchers selected different research avenues, assimilating knowledge from their past experiments, then charting new discoveries in hopes of refining or improving a technology even further. What can perhaps be said in this context is that there is no right or wrong approach, or appropriate or inappropriate avenue, as both databases have been important contributions to the field of osseointegration and dental implants. The ultimate result is that the research has benefited our patients.

The Toronto Conference on Osseointegration in Clinical Dentistry that was initiated and organized in 1982 by professor emeritus George Zarb is regarded by many as the single event that catalyzed the acceptance and introduction of modern implant dentistry in North America, and even globally. In 1982, the focus was on 1 implant design, made from 1 grade of titanium, using 1 surgical procedure advocated by Dr. P.I. Brånemark, and for 1 indication, i.e., completely edentulous jaws. Today, we are confronted with a phenomenal diversity of products, materials, techniques and applications of technologies built on osseointegration.

The 25th anniversary of the inaugural osseointegration conference is an appropriate time to take stock of what has been achieved and to focus on what is emerging as new and innovative developments in the field of osseointegration. Thus, the University of Toronto's faculty of dentistry decided to host another major international conference on osseointegration and dental implants in May 2008 (Fig. 2; see also [www.torontoimplantconference.ca](http://www.torontoimplantconference.ca)). Three simple questions will form the contents of the lectures presented by 70 of the world's top experts, scientists and clinicians: what did the profession believe in

1982? what do we believe now and why? and where do we believe that osseointegration research and the practical applicability of oral implants will go in the next 5–25 years? The conference is open for all to attend and hear about the cutting-edge research and state-of-the-art protocols and technologies that will further advance implant supported treatment. ♦

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2. Albrektsson T, Zarb G, Worthington P, Eriksson AR. The long-term efficacy of currently used dental implants: a review and proposed criteria of success. *Int J Oral Maxillofac Implants* 1986; 1(1):11–25.