Section: Research Paper
ISSN 2063-5346

Evolution of Magnet Retained Overdenture: A Qualitative Review

Dr Rajendra Kumar Dubey[1], Dr Shubhash Chandra Pankaj[2], Dr P Aarani[3]
[1]Professor, Department of Prosthodontics, Government Dental College, Raipur
[2]Lecturer, Department of Prosthodontics, Government Dental College, Raipur
[3]PG Student, Department of Prosthodontics, Government Dental College, Raipur
Corresponding Author: Dr Rajendra Kumar Dubey
B-12, Staff Quarters, Government Dental College Campus, Raipur

---

Abstract: Development of small size magnets with capability of stronger permanent magnetic forces has enable its diverse clinical uses in field of dentistry. The strong attractive force of magnets is harnessed for retention of overdentures as one part is either embedded or attached with bone, decoronated root or implants and another into overdenture base. The basic aim of this paper is to critically review the evolution of numerous magnetic attachment systems that are available for retaining the overdentures, their comparative evaluations to other available contemporary retentive attachment systems, effect of magnetic system on oral tissues & oral environment and the recent advancements in materials and techniques which maintain magnetic properties for longer duration with exceptional corrosion resistance.

Keywords: Magnetic attachment, Overdenture, Retention, Biocompatibility

---

Introduction: Retention is always remained a problem in conventional removable dental prosthesis and the difficulty further enhanced when residual ridges are severely resorbed specially in mandibular arch[1]. Variety of materials and aids like adhesives[2] suction cups[3], springs[4], implants and remaining healthy/ decoronated RC treated roots[5] with various types of mechanical/ magnetic attachments[6] has been evolved to attain retention for removable dental prosthesis in such cases. The Roots or implants utilized to gain support to some extent for overdentures has also proved to be a good means of retention through numerous mechanical or magnetic attachments. Every attachment system has its own advantages and disadvantages and their best uses are decided as per social, economic, clinical and overall health condition of the patient.

Since first introduction of magnetic attachment as retainer for mandibular overdenture, various attempts were made to improve their form, function and biocompatibility. Started from Alnico V alloy permanent magnet, the newly introduced magnetic alloys for permanent magnet like Samarium- Cobalt, Samarium Cobalt Nitrides, Samarium Iron Cobalt Copper Zirconium and Neodymium Iron Boron with provision of encapsulation with nonferromagnetic alloys have enabled to make a small size, corrosion resistant magnet with capability to generate high retentive forces. Closed circuit magnetic system have also empowered to reduce the magnetic field leakage. The permanent magnets produces constant magnetic force and magnitude of force will not decreases overtime[7,8] except the certain extreme conditions like high temperature, large external magnetic field, damage of the magnet due to extreme physical or chemical exposure or corrosion of magnet itself [9,10].

Despite low generation of retentive force and satisfaction in healthy patients compared to other mechanical attachments (ball, stud, bar, locators)[11,12] the magnetic attachments are still popular in certain overdenture cases because of the ease of placement & removal by both patient and dentist, automatic reseating, constant retentive force for longer duration and ease of cleaning[13,14,40]. Thus, this article reviews the evolution of various types of magnetic materials and attachment systems available for root or implant supported overdentures along with comparative evaluation with other contemporary mechanical attachments.

Evolution of Magnetic materials for magnetic attachments: About 3000BC earlier an iron-ore called magnite was discovered from the rock situated in Magnesia, an area of ancient Greece. It's ability to attract particles of iron was observed by Greek and called this invisible attractive effect 'magnetism' named after magnesia [15]. The use of magnets in medical field dates back to more than 2000BC when Hindus refers to treatment of disease with magnet and Chinese developed a written protocol for using loadstones at acupuncture points. Load stones for treatment of seizures by Paracelsus (1550 AD), use of magnet to treat the psychiatric patient by German physician Frenz Mesmer and incorporation of magnets in his treatment by Hahnemann (late 18th century)[16] were the milestone for the use of magnet in medicine. Later on development of magnet alloys with greater permanent magnetic field made the use of magnet in orthopaedic surgery to overcome the non-union of fractures in early 19th century[15]. Since then meticulous advancement in rare earth metal based alloy enabling the magnet with very high permanent static magnetic field per unit volume as well as evolution of Nano magnetic particles (NMPs) has now empowered medical science for diverse application of magnets as tools for diagnostic(MRI, NMPs in contrast imaging), surgical (guide the placement of catheters and tubes, create new connections in GI tract as well as blood vessels and manipulate internal tissues via external magnet) or treatment procedure of neoplasia[17].

In dentistry, Prosthodontist were first to recognise the use of then available permanent magnetic alloys (Alnico based) for retention & stability of dentures utilizing the repulsive forces of magnets by embedding it in opposing dentures (Goldsmith 1952, Freedman 1953, Tsubone 1955)[18,19]. The attractive forces of magnets were harnessed for stabilisation of maxillofacial prosthesis to dental prosthesis or split denture parts (Nadeau 1956, Robinson J E (1963),Rosenthal L E(1964), Boucher J L(1966), Thomas C J (1970) and N Javed (1971), Fredrick 1976, Sasaki H et.al.1984)[20,21,22,23,24].

Behrman was the first, who inserted the Alnico V magnet coated with medical grade acrylic resin in molar region of edentulous mandible for achieving retention of overlying complete denture with another embedded magnet in the base to accomplish attractive force[25]. After advent of Co Pt a magnetic alloy with good Remanence, high coercivity and corrosion resistance in 1961, Toto et.al.(1962)[26] and John F. Schmitz (1966)[27] implanted Co Pt magnet in alveolar bone of dogs and human being respectively. They observed good adherence to bone and fibrous tissue as well as substantially increased vertical and horizontal resistance of denture generated by the implant. But the procedures were abandoned due to high cost of Co Pt, difficult fabrication and low success rate due to migration of magnet through bone & soft tissue [28,10].

The first tooth supported overdenture gaining some retention by utilizing attractive force of magnet was presented by Thomson (1964)[29]. He obtained coping over remaining 3 maxillary teeth and properly fit thimbles over the coping by casting with Co Pt castable alloy and subsequently magnetised both before cementation of coping and placement of thimbles into denture base. Later on Moghadam B K (1979)[30], cemented an Alnico V magnet (customised by cutting in proper shape and size) in prepared space involving cervical part of root canal & coronal chamber and another customised magnet opposite to it into the overdenture base to successfully achieve retention. Evolution of rare earth metal based $SmCo_5$ magnet in 1967-68[31] enabled to get a smaller, permanent and more powerful magnet for use of smaller magnetic root attachment system but low corrosion resistance and fear of harmful effect due to persistent magnetic field over oral soft tissue remained an issue. Sasaki H et al and H Harada[32,33,34] proclaimed the use of Pd-Co-Cr/Ni alloys as root keeper in place of magnet due its property of easy magnetisation when it comes in contact of another magnet and demagnetisation after removal of magnet (soft ferromagnetic material) with satisfactory corrosion resistance. Numerous Pd based alloys were investigated as soft ferromagnetic material for root keeper, the Pd Co Pt proven to be best corrosion resistant[35]. Thus the use of corrosion resistant soft ferromagnetic material as root keeper decreased the apprehension of harm by magnetic field as well as corrosive products to oral tissue when the prosthesis is out of oral cavity. But magnet into overdenture still remains reason for fear of corrosion and magnetic field harm to oral tissue, which were appreciably reduced by evolution and use of closed field magnet[36] (prepared either split pole design by pairing or by making circular disc of single magnet and soft ferromagnetic keeper to shunt the magnetic field and concentrate the magnetic field near the magnet) and coating/encapsulation of magnet with non- corrosive nonferromagnetic alloys[37,38].

Invention of Nd Fe B RE based magnetic alloy[39] with very high magnetic remanence and coercivity, further facilitated to make much smaller size magnet. But low corrosion resistance and low curie temperature was the concern for its use. Encapsulation of Nd Fe B magnet with thin sheet of nonferromagnetic corrosion resistant material like Pd Co Pt /stainless steel/Titanium by laser welding, cup yoke type systems were developed to efficiently address this problem. Chronology of magnetic materials development for various dental usage in general and overdenture in particular may enable us make a understanding in this regard (table -1)

Types of magnet used for retaining overdentures: The magnets used for overdenture magnetic attachments(MGA) are classified on the basis of alloy material used, its ability to retain the magnetic properties, nature of magnetic field generated, surface coating for reducing corrosion and number of magnets in magnetic attachment. The classification along with key features of magnets are summed up in table-2[40, 41.]

Evolution of overdenture magnetic attachment's design: The conventional overdenture magnetic attachment system is a two-component system – one component is attached with root/ implant and the other is incorporated into the base of overdenture. In the very beginning both the components were magnets including a casted coping and the properly fitted thimble of Co Pt, which are magnetised before cementation over prepared tooth and placement into denture base respectively [29]. Subsequently with advent of small size corrosion resistance coated magnets ($SmCo_5$), the magnetic attachment system had a small disc shaped magnet with/ without root extension or screw which has to be cemented/screwed in prepared tooth space of RC treated decoronated root /osseo-integrated implant. The other small oval or circular disc shaped magnet was placed into base of overdenture facing opposite pole in contact of first cemented or screwed. To reduce the fear of persistent magnetic field harm to oral tissue, the component attached with roots / implants are replaced with corrosion resistant soft ferromagnetic material called as root/ implant keeper. Such alloys have been casted to form a root coping or preformed keeper with or without a screw thread[10]. Pd Co, Pd Co Cr, Pd Co Pt, Pd Co Ni, stainless steel, Permendur (an alloy of iron and cobalt), Chromium molybdenum alloy, Titanium and its alloy with molybdenum has been investigated and found suitable material for keeper[42]. Titanium or its alloys are preferred materials for implant keeper. The keeper is magnetized (induced) when it comes into the contact of another magnet, called as retentive component placed into overdenture base and demagnetised immediately after removal of overdenture. Various types of root keepers, available for use in different clinical situation, are summed up in **Box-1**[43].

Introduction of a new permanent magnetic alloy of neodymium-iron-boron[39], which has 20% more magnetic strength than cobalt samarium per unit volume, has provided the opportunity to further reduce the size of magnet. But its high susceptibility to corrosion in oral environment and low curie temperature compelled to develop a corrosion resistant non ferromagnetic material with greater resistance toward abrasion for encapsulating the magnet. Encapsulation is done by sealing the hard magnetic material (Nd Fe B) inside soft magnetic component (cap and bottom plate) and a nonmagnetic ring. Cap, bottom plate and nonmagnetic ring are sealed by laser welding. Nonmagnetic area created by ring is essential for generation of magnetic circuit enhancing the retentive force between keeper and retentive magnetic assembly. The keeper is a thin disc of soft ferromagnetic material with small diameter long screw for attaching with root/implant. On the basis of connection between keeper and retentive magnet , the magnetic attachments are grouped as flat type, dome type and cushion type[44]. The flat type generates greater retentive force compared to dome and cushion type magnetic attachment hence creates greater lateral load and crestal bone loss. Cushion-type and dome-type attachments are better choices in two-implant-retained mandibular overdentures, especially for patients with bad bone conditions such as osteoporosis or when a shorter or smaller diameter implant has to be used[45]

A navel cup-yoke type magnet, with neodymium–ferrite–boron (Nd–Fe–B) as the magnetic component, surrounded by a cup of ferritic stainless steel (SUS434) and a bottom plate (SUS304), and sealed using the laser-welding technique is reported with good retention, strength and durability for clinical use. Nonmagnetic area is created on bottom plate by high frequency heat treatment[46].

The commonly used contemporary prefabricated implant keepers and encapsulated magnet of different materials and compatible with different implant systems or decoronated root, supplied and marketed by manufacturers, are enlisted in **table -3**.

Comparison of magnetic attachment verses mechanical attachments used for overdenture

Numerous mechanical attachments (MCA) like ball/bar/locator are available to provide excellent initial retention to implant/ root supported overdentures. Several studies[47, 48, 49, 50, 51, 52, 53,54, 55, 56, 57] compared the magnetic attachment (MGA) to mechanical attachments(MCA) out of which only one study is reported 10 years prospective comparison. However number of studies were performed separately to evaluate of various properties of mechanical or magnetic attachments. On the basis of these studies, comparision was made and conclusions were drawn (table -4.)

Most of the studies reported that magnetic attachment(MGA) were proved to be as good as MCA as they exhibited good comparable survival rate, higher plaque accumulation but good Periotest value (PTV) in longer duration, lower crestal bone loss, lower stress over the abutments and lesser maintenance cost. Low initial retention besides maintained over longer duration, lower patient satisfaction, high initial cost and chances of exposure of the corrosion susceptible magnet were the notable pitfalls of MGA compared to the MCA. Easy to clean, easy removal and placement by patient , automatic reseating, less lateral loading may prove the MGA retained overdenture to be a choice of preference in patient of physically handicapped or mild Parkinson's disease.

All the studies conducted to compare the MGA to MCA were performed before the advent of novel magnetic attachment claimed to be generate good retentive force and high corrosion resistance capability for longer duration with being a much smaller in size.

Effect of magnetic system used in overdenture on human body and oral tissue

Commonly used magnetic system for retaining overdenture in recent past are Rare Earth (RE)metal based alloys permanent magnets (Neodymium-iron-boron or samarium-cobalt based magnets) with moderate magnetic intensity(1mT -600mT).[63]Closed field type magnetic attachment or open field type RE magnets, usually employed for retention of removable prosthesis, will expose the adjacent oral tissues with sustained static magnetic field (SMF)[64,65]. These magnetic field attachments will also generate stray fields called flux leakage that spread to adjoining oral tissues.[65,66,67,68]

The RE metal based permanent magnets used in overdentures produces magnetic field in range of 1 mT – 500mT. There is negligible chances of deleterious effect of these magnet on human body as number of laboratory studies confirms that static magnetic field up to 1-2 T do not seem to influence the vital biological processes like cell growth and morphology, DNA structure, reproduction, physiological regulation and circadian rhythms[69]. In- vitro studies [70,71]performed on cultured mouse fibroblasts directly exposed to rare earth samarium-cobalt and neodymium-iron-boron magnets observed mild or negligible cytotoxicity in the cells exposed to coated magnets, while uncoated magnets showed obvious cytotoxicity. One study[72] reported cytotoxicity with bare magnet as well as magnet coated with parylene C.

Some In-vitro studies[73,74] when gingival fibroblast exposed with moderate SMF for longer period (7-8 Months) or high SMF with non-homogeneous magnetic field of the intensity and the gradient but not in direct contact of magnet, reported no significant difference in cell size and surface morphology as well DNA contents of exposed and control cells, while some studies[75]observed that exposure of fibroblast cultures to moderate strength SMF has little influence on growth. High-density SMF exposure may increase DNA damage due to a significantly higher micronucleus frequency was perceived in the only study conducted by Yagci and Kesim[76]. A study[77] found significantly higher cellular activity and anabolic processes, indicating that SMFs stimulate the proliferation and synthetic activity of fibroblasts, collagen in particular, with osteoblasts devoid of any significant trend in response to SMFs.

In vivo studies performed on dogs[78], monkeys [79, 80] or human beings[81,82,] when coated/encapsulated RE metal dental magnets were implanted on surface of teeth for duration of 4 to 8 weeks, the SMF generated by these magnets did not exhibit any morphological or histological changes in the dental tissues (pulp) and to those tissues adjacent to the teeth (gingiva, oral mucosa and alveolar bone).

Extensive laboratory studies shown that various other significant biological processes do not seem to be influenced significantly by static magnetic fields even up to 1–2 T. These processes include: cell growth and morphology, DNA structure, reproduction, physiological regulation and circadian rhythms .[83]

Therefore, almost all the in-vitro or in-vivo studies indicated that moderate static magnetic field generated by RE dental Magnets had no significant effect or changes in the adjacent oral soft and hard tissue even at cellular level but may stimulate the anabolic processes and mild proliferative activity in collagen fibres in fibroblast . The SMF itself did not induce cytotoxicity but corrosion products of bare magnets lying in contact of tissue showed strong affiliation with cytotoxicity. Duration of exposure with SMF was within the limit of a year or less in all the studies included. Long term studies with exposure duration more than 2 years are yet to be conducted to verify the effect of SMF on adjacent tissue mimicking the real clinical scenario.

Evolution of corrosion resistant magnetic attachment for overdenture

The early cobalt based magnetic material utilized for retaining overdentures like Alnico V is quite corrosion resistant in oral environment but generates low retentive force per unit volume. Therefore a bulky magnets required to achieve the adequate retention are now abandoned for use. Smaller Co Pt magnets with greater corrosion resistance and satisfactory retentive force are also cast-offed due to high cost, difficult casting to fabricate and limited availability. New powerful magnetic materials based on Rare earth metal, samarium with cobalt and Nd Fe B were introduced in 1967 and 1984 respectively having more than 5 times magnetic remanence compared to previous cobalt based materials. But susceptibility to corrosion in oral environment was the measure limitation encountered with these materials. The Nd Fe B exhibited much higher corrosion susceptibility than Sm Co_5 observed in studies[84].Coating of magnet with polymers , were tried to prevent the corrosion but ingress of moisture and ions as well as easy wear of polymer expose the magnet to corrode in oral environment. Encapsulation of RE alloy magnet with various corrosion resistant and wear proof materials like stainless steel and titanium/ titanium based alloys with laser cold welding were introduced and proved to be quite successful. The magnet is encapsulated in a soft magnetic corrosion resistant cup and bottom plate with a nonmagnetic ring creating two laser welded joint at the bottom. A novel cup-yoke type magnet was recently presented with (Nd–Fe–B) magnetic component, surrounded by a cup of ferritic stainless steel (SUS434) and a bottom plate (SUS304), and sealed using the laser-welding creating a single joint at bottom, which further strengthen the idea of good seal. Nonmagnetic area is created on bottom plate by high frequency heat treatment.[46]

Replacement and advent of corrosion resistant material for root/ implant keeper similar to the encapsulating material also empowered the magnetic attachment being more wear and corrosion resistant.

Table 1 Chronology of invention and development of magnetic materials in general and their uses in dentistry in particular

3000-2500 BC	Very first documentation of magnet noted in area of Asia minor called magnesia, where a type of rock with ability to attract the tiny bit of iron was observed by locals and called it “magnetite”.
1930	Yogoro Kato and Takeshi Takei developed a ceramic material called ‘ferrite’ with composition Fe_3O_4 and additional metallic element Mn or Ni with Zn having initially soft magnetic properties. Later on during 1950-1960 development of Fe_3O_4 with Co make it semi hard and with Sr or Ba it converted into hard magnets. Besides being economical, low magnetic remanence per unit volume and low corrosion resistance defies its use in field of health sciences.
1931	Alni(AL20% Ni10% Fe65%) was the first magnet developed by Tokushichi Mishima also called as MK steel magnet having good magnetic remanence but low coercivity and corrosion resistance
1932	Alnico(Al Ni Co Fe) magnet was the first Cobalt containing isotropic cast magnet introduced by T. Mishima having improved magnetic remanence and corrosion resistance but low coercivity.
1938	Oliver and Sheldon invented anisotropic Alnico magnets with very good magnetic remanence, moderate corrosion resistance and high coercivity making it a permanent magnet.
1961	Marlin S Walmer developed and patented Co Pt magnet, a powerful permanent magnet with small size, high coercivity and corrosion resistance compared to the other magnetic material available till date.
1966	Hoffer reported that YCo_5 has a relatively large crystal anisotropy with a single easy axis of magnetization.

1967 - 68	Becker and Hoffer developed a new magnetic alloy $SmCo_5$. KarlStrnat reported improved maximum energy density i.e. (BH)max of this magnet which further improved by the work of Buschow. $SmCo_5$ is generally considered as first generation of rare earth permanent magnetic material.
1977	Robert J Connor – Protect the Sm-Co magnet from oral environment by applying a coat of Proplast, PTFE or Pyrolytic graphite to make it corrosion resistance
1978	Sasaki H et al reported Pd- Co / Pd-Co-Cr alloys as soft ferromagnetic material used for root keeper.
1984	Masato Sagawa invented Nd Fe B material having a very high magnetic remanence, coercivity but low curie temperature and corrosive resistance.
1984	Neodymium-iron-boron magnets were developed by General Motors and Hitachi simultaneously for commercial use
1991	Osamu OKUNO developed cup yoke type magnetic attachment , The magnetic attachment has a Sm-Co magnet kept in a cup yoke and a disk yoke made of ferromagnetic stainless steel. The corner of the cover should be insulated flux with a non-ferromagnetic stainless steel ring. The yoke and the cover were sealed with the ring by laser welding.

Uses of magnet in dentistry

1950- 1959 Utilisation of repulsive forces for denture stabilisation	Goldsmith(1952) U.S. patent "Denture and Artificial teeth" is considered to be the first application of magnet in dental prosthesis. Freedman(1953) – Uses repulsive forces to stabilize dentures by applying magnets in dentures occlusal surface opposing to each other in compromised alveolar ridge cases.Tsubone (1955) is early researcher who patented the magnet embedded in denture
1960-1970 Utilisation of attractive forces by implanting/ incorporating magnets in jaw bone and base of denture for denture retention	Berhman (1960)developed the method of implanting a magnet in the jawbone.Two magnets are embedded in the denture, and the attraction force of the these magnets is applied to the denture for getting retention.Toto et al. (1962) implanted Co-Pt root magnet in dogs and observed good adherence to bone and fibrous tissue. Thomson(1964)- tooth supported overdenture gaining some retention by utilizing attractive force of castable Co Pt magnet. John F. Schmitz(1966)inserted Co Pt implant in mandibular alveolar bone

	of 7 patients and noted substantially increased vertical and horizontal resistance of denture generated by the implant.
1956-70 Utilisation of attractive forces for retention stabilisation of maxillofacial prosthesis	J Nadeau (1956)was first to place " Magnetic stabilizer" to stabilise the obturator and facial prosthesis. Robinson J E (1963),Rosenthal L E(1964), Boucher J L(1966), Thomas C J(1970) and N Javed(1971) are presented and described the use of attractive magnets for retention and stabilisation of maxillofacial prosthesis.
1975-1990 Utilisation of attractive forces in orthodontic Procedure	Blechman and Smiley (1978)-Bonded aluminium-nickel-cobalt magnets to the teeth of adolescent cats to produce tooth movement. Muller(1984) described diastema closure using samarium-cobalt magnets bonded to the labial surfaces of the incisors.Blechman(1985) carried out first in vivo magnet study in which samarium-cobalt magnets were attached to the teeth of two patients and combined with a sectional archwire technique.Kawata et al.(1987) described a new magnetized edgewise bracket which consisted of a $CoPt_5$ magnet, plated with chromium to prevent corrosion and with nickel, to allow soldering to attach the edgewise bracket.
1980 -onwards Utilisation of attractive forces for retention of tooth/implant supported overdentures	Moghadam B K (1979) presented the use of modified small disc magnet(Alnico V) cemented in RC treated root cavity and another magnet in base of overdenture and reported much improved retention of the overdenture. D M Davis(1997) reported 12 cases of implant supported overdenture retained with magnetic attachment (Sm Co) treated during 1990-92 utilizing Astra tech Implant System.

Table 2 Types of Magnets used in overdenture magnetic attachments [40,41]

Basis of classification	Class	Examples / composition	Remarks
Alloy material used	Alloy with Co	MK steel, Alnico V, Co-Pt, Co_5Sm, Sm-Pr-Co_5, $Sm_2(Co\text{-}Fe\text{-}Cu)_{17}$, $Sm_2(Co\text{-}Fe\text{-}Cu\text{-}Zr)_{17}$,	Best for high temperature use, readily available in rods bar and button, good corrosion resistance. Rare earth(RE) metal (Sm) based magnets have high magnetic force per unit volume.
	Alloy without Co	Nd_2-Fe_{14}-B, Sm-Fe-nitride	RE metal based Permanent magnets having very high magnetic force/ unit vol. but less corrosion resistance. Hence generally available
			in coated/encapsulated form for clinical use.
Ability to retain magnetic properties	Soft	Alloy of Pd-Co, Pd-Co-Ni, Pd-Co, Cr-Pd, Fe-Co, Cr-Mo, Magnetic stainless steels.	Easy to magnetise but loose its magnetic properties in short period. Used for preparation of Keeper
	Hard	Alnico alloys, Nd-Fe-B, Co-Pt, Co_5Sm.	Able to retain its magnetic properties for longer period, permanent magnets, commonly used for retention of Prosthesis
Surface coating/encapsulation	Coated	Magnets Coated / encapsulated with Au, TiN, Parylene C or Stainless steel	Coating /encapsulation provides corrosion resistance enabling the magnet to function for longer duration in oral environment without causing cytotoxicity
	Uncoated	Bare magnets	Creates higher magnetic force but Less corrosion resistance defies its clinical use.

Type of magnetism	Repulsi on	Use of two magnets facing same pole to generate repulsive force	Used for retention of maxillary and mandibular dentures in early days.
	Attracti on	Use of opposite poles of two magnets or a magnet & a keeper (ferromagnetic alloy) to create attractive forces.	Magnet and keeper system is commonly utilized today for retention in dentistry
Type of magnetic field	Open Field	Single or paired cylindrical open end magnet	Only one pole attraction force used for attachment. Open magnetic field may affect the oral tissue.
	Closed Field	Soft magnetic materials that connects 2 poles so the external field is shunted through the path of less	Provide higher retentive force than similarly sized open end system but force reduces rapidly with increasing separation. It limits the magnetic field effect in oral cavity
		resistance, reducing external field.	
Number of magnets in the system	Single		Lesser breakaway force than Paired
	Paired	Two magnets with opposite poles next to each other	Provides a greater breakaway force than single magnet

Box-1 **Types of root keeper**[42]

Cement-in keeper: Indicated in limited denture space situation and unsuitable for small roots due to fair chances of lateral root perforation or for patients prone to caries . Prefabricated 5 mm long, 3 mm wide, and 1.2 mm thick, with the root face large enough to accommodate a cavity of this size. It can be cemented /fitted in one visit.

Screw-on keeper: Indicated where enough denture space is available or the root face is too small to accommodate a cement-in keeper. It is used where the root may require shortening. It can be easily removed and replaced. Its most extensive measurements are 6 mm long and 4 mm wide and typically covers much of the root face. It can be fitted in a single visit.

Cement-on keeper: its retention is gained by a soldered-in wire loop, and it is comparable to the screw-on holder. It is easiest one to match with all keepers but its removal is difficult. It can be fitted in very short time and most favoured type to use.

Cast root cap and dowel keeper: it is indicated where coverage of complete root face is required to reduce the risk of dental caries. It is casted in a magnetizable alloy utilizing techniques for base metal (Co Cr) casting

Table 3 Commonly utilized implant / root magnetic attachment to retain overdentures

A. Magnetic attachment utilised with dental implant				
Name of manufacturer	**Magnet**		**Keeper**	
	Trade name	**Material/ seal**	**Trade name**	**Material**
Aichi Steel Co., (Aichi, Japan)	Magfit-IP-IDN Dome type	NdFeB-laser welded seal	Magfit-IP-IDN abutment	CrMoTiMnC : Febal AUM 20
	Magfit-IP-IFN flat type	NdFeB-laser welded seal	Magfit-IP-IFN abutment	CrMoTiMnC : Febal AUM 20
	Magfit IP-ICN cushion	NdFeB-laser welded seal	Magfit-IP-ICN abutment	CrMoTiMnC : Febal AUM 20
	MicroPlant Primary anchor	NdFeB-laser welded seal		**Ti**
Brasseler, Lemgo, Germany	MicroPlantsecodary anchor	NdFeB-laser welded seal		**Ti**
Dyna , bergam op zoom, Netherlands	**WR magnet S3 small**	NdFeB-laser welded seal	**Medical anchor**	**CoCrNiMo:febal**
	WR magnet S5 standard	NdFeB-laser welded seal	**Medical anchor**	**CoCrNiMo:febal**
Stecho, Hamburg, Germany	X-Line ,Z-line and k-line KTitanmagnetics	**$SmCo_5$**-laser welded seal		**Ti**
Technovent,	**Magna cap - Micro**	NdFeB-laser welded seal	**Magnabutmet mini**	CrMoTiMnC : Febal

Leeds, UK	**Magna cap - Mini**	NdFeB-laser welded seal	**Magnabutment maxi**	CrMoTiMnC : Febal
	Magna cap - Midi	NdFeB-laser welded seal		
	Magna cap - Maxi	NdFeB-laser welded seal		
Attachments international, USA	**Magnedisc 800**	NdFeB-laser welded seal	**Universal keeper**	CrMoTiMnC : Febal
Preat, USA	**Shiner regular magnet**	NdFeB-laser welded seal	**Shiner regular implant keeper**	CrMoTiMnC : Febal
	Shiner mini magnet	NdFeB-laser welded seal	**Shiner mini implant keeper**	CrMoTiMnC : Febal
B. Magnetic attachment utilized with root/ reduced coronal part				
Aichi Steel Co., (Aichi, Japan)	Magfit DX 400	NdFeB-laser welded seal	Magfit DX 400 keeper	CrMoTiMnC : Febal
	Magfit DX 600	NdFeB-laser welded seal	Magfit DX 600 keeper	CrMoTiMnC : Febal
	Magfit DX 800	NdFeB-laser welded seal	Magfit DX 800 keeper	CrMoTiMnC : Febal
Dyna , bergam op zoom, Netherlands	WR magnet S3 small	NdFeB-laser welded seal	Direct-System-Keeper	PdPtCo
	WR magnet S5 small	NdFeB-laser welded seal	EFM Alloy	PdPtCo
Technovent, Leeds, UK	Magna cap - Mini	NdFeB-laser welded seal	Insert keeper-mini	CoCrTiNiMo : Febal
	Magna cap- Maxi	NdFeB-laser welded seal	Insert keeper-maxi	CoCrTiNiMo : Febal
			Post keeper-mini	CoCrTiNiMo : Febal
			Post keeper-maxi	CoCrTiNiMo : Febal
Preat, USA	Shiner regular magnet	NdFeB-laser welded seal	Regular toothpiece	
	Shiner mini magnet	NdFeB-laser welded seal	Mini toothpiece	
Magnedesign, Nagoya, Japan	**Magteeth (MT 600)**	NdFeB-laser welded seal	Castable type	Pd Co
	Magteeth (MT 800)	NdFeB-laser welded seal	Root keeper(RK)	Stainless steel (AUM20)

Section: Research Paper
ISSN 2063-5346

Table 4 Comparison of MGA to MCA

Parameters	Magnetic attachment	Mechanical attachments
Retention	-Initially quite low (2-5 times low) range from 1.6-6.5gf [52] compared to mechanical attachments but remains same for longer period. -Beyond 5000 functional cycle of removal and insertion equivalent to 2.7 yrs , the magnet started losing its retentive property[57]while several observations[58,59,60] contradicted it. -Exposure of 20% magnet observed [52] in 2 yrs hence replacement neededas corrosion may start.- Use of number of magnetic attachments also increases the retentive force[61]	-Initially higher retentive force (6-12gf for ball and 16-20gf for bar[52]but decreases with time. - After every 1-2 years elastic ring / clip has to be replaced due to loss of its elasticity
Survival rate of MGA/MCA	Good survival rate (90-92%)of MGA but less than MCA when observed for 60 months[51]. But few studies shows that corrosion of magnet due to abrasion of capsule and exposure magnet may decrease the survival of attachment	Good survival(96-98.6 %)[51]but frequent replacement of elastic ring or bar clip required.
Bone loss around root/ implant abutment	Studies observed less bone loss distal to the abutment in MGA group compared to bar attachment[47,48,52]during the18 months of function , the reason may be less lateral loading but annual bone loss is slightly higher with MGA when compared with MCA[51,52]	More vertical and horizontal crestal bone loss due to greater lateral loading with ball and bar attachments
Periodontal status	Significantly higher Plaque accumulation with MGA compared to ball group but comparable to bar group[47,50].the probable cause suggested were trapping of plaque by magnet or magnetic keeper or neglected oral hygiene by dissatisfied patient[47,53], No significant difference in Periotest value PTV in 5 years between MGA and MCA[50].	Least Plaque accumulation in ball group observed[47.50]
Prosthetic maintenance and complaints	Initially maintenance demand of MGA wasless or comparable to ball but lesser than bar attachment[52,53] for first 2-3years . But maintenance demand of MGA group was increased after 5 years of function.[50,51]	Maintenance demand is initially is higher with MCA group than MGA group, reason may be the screw loosening

Cost of attachments and overall	Higher initially compared to ball and bar attachment but became comparable after 1 year of function as more complications were encountered by MCA group.[48]	Initially very less in ball attachment but overall maintenance cost in 5 years is
treatment cost		comparable but always higher in MGA group.[48]
Patient satisfaction(retention, stability and chewing ability)	Most studies showed less patient satisfaction[46,50,51,55] with MGA compared to MCA but No significant difference was found during 6 monthsobservation in one study[56]. The reason for dissatisfaction might be low retention initially and corrosion led to replacement of magnet later on.	More satisfaction with bar than ball as retention was observed quite higher in bar group because of quite good retention.[50,51,52]

Conclusion: Magnetic attachments, fabricated with earlycobalt based materials, used to retain the overdenture were unsuccessful due to their large size ,low retentive capability or high cost and limited availability. With advent of newer RE metal base powerful small size magnet with newer encapsulating material and technique to make it corrosion resistant and biocompatible, enabled to use it successfullyfor retaining the overdenture.But still further development is required to make a cost effective powerful corrosion resistant material to effectively competes with contemporary mechanical attachments. However the recently available magnetic attachments may proved to be effective tool to retain the overdenture in certain clinical situations like osteoporotic resorbed ridge cases, small length healthy roots and mild Parkinsonism.

References

1. Warreth A, Alkadhimi, Sultan A, et al. Mandibular implant- supported overdenture: attachment system, and number and location of implants-part 1. J Ir Dent Assoc 2015;61: 93-7.)
2. Shu X, Fan Y, Lo ECM, Leung KCM. A systematic review and meta-analysis to evaluate the efficacy of denture adhesives. J Dent. 2021 May;108:103638.
3. Pradyumna Ku Sahoo1 , Smita R. Priyadarshini2 , Kajal Kiran Sahu3.Suction Cup on Denture: A Case Report . Indian Journal of Forensic Medicine & Toxicology, 2020 ;14(4):8102-8105
4. Wright SM. Use of spring-loaded attachments for retention of removable partial dentures. J Prosthet Dent. 1984 May;51(5):605-10.
5. Laverty, D., Green, D., Marrison, D. et al. Implant retention systems for implant-retained overdentures. Br Dent J2017; **222**: 347–359.
6. Pawar Anupam, G. N. Anandakrishna, Shetty Vibha, Janya Suma, and Khanna Shally.

Mandibular Overdenture Retained by Magnetic Assembly: A Clinical tip. Indian Journal of Prosthodontic Soc. 2014; 14(Suppl 1): 328–333.
7. M. Ai and Y. Y. Shiauw. New Magnetic Applications in Clinical Dentistry, Quintessence, Tokyo, Japan, 2004
8. Mizutani, Basic Clinical Manual of Magnetic Overdenture, Quintessence Publishing, Tokyo, Japan, 2006.
9. An-NissaKusumadewi ,Lisda Damayanti ,Rukiah ,and Risdiana. Factors Affecting the Attractive Force of Dental Magnetic Attachment: A Literature Review for Guiding Dentists in Clinical Application International Journal of Dentistry 2022;
10. Riley M. A., Walmsley A. D., Harris I. R. Magnets in prosthetic dentistry. *The Journal of Prosthetic Dentistry* . 2001;86(2):137–142.
11. Mohamed Y Sharaf, El Bakry, Mohamed Farouk Abdall. A comparison of the retentive force of ball and socket attachment versus magnet attachment in mandibular overdentures: A randomized control trial. journal of international oral health 2020;12(5):420-426
12. Chaware, Sachin Haribhau; Thakkar, SmrutiTusharA systematic review and meta-analysis of the attachments used in implant-supported overdentures *The Journal of* Indian Prosthodontic Society 20(3):p 255-268, Jul–Sep 2020
13. Thean HP, Khor SK, Loh PL. Viability of magnetic denture retainers: a 3-year case report. Quintessence Int. 2001 Jul-Aug;32(7):517-20.
14. Barrie. R. D. Gillings: Magnetic retention for complete and partial overdentures, Part - I. J Prosthet Dent.1981;45(5): 464-491,
15. Kshama Chandan, Dr.Naina Swarup and Dr.Gaurang Mistry, 2017. "Review article-magnets in Prosthodontics", International Journal of Current Research, 9, (10), 59968-59972.
16. Wilfried Andra¨ and Hann Nowak , Magnetism in Medicine: A Handbook, Second Edition : 2007 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim ISBN: 978-3-527-40558-9
17. li A, Shah T, Ullah R, Zhou P, Guo M, Ovais M, Tan Z, Rui Y. Review on Recent Progress in Magnetic Nanoparticles: Synthesis, Characterization, and Diverse Applications. Front Chem. 2021 Jul 13;9:629054.
18. Freedman H. Magnets to stabilize dentures. J Am Dent Assoc 1953;47:288.
19. Tsubone, M.: Embedding of Magnet into Denture Base (Japanese), *PAT. Showa* 33-1547,Japan, 1958.
20. Nadeau, J.: Maxillofacial Prosthesis with Magnetic stabilizers. J. Prosthet. Dent. 6 : 114119, 1956.
21. Robinson, J. E.: Prosthetic Treatment After Surgical Removal of the Maxilla and Floor of the Orbit. J.Prosth.Dent. 13: 178-184, 1963.
22. Federick, R.: A magnetically retained interim maxillary obturator. J. Prosthet. Dent. 36 : 671-675, 1976.
23. Javid N. The use of magnets in a maxillofacial pros- thesis; J Prosthet Dent 1971;25:334-40

24. H Sasaki , Y Kinouchi, H Tsutsui, Y Yoshida, M Karv, T Ushita. Sectional prostheses connected by samarium-cobalt magnets J Prosthet Dent1984 ;52(4):556-8.
25. Behrman, S. J.: The implantation of magnets in the jaw to aid retention. J. Prosthet. Dent.1960;11:807-841
26. Toto, P. D., Choukas, N. C. and Sanders, D. D.: Reaction of bone and mucosa to implanted magnets. J. Dent. Res. 1962; 41 : 1438-1449.
27. Schmitz, J. F.: Measurement of the efficiency of the platinum-cobalt magnetic implant. J. Prosthet. Dent. 16: 1151-1158, 1966.
28. Toto PD, Choukas NC, Abati A. Reaction of bone to a magnetic implant. J Dent Res 1963;42:643-52.
29. Thompson IM. Magnetism as an aid to a prosthetic problem. Br J Oral Surg 1964;2:44-6.
30. Moghadam, Khaknegar B, Scandrett, Forrest R. Magnetic retention for over dentures. J Prosthet Dent 1979;41:26-9
31. Strnat, K.; Hoffer, G.; Olson, J.; Ostertag, W.; Becker, J.J. A Family of New Cobalt-Base Permanent Magnet Materials. *J. Appl. Phys.* **1967**; *38*:1001–1002
32. Sasaki H, Yoshida Y, Kinouchi Y, Miyazaki T. Studies on dental casting ferromagnetic alloy. ShikaRikogakuZasshi. 1978 ;19(45):8-14.
33. Harada H Studies on Pd-Co-Ni dental casting ferromagnetic alloys(part-1)ShikaRikogakuZasshi. 1981 ;22(59):241-45.
34. Harada H. Studies on Pd-Co-Ni dental casting ferromagnetic alloys(part-2)ShikaRikogakuZasshi. 1981 ;22(59):246-52.
35. Vrijhoef MM, Mezger PR, Van der Zell JM, Greener EH. Corrosion of ferromagnetic alloys used for magnetic retention of overdentures. J Dent Res 1987;66:1456-9.
36. Gillings BR. Magnetic retention for complete and partial overdentures. Part I. J Prosthet Dent. 1981; 45:484-91.
37. Connor, R. J.: Proplast-coated high-strength magnets as potential denture stabilization devices. J. Prosthet. Dent. 37 : 339-343, 1977.
38. Osamu Okuno, Shin Ishikawa, Florentina Takako Iimuro, Yohsuke Kinouchi, Hirohide Yamada, Tsuyoshi Nakano, Hitoshi Hamanaka, Nobuo Ishihata, Hiroshi Mizutan, Minoru A. Development of Sealed Cup Yoke Type Dental Magnetic Attachment Dental Materials Journal 1991;10(2): 172-184,
39. Masato Sagawa, Setsuo Fujimura, Norio Togawa, Hitoshi Yamamoto, and Yutaka Matsuura. New Material for Permanent Magnets on a Base of Nd and Fe . Journal of Applied Physics. 1984;55(6)15:2083-2087,
40. Vidya S. Bhat, K. Kamalakanth Shenoy, Priyanka Premkumar. Magnets in Dentistry Archives of Medicine and Health Sciences 2013; 1 (1):73-79
41. Satya Sai Sruthi Yalamolu , Lakshmana Rao Bathala , Satyanarayana Tammineedi , Sri Harika Lakshmi Parvathi Pragallapati , Chakradhar Vadlamudi . Prosthetic journey of magnets: a review Journal of medicine and life. 2023; 16 (4) 501-506
42. Wang NH, von der Lehr WN. The direct and indirect techniques of mak- ing magnetically retainedoverdentures. J Prosthet Dent 1991;65:112-7.
43. Wirz J, Lopez S. Magnetverankerungen auf implanten. Teil 1: bestandesauf- nahme.

Quintessenz 1993;44:579-88.

44. Gillings, B. R. D. . Magnetic retention for overdentures.Part II. The Journal of Prosthetic Dentistry. 1983 ;49(5):607–618.
45. Comparison of Three Different Types of Two-Implant-Supported Magnetic Attachments on the Stress Distribution in Edentulous Mandible.englingHu,Yiming Gong,Zhen Bian,Xiaoying Zhang,Bin Xu,Jianguo Zhang,Xiaojun Shi,Computational and Mathematical Methods in Medicine/2019
46. Putra Wigianto AY, Ishida Y, Matsuda T, Goto T, Watanabe M, Ichikawa T. Novel Magnetic Attachment System Manufactured Using High-Frequency Heat Treatment and Stamp Technique: Introduction and Basic Performance. Dent J (Basel). 2022 May 2;10(5):75.
47. Sharaf Mohamed Y, Bakry El, Abdall Mohamed Farouk **comparison of the retentive force of ball and socket attachment versus magnet attachment in mandibular overdentures: A randomized control trial** Year : 2020;12 (5)Page: 420-426
48. Assad AS, Abd El-Dayem MA, Badawy MM. Comparison between mainly mucosa-supported and combined mucosa-implant-supported mandibular overdentures. Implant Dent. 2004;13:386–94.
49. Cristache C, Ionescu C, Cristache G. A 5-year prospective randomised clinical trial on the efficiency of two different attachment systems as retention for implant-supported mandibular overdenture. Metalurgicainternationale. 2009;14:2016–9.
50. Elsyad MA, Mahanna FF, Elshahat MA, Elshoukouki AH. Locators versus magnetic attachment effect on peri-implant tissue health of immediate loaded two implants retaining a mandibular overdenture: a 1-year randomised trial. J Oral Rehabil. 2016 ;43(4):297-305.
51. Naert I, Gizani S, Vuylsteke M, van Steenberghe D. A 5-year randomized clinical trial on the influence of splinted and un- splinted oral implants in the mandibular overdenture therapy. Part I: Peri-implant outcome. Clin Oral Implants Res 1998;9:170-179
52. Naert I, Alsaadi G, Quirynen M. Prosthetic aspects and patient satisfaction with two-implant-retained mandibular overdentures: a 10-year randomized clinical study. Int J Prosthodont 2004;17:401-10
53. Naert I, Quirynen M, Hooghe M, van Steenberghe D. A comparative prospective study of splinted and unsplintedBranemark implants in mandibular overdenture therapy: a preliminary report. J Prosthet Dent 1994;71:486-92.
54. Davis DM, Rogers JO, Packer ME. The extent of maintenance required by implant-retained mandibular overdentures: a 3- year report. Int J Oral Maxillofac Implants 1996;11:767-74
55. Davis DM. Implant supported overdentures-the King's experience. J Dent 1997;25:33-7.
56. Cune M, van Kampen F, van der Bilt A, Bosman F. Patient satisfaction and preference with magnet, bar-clip, and ball-socket retained mandibular implant overdentures: a cross-over clinical trial. Int J Prosthodont. 2005;18(2):99-105.
57. Burns DR, Unger JW, Elswick RK Jr, Giglio JA. Prospective clinical evaluation of

mandibular implant overdentures: Part II – Patient satisfaction and preference. J Prosthet Dent. 1995;73(4):364-9.

58. Z. Hao, Y. Chao, Y. Meng, and H. Yin, "Influence of repeated insertion-removal cycles on the force and magnetic flux leakage of magnetic attachments: an in vitro study," The Journal of Prosthetic Dentistry, 2014;112(2): 235–240,.
59. K. H. Chung, D. Whiting, M. Kronstrom, D. Chan, and J. Wataha, "Retentive characteristics of overdenture attachments during repeated dislodging and cyclic loading," The International Journal of Prosthodontics, 2011; 24: 127–129,.
60. Z. Hao, Y. Chao, Y. Meng, and H. Yin, "Influence of repeated insertion-removal cycles on the force and magnetic flux leakage of magnetic attachments: an in vitro study," The Journal of Prosthetic Dentistry, 2014: 112 (2) :235–240.
61. T. Y. Kang, J. H. Kim, K. M. Kim, and J. S. Kwon, "In vitro effects of cyclic dislodgement on retentive properties of various titanium-based dental implant overdentures attachment system," Materials, vol. 12, no. 22, pp. 1–12, 2019.
62. Lee E, Shin SY. The influence of the number and the type of magnetic attachment on the retention of mandibular mini implant overdenture. J Adv Prosthodont. 2017 Feb;9(1):14-21
63. Ba X, Hadjiargyrou M, DiMasi E, Meng Y, Simon M, Tan Z, Rafailovich MH. 2011. The role of moderate static magnetic fields on biomineralization of osteoblasts on sulfonated polystyrene films. Biomaterials 32:7831–7838.).
64. Bondemark L., Kurol J., Larsson Å. Human dental pulp and gingival tissue after static magnetic field exposure. Eur. J. Orthod. 1995;17:85–91.
65. Nishida M., Tegawa Y., Kinouchi Y. Comparison and evaluation of leakage flux on various types of dental magnetic attachment; Proceedings of the 30th Annual International Conference of the IEEE Engineering in Medicine and Biology Society; Vancouver, BC, Canada. 20–25 August 2008;) .
66. 3. Xu C., Fan Z., Chao Y.-L., Du L., Zhang F.-Q. Magnetic fields of 10mT and 120mT change cell shape and structure of F-actins of periodontal ligament cells. Bioelectrochemistry. 2008;72:41–46.
67. Nishida M., Tegawa Y., Kinouchi Y. Evaluation of leakage flux out of a dental magnetic attachment; Proceedings of the 29th Annual International Conference of the IEEE Engineering in Medicine and Biology Society; Lyon, France. 22–26 August 2007.
68. Yagci F., Kesim B. Cytotoxic and genotoxic effects on gingival fibroblasts from static magnetic fields produced by dental magnetic attachments. Gerodontology. 2016;33:421–427).
69. Fayol D., Frasca G., Visage C.L., Gazeau F., Luciani N., Wilhelm C. Use of magnetic forces to promote stem cell aggregation during differentiation, and cartilage tissue modeling. Adv. Mater. 2013;25:2611–2616)
70. Bondemark L., Kurol J., Wennberg A. Orthodontic rare earth magnets—In vitro assessment of cytotoxicity. Br. J. Orthod. 1994;21:335–341.
71. Guttal S.S., Nadiger R.K., Shetty P. Cytotoxic effect of indigenously fabricated dental magnets for application in prosthodontics. J. Indian. Prosthodont. Soc. 2018;18:29–34

72. Donohue V.E., McDonald F., Evans R. In vitro cytotoxicity testing of neodymium-iron-boron magnets. J. Appl. Biomater. 1995;6:69–74.
73. Sato K., Yamaguchi H., Miyamoto H., Kinouchi Y. Growth of human cultured cells exposed to a non-homogenous static magnetic field generated by Sm-Co magnets. Biochim. Biophys. Acta. 1992;1136:231–238.
74. Yamaguchi H., Hosokawa K., Soda A., Miyamoto H., Kinouchi Y. Effects of seven months' exposure to a static 0.2 T magnetic field on growth and glycolytic activity of human gingival fibroblasts. Biochim. Biophys. Acta. 1993;1156:302–306
75. Yagci F., Kesim B. Cytotoxic and genotoxic effects on gingival fibroblasts from static magnetic fields produced by dental magnetic attachments. Gerodontology. 2016;33:421–427
76. McDonald F. Effect of static magnetic fields on osteoblasts and fibroblasts in vitro. Bioelectromagnetics. 1993;14:187–196
77. Cerny R. The reaction of dental tissues to magnetic fields. *Aust. Dent. J.* 1980;25:264–268, Abati, V.: The Study of Tissue Reaction to a Magnetic Implant. Thesis, Loyola University, 1961.
78. Linder-Aronson A., Lindskog S., Rygh P. Orthodontic magnets: Effects on gingival epithelium and alveolar bone in monkeys. *Eur. J. Orthod.* 1992;14:255–263.
79. Linder-Aronson A., Forsberg C.-M., Rygh P., Lindskog S. Tissue response to space closure in monkeys: A comparison of orthodontic magnets and superelastic coil springs. Eur. J. Orthod. 1996;18:581–588.
80. Bondemark L., Kurol J., Larsson Å. Human dental pulp and gingival tissue after static magnetic field exposure. Eur. J. Orthod. 1995;17:85–91
81. Bondemark L., Kurol J., Larsson Å. Long-term effects of orthodontic magnets on human buccal mucosa—A clinical, histological and immunohistochemical study. Eur. J. Orthod. 1998;20:211–218
82. T.S. Tenford, T.F. Budinger, NMR in Medicine: instrumentation and clinical applications, New York (1986) 493-548.
83. Zadeh-Haghighi H, Simon C. Magnetic field effects in biology from the perspective of the radical pair mechanism. J R Soc Interface. 2022 Aug;19(193):20220325-35
84. Asahi Kitsugi, Osamu Okuno, Tsuyoshi Hamanaka and Takayuki Kuroda. Corrosion Behavior of Nd2Fe14B Materials Journal 11 (2): 119-129, 1992