REVIEW ARTICLE

SMART MATERIALS: A REVIEW

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ABSTRACT
Future developments of smart materials for domains such as self-sustainable wireless sensor networks, self-tuned vibration energy harvesting devices, seismic applications etc. is the need of an hour. Such smart materials have the potential to build smart structures and materials. Smart materials are stimuli-responsive which constituted a broad range of materials to exploit vibration control such as piezoelectric, shape memory alloys, electro-rheological fluid and magneto-rheological fluid. Smart materials show a certain amount of analogy with respect to biological systems. For instance, piezoelectric hydrophones, shape-memory materials with a potential to recollect the original shape and electro-rheological fluids with manipulative viscosity strength etc. Such potential grabbed the attention of research and allow them to think and integrate varied advanced technologies into compact, diverse functional packages with an ultimate aim to develop advanced smart materials and revolutionize the research field of smart materials. This review initially discusses a brief summary of the aforementioned stimuli-responsive smart materials following a complete description of some of the smart materials.
Keywords: Smart Materials, Intelligent, Shape Memory Alloys

INTRODUCTION
McCabe et al. defined “Smart materials” as Materials that are able to be altered by stimuli and transform back into the original state after removing the stimuli". Materials whose properties may be altered in a controlled fashion by stimuli, such as stress, temperature, moisture, pH, and electric or magnetic fields.[1].Material science is not what it used to be .[2] Various materials have been formulated,tested,andstandardisedtoobtain maximumbenefitsforgood clinicalperformance.[3]
Early smartmaterial application started with magnetostrictive technologies. This involved the use of nickel as a sonarsource during world war I to find German U- boats by Allied forces. Due to the interestingbehaviour of Smart materials, scientists were encouraged to apply them in various fields, mostlyintobiomedical scienceand dentistry.[4]
The first smart material to be used in dentistry were the nickel-titanium alloys, or SMAs used inas orthodontic wires in the year 1988. [1,4]The use of Smart materials since then has

revolutioniseddentistry and the recent advances in design of smart material have created novel opportunitiesfor their application in dental field which is an indicator of potential and rapid progress in thisarea.

There are variable types of smart materials available including piezoelectrics which producevoltage when stress is applied e.gpiezoscalers, shape memory alloys which are unique class ofmetalalloysthatcanrecoverapparentpermanentstrainswhenheatedaboveacertaintemperature eg Ni-Ti alloys,magnetostrictive materials which produce voltage when magneticfield isapplied eg ultrasonic scalers, thermoresponsive materials respond to temperature changes egthe use of pressure bandages, smart polymers which change according to the environment thatthey are in eg hydrogels.[5]Thus the advances in the design ofsmart materials have created novelopportunities for their application in the pediatricrestorativedentistry such as smart composite,smart ceramic, resin modified glass ionomer, amorphous calcium phosphate releasing pit andfissure sealants, smartprep burs, smart seal obturation system.

CLASSIFICATION OF SMART MATERIALS

According tonature (ShanthiMetal2014)

1. Activesmartmaterials
2. Passivesmartmaterials

Active smart materials- they sense a change in the environment and respond to them. It canbe defined as those materials whichhave the capacity to modify their geometric or materialproperties under application of electric, thermal or magnetic fields thereby acquiring an inherent capacity to tranduce energy. It includes smart composties, smart ceramics, smart impression materials, fluoride releasing pit and fissure sealants etc.

Passive smart materials- The material which are inactive to response and functioning arecalledpassivesmartmaterials.Theypossessselfrepairingproperty.Itincludesfiberopticmaterials,glassionomercements,resinmodifiedglassionomer,compomer,dentalcomposites.

Classification: (Fareen F, Kandaswamy 2021)

I. Passive Smart Restorative Materials: Respond to external change without external control.

- GIC
- Resin Modified GIC
- Compomer
- Dental Composites

II. Active Smart Restorative Materials: Utilize a feedback loop to enable them to function like a cognitive response through an actuator circuit.

1. Restorative Dentistry
- Smart GIC
- Smart composites
- Ariston Phc
2. Prosthetic Dentistry
- Smart ceramics
- Smart impression materials
3. Orthodontics
- Shape memory alloys.
4. Pediatric and Preventive Dentistry
- Fluoride releasing pit and fissure sealants
- ACP releasing pits and fissure sealants
5. Endodontics
- NiTi rotary instruments.

6. Smart Fibers for Laser Dentistry
- Hollow-core Photonic-Fibers
7. Smart suture

NITI ALLOY

Nickel–titanium (NiTi) alloys in the late 1980s led to a revolution in endodontics as these files were shown to have considerable advantages over stainless steel (SS) files, especially in relation to the safety of instrumentation. These enhanced characteristics allowed a substantial improvement in engine-driven endodontic instruments (Fife *et al*. 2004). Though, fracture of rotary NiTi instruments remains an inadvertent incident during clinical use (Pruett *et al*. 1997, Gutmann & Gao 2012).

Generations of the Niti Rotary Instruments [8]

FIRST GENERATION

This generation of instruments in general, have passive cutting radial lands, which helped a file to stay centered in the canal curvatures during work and fixed tapers of 4% and 6% over the length of their active blades. Several researches showed that all first-generation rotary instruments created smooth root canal walls which centered in the middle and caused low procedural errors. The main deficiency of this generation of NiTi rotary instruments was requiring numerous files to achieve these goals and complexity.

SECOND GENERATION

The second generation of NiTi rotary files appeared on dental markets in 2001. The feature that distinguished this generation of instruments from the first generation is that they have active cutting edges and thus require fewer instruments to prepare a root canal. These instruments had active cutting edges with greater cutting efficiency, so the number of instruments required to achieve complete cleaning and shaping was almost less in comparison with the previous generation.

THIRD GENERATION

It was in late 2007 that the manufacturers started to apply the heating and cooling technologies on NiTialloys to improve the safety of these instruments, especially in the curved root canals. This third generation of NiTi instruments significantly reduced cyclic fatigue and consequently, less breakage of files occurred.

FOURTH GENERATION

This technology was first introduced in the late 1950s by a French dentist Dr. Blanc. An advancement in canal preparation procedures was achieved with reciprocation, a process that may be defined as any repetitive up-and-down or back-and forth motion. Innovation in reciprocation technology led to a fourth generation of instruments for shaping canals. This generation of instruments and its related technology have again fuelled the hope for a single-file technique. The reciprocating movement allows a file to progress more readily, cut efficiently, and remove debris from the canal effectively.

FIFTH GENERATION

The latest generation of shaping files have been designed in such a way that the center of mass or the center of rotation, or both are offset. When in rotation, files that have an offset design produce a mechanical wave of motion that travels along the active length of the file. In addition, it enhances the removal of debris from a canal and improves flexibility along the active portion of the file. This generation's files have been recently introduced, adapting the advantages from both the second and the third generations.

SMART COMPOSITES

Technologyshouldservemankindandnotvice-versa. [9]Composites were introduced by Bowen in 1962. Conventionally, it is made up ofeither bisphenol-Adiglycidylmetacrylate (bis-GMA) or urethane dimethacrylate (UDMA) with glass fillers andcolloidal silica. Classification of composites is typically related to the distribution and averagefiller particle size (eg, microfill, hybrid, and nanohybrid). As new composite formulations have beenintroduced, their classification has expanded to include the physical and chemical characteristicsof the restorative material. Within the composite resin family, composites have been describedbased upon the location of the teeth being treated (eg, anterior, posterior, universal); materialviscosity (eg, flowable, packable); method of placement (eg, bulk fill); and recently, bioactivity(eg, abilityto releasefluoride).

Packable resin based composite for posterior restoration were introduced in 1995 by Dr LarsEhrnford of Sweden. This system was composed of a resin matrix, and an inorganic ceramiccomponent. This concept resulted in advantages like bettermarginal adaptation, lower potentialfor incorporation of microscopic porosities, lesser polymerization shrinkage, optimal mechanicalcharacteristics like flexural strength, modulus of elasticity and coefficient of thermal expansionand greater wear resistance. Indirect resin based composites were also introduced with unusuallygood properties like wear resistance, aesthetics, marginal adaptation control over polymerizationshrinkage like the introduction of Art glass in 1995.

In 1998 the introduction of smart composite which islight activated alkaline, nano filled glass restorative material has revolutionized dentistry and areoftwo types. [1]

1. AmorphousCalciumphosphatereleasingcomposite
2. Selfhealingcomposite

Synthetic and biological routes to healing. (*Right*) In biological systems, wound healing follows three sequential steps,the first of which is an immediate inflammatory response, including blood clotting. In the second stage, cell proliferation andmatrix deposition occur and can extend for several days.

The long-term response is matrix remodeling, which sometimes extendsfor several months. (*Left*) In synthetic materials, damage healing proceeds by an immediate response that actuates (triggers) thehealingmechanism (e.g.,therupture ofembedded microcapsules).Once triggered,the second stage involvestransportofchemical species to the site of damage at a relatively rapid rate. During the final stage of healing, chemical repair takes place andcanextendforseveral hours ordays.

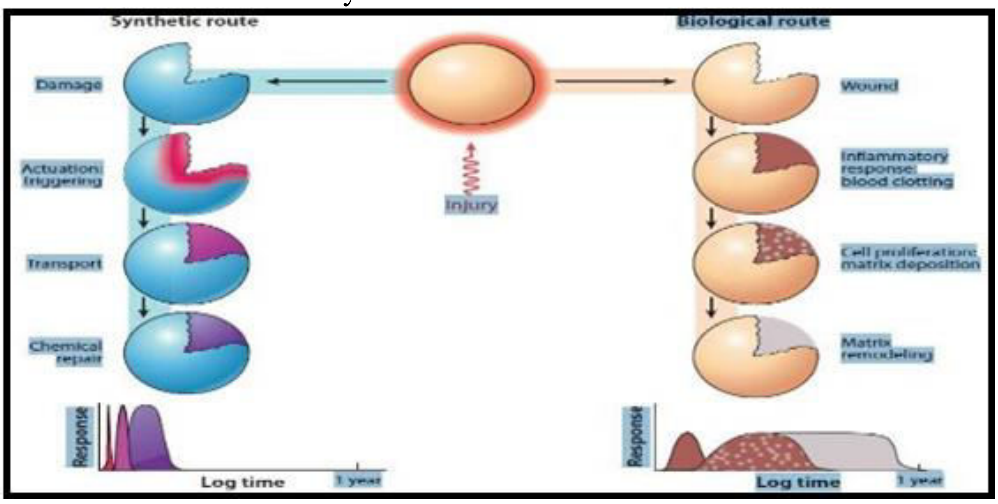
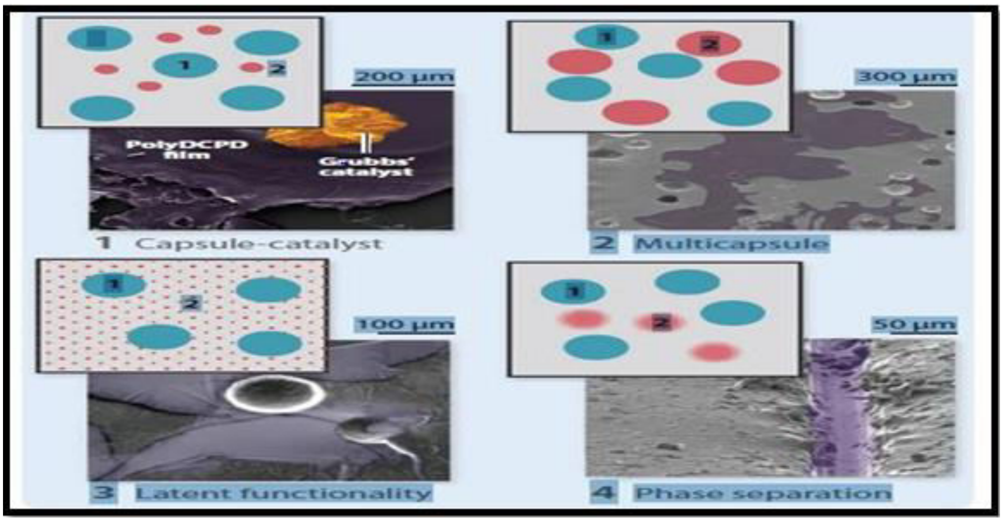


Fig: - Four schemes for sequestration of the healing agent.



SMART CERAMIC

Ceramicmaterialsarethemostbiologically acceptableofallmaterials.Ceramicsarefullyoxidized or chemically stable compounds. Because of their chemistry, ceramics are much lesslikely to produce any adverse effects, compared with metals and polymers, which are not aschemicallystable.[10]

CERCONSMARTCERAMICS [11]

Cerconsmartceramicsallrestorationscanbe shapedso naturallythat theycannotbe distinguishedfromyour real teeth.Zirconiaisapolymorphicmaterialandexistsindifferenttemperaturedependentphases: monoclinic,tetragonalandcubic.Purezirconiaexistsinmonoclinicphaseatroomtemperature and remains stable upto 1170ºC. Above this temperature, it transforms into tetragonalandthen into cubicphasethatexistsup tothe meltingpoint at 2370ºC.

Zirconia reinforced ceramics has an excellent aesthetic quality, biocompatibility, and mechanical property. It has mechanical properties of 1200 HV hardness, 900-1200 MPa flexural strength, and fracture toughness of 6-8 MPa. It has higher strength even when tooth preparation volume is small during making a crown. Moreover, compared to gold, zirconia is less costly. (Alrashadan AF et al 2021).

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GLASSIONOMERCEMENT

A technique or material is considered biomimetic if it is able to re-establish and/or recreate thefunctional ability of the element that was lost due to disease, trauma, or aging-related problems. Anexample of dental biomimetics in this sense is the replacement of tooth structure destroyed due tocarious disease, and one of the biomimetic or artificial replacements of dentin is glass ionomer dueto which itisasmartmaterial. [13]

Glass-ionomers, made of calcium or strontium alumino-fluoro-silicate glass powder (base) arecombinedwithawater-solublepolymer(acid).Glass-ionomerswereinventedin1969andreported by Wilson andKent in the early 1970s.

In dentin replacement, glass ionomer not only recreates the functional strength of dentin, but it also rejuvenates the remaining affected dentin through remineralization. Glass-ionomer cement has similar mechanical properties to dentine. This, together with the important benefits of adhesion and release of fluoride, render it an ideal material in many restorative situations. Because of the extensive use of this cement as a dentin replacement material it has been referredtoas“MANMADEDENTIN”and“DENTINSUBSITUTE”.

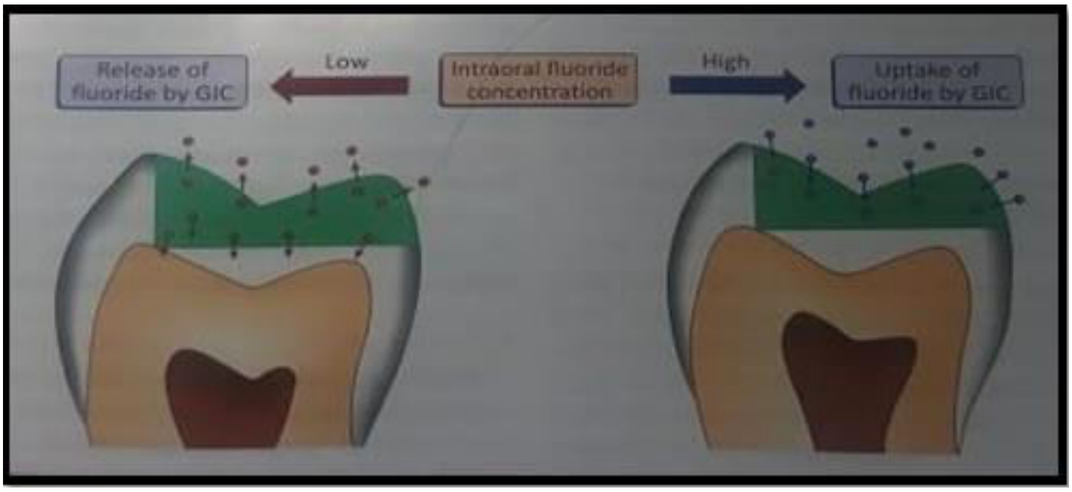


Fig: - AnticariogenicProperties(Fluorideionreleaseanduptake)

ThemainadvantagesofGICsoverPMMAinclude

- Goodadhesionto the bone.
- Minimalpolymerizationshrinkage
- Nosignificantheatevolutionduringsetting.
- Theself-settingcapacityofGICsinabodyfluidisconsideredtobepotentiallyapplicableinthebonereconstructionarea. [14]

COMPOMERS

compomerswere introduced to the market.[15]Compomers (Poly-acid-modified resin composites) were introduced in 1993 as hybrid dentalmaterials.[16] They were marketed as a new class of dental materials that would provide the combined benefitsof composites(the–comp‖ in their name) and glassionomers(–omer‖).These materials have two main constituents: dimethacrylate monomer(s) with two carboxylic groupspresent in their structure and filler that is similar to the ion-leachable glass present inGICs.

AdvantagesofCompomers [17]

(a) Ease ofplacement.
(b) Nomixing
(c) Easytopolish
(d) Goodesthetics
(e) Excellenthandling
(f) Lesssusceptibletodehydration
(g) Radiopaque

DisadvantageofCompomers[17]

(a) Limitedclinicalexperienceandfewlongtermclinicaltrials
(b) Requirebondingagentlikecomposite
(c) Moremarginalstainingandchipping
(d) Wearsmore thancomposites
(e) Weakerphysicalpropertiesthatdecreaseovertime
(f) Clinicalsignificanceoffluoridereleaseundetermined

Clinicalapplicationofcompomers[18]

- ClassII and Vcavities
- Fissuresealants
- Bondingagentsforthe retentionoforthodontic bands

SMARTPITANDFISSURESEALANT

Thecariesprocessiswellunderstoodasaprocessofalternatingdemineralizationandremineralization of tooth mineral (Featherstone 1999).[19,29] Deep pits and fissure (deep, narrow I –shaped and K shaped) whicharenot accessiblefor cleaning, havehighest caries susceptibilityand have always remained an area of concern for dentists.[20,30]Application of sealants is one of themost effective methods of preventing dental caries in high-risk children and young adults. Thesealant forms a protective layer on the tooth structure that prevents metabolic exchange betweenthe fissure micro-organisms and oral environment. [21,31]Thus prevents these pits and fissures frombecomingcarious,and reducetheformation of majorcavitated lesions. [20]

- FLUORIDERELEASINGPITANDFISSURESEALANTS.
- ACPRELEASINGPITANDFISSURE SEALANTS.

Table 1: History of pit and fissure sealants

Years	Authors[2-7]	Contribution
1895	Wilson	Placement of zinc phosphate cement in pits and fissures
1923	Hyatt	Prophylactic odontomy
1942	Kline and Knutson	Treatment with ammoniacal silver nitrate
1955	Buonocore	Sealing of pits and fissure with bonded resin material
1971		Pit and fissure sealant recognized by ADA
1978	Simonson	Preventive resin restoration
1986	Garcia-Godoy	Preventive glass ionomer restoration

ADA: American dental association

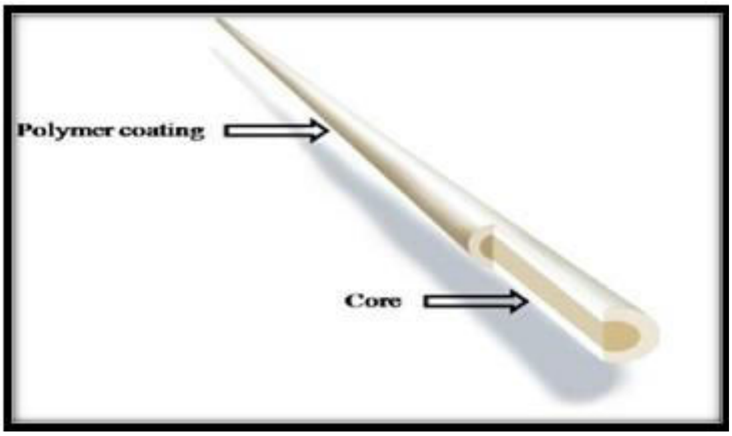
SMARTPREP BURS(SSWHITE BURS,POLYMERBURS)

Disease prevention is the ultimate goal in restorative dentistry (Featherstone 2000; Pitts 2004).Ideally, caries removal should be accomplished with minimal patient discomfort during and afterthe restorative procedures (Malmström *et al.*, 2003).

Theconceptofminimallyinvasivedentistrypracticesthescienceofdetecting,diagnosingandintervention at the earliest and treating at the microscopic level. [22,32] This helps to preserve most ofthehealthystructureofnaturalteethandhasbecometheobjectiveofeverydentistandifitisnotthecase,itshouldbetheobjectiveofthedentistinpatient'sbestinterest.Thenewermethodforcaries removalwhichfollowstheprincipleofminimallyinvasivedentistryhasdevelopedrecentlysincelast decades.Theseincludelasers,chemo-mechanicalmethod,airabrasion,airpolishing,ultrasonic,ozonemethod,polymerbursandenzymes.[23,33]Conventionalmethodsforcariousdentinremovalincludemanualexcavationwithhandexcavatorsandbursbyusingdiamondandcarbideburs associatedwithloworhighspeedhand piece.Bothare dependentoftheoperator'sopticalandtactilesensitivityandmayleadtoanunnecessaryremovalofdentaltissues.Moreover,infectedandaffected dentin have somedifferencessuchasinthe hardness, toughnessandresilience,which determinetherelativeefficiencyofcariesexcavationtechniques.

Smart prep polymer burs arerelatively recent (2006) and naval introduction for selective dentine cariesremoval.Inrecentyears,polymerbursdescribedas–dentinsafe, ‖itmeansthatitremoves onlycariousdentine;theburwillbeself-limitingwhenitreachessound,healthydentin.Itsusehas shown to be effective in caries removal. Polymer burs can remove softened dentin but cannotcuthard healthydentin [23,34]

Polymide polymer burs were found to be effective compared to carbide burs in removal of carioustooth. It will be challenging for the general dentists and other specialists to imbibe this newconcept intotheclinicalpractice.Therearenumberoffactorsforthis;firstly thebeliefofcliniciansinnewertechniquesandconceptitselfbecausetheywouldliketoexpecttoseeimmediate results rather than the results on follow-up basis. Secondly, the cost to the patient andpatient co-operation(time taken by polymer bur is more), lastly the time factor in dental clinicshave greater impact on transforming traditional practice to minimally invasive.[23]



SMARTSEALOBTURATIONMATERIAL

The purpose of the obturation phase of root canal treatment is to prevent re-infection of thecanal space that has been biomechanically cleaned, shaped and disinfected by instrumentation,copiousirrigationandmedicationproceduresthatultimatelypreventperiradicular disease.[24]Itis difficult to consistently and totally disinfect root canal systems. Therefore, the goal of three-dimensional obturation is to provide an impermeable fluid-tight seal within the entire root canalsystem,to prevent oraland apical microleakage.

Smartsealisa two-partsystemconsistingof:

1. Propoint/C point.
2. Smartpaste/SmartpasteBio/Hyseal-Bio.

4% taper - ISO tip sizes 25 to 45

ProTaper™-F1,F2,F3,F4&F5

Sendoline™S5-S2,S3,S4.

CANALOBTURATION[25]

- Simplychoose thePropointthatmatchesthe sizeofthe finalfile usedtocompletethecanal.
- Try in a matching Propoint to ensure it reaches full working length and you have tug-back. Ifthe point does not go to length then either use the final file again to ensure adequate shape or usea smaller sizePropoint.
- Takearadiographtoconfirmthe positionofthe point.
- Place the sealer into the canal. The sealer can be introduced into the coronal two-thirds of thecanalusingtheprovided syringetips.
- ThePropointisintroducedintothecanaltotheworkinglengthusingtweezers.
- ThePropointcanbetrimmedtothelevelofthecanalorificeusingahigh-speedhand pieceandadiamondbur. Thisisavailable in theSmartTrimtrimmingKit.[35]

A study by Didato A et alrevealed that, lateral hygroscopic expansion ofwater-expandable obturation point increased significantly when compared to gutta-percha after aperiod of 20 minutes.[26,36] Anexvivocomparison of the push-out bondstrengthof Propoint(SmartsealTM) and various gutta-percha filling techniques revealed no difference in adhesion todentine between the SmartsealTM system and gutta-percha/AH-26 applied using either the singlecone orlateral condensationtechnique.[27,37]AstudybyEidAAetal revealedthat the invitro biocompatibility ofC-pointiscomparabletogutta-perchawithminimaladverseeffectsonosteogenesisafter elution of potentiallytoxiccomponents.[28,38]

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