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The Effect of Steel Fibers with Different Diameters and Types on Idealized Rice Husk Ash Concrete in Terms of Tensile Strength

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Abstract

Reinforced concrete with steel fibers has become prevalent in structural engineering in recent decades due to its good mechanical performance. The primary purpose of this study is to increase concrete resistance properties using steel fibers and polypropylene. The reduction of cement consumption in concrete by using rice husk ash pozzolan was 10%, which replaced part of the cement. The effect of hooked steel fibers with two different diameters and corrugated steel fibers on compressive and tensile strength and modulus of elasticity with the same mixing design on standard cubic and cylindrical samples at 7 and 28 days was studied. The highest compressive strength of concrete contains hooked fibers with a diameter of 0.8 mm, and this increase reached 102% at the age of 28 days of concrete. The maximum tensile strength was also at 28 days of concrete with 0.8 mm diameter hooked fibers, which increased by 22% compared to concrete without fibers. The highest increase in the modulus of elasticity is also seen in sinusoidal fibers, which have a value of 29.6 GPa and a 19% increase compared to concrete. As the compressive strength increased, the modulus of elasticity also increased.

Keywords: Concrete reinforced with steel fibers, Corrugated and corrugated fibers, Polypropylene fibers, Rice husk ash.

1 | Introduction

Fiber-Reinforced Concrete (FRC) contains fibrous materials that increase its structural integrity. This concrete consists of short discrete fibers that are uniformly distributed and randomly oriented. The fibers used in concrete are steel, glass, synthetic, and natural fibers, each of which gives concrete different characteristics. The fibers are uniformly distributed in the concrete, which prevents or delays the initiation

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and propagation of cracks. This supplement changes single large cracks into a system of several smaller cracks, which is favorable regarding safety and durability [1]. Steel Fiber Reinforced Concrete (SFRC) has become a prevalent and attractive material in structural engineering in recent decades due to its good mechanical performance [2].

Among essential advantages, we can mention the prevention of macrocracks development, the delay in the propagation of microcracks to the microscopic level, and the improvement of ductility after the formation of microcracks, which shows a high final strength after the appearance of the first crack. In addition to creating cracks with a closer distance, the fibers reduce the crack width and improve resistance to cracks [3].

Depending on the type used, the orientation, and the length of the embedded fibers, they play an important role in reaching the specific load-bearing capacity after the matrix fracture. All these properties are influenced by concrete composition (grain size and shape, concrete content, water-cement ratio, additives), fiber type, rheological properties, casting method, composition, etc. [4]. The best performance for steel fibers is among the existing fibers. However, steel fibers cannot guarantee the required safety of reinforced concrete structures during fire, which has become an important aspect nowadays. The process of concrete degradation at high temperatures can be delayed by adding Polypropylene (PP) fibers [5]. Among other things that have recently received special attention in East Asia and North America is the property of rice husk as a high-quality artificial pozzolan in concrete compounds, which has found many uses in the world today [6].

Barkhordari et al. [7] investigated the effect of steel fibers on the compressive strength and weight of concrete for all types of fibers by changing the percentage of fibers in concrete. Due to the presence of steel fibers in concrete, ordinary Portland cement has significantly improved its mechanical properties. Compared with plain and corrugated steel fibers, there is a significant increase in the compressive strength of concrete with the addition of corrugated steel fibers. The percentage drop in the compressive strength of plain steel fibers (2%), hooked steel fibers (2%), and treaded steel fibers (2%) is 5.98, 6.1 and 5.86%, respectively. The same process is followed for weight loss.

Zhao et al. [8] conducted an experimental investigation on the effect of steel fiber types and their amounts on the flexural tensile strength, fracture behavior, and performance of high-strength concrete beams reinforced with steel bars. In the research framework, different rod reinforcements (206 mm and 2012 mm) and three types of fibers (two models of hooked fibers with different tensile strength and ribbed) were used in three different volumes. Experiments show that higher ductility and higher load in the post-cracking range for all the selected fibers have been obtained.

This research is the basis for choosing the right types of fibers for their most efficient combination with the reinforcement of regular steel bars. In samples with fiber contents of 0 and 20 kg/m3, samples containing 1% bar reinforcement failed in shear or compression.

Initial compression failure was observed for samples with a 40 kg/m3 fiber content. For an amount of 60 kg/m3 fibers, beams with a longitudinal reinforcement ratio of 1% failed only in shear. Tayeh et al. [9] conducted a search on the effect of different amounts of steel fibers in terms of volume on the mechanical properties of FRC. These properties included flowability, compressive strength, and direct tensile strength. The results showed that increasing the volume of steel fibers gradually decreases the flowability.

The combination of steel fibers significantly reduces the flowability of concrete with high fiber resistance. As the content of steel fibers increases, the flowability decreases gradually. The flowability was reduced by 7.79, 14.48, and 18.57 percent for the compositions containing 0.5, 1, and 1.5 percent steel fibers, respectively. Singh et al. [10] presented the results of an experimental program to investigate the durability aspects of conventional concrete and concrete containing steel fibers and rice husk ash. The characteristic strength of concrete is 25 MPa. Concrete was designed and used using conventional construction materials.

Rice husk ash was considered to partially replace ordinary Portland cement at different levels of 10, 15, 20 and 25%. It was found that the efficiency of concrete decreases with the increase of this amount. The compressive strength results showed that the optimal replacement level was 15%. Hooked steel fibers were added to concrete containing rice husk ash. Concrete cubes were cured in drinking water and also in a 5% nitric acid solution for up to 90 days.

The compressive strength of the cubes was determined after 7, 28, 56, and 90 days. The compressive strength of concrete containing steel fibers and rice husk ash is higher than that of normal concrete. The compressive strength of both designs of normal concrete and concrete containing steel fibers and rice husk ash in an acid solution decreased in all periods of acid exposure .In this research, replacing some cement with rice husk ash, which is a suitable substitute for the presence of micro silica in concrete, as well as adding metal fibers (in different models and diameters) and polypropylene to achieve concrete with higher strength, especially improving The compressive and tensile strength of concrete was discussed.

2|Laboratory Work Program

2.1|Properties of Fine and Coarse Grain Materials

The modulus of softness is a coefficient obtained from the sand grading test, which is called the sum of the cumulative percentages remaining on the standard sieves (minus under the sieve) divided by a hundred. The modulus of elasticity determines the fineness and coarseness of the grains; the coarser the stone grains, the higher their modulus of elasticity, and fine grains have a lower modulus of elasticity. The permissible amount of modulus or material softness factor for concrete is in the range of 2.3 to 1.3 [11].

The amount of particles smaller than 0.6 mm significantly affects the efficiency of the mixture. The amount of sand used in the concrete mixture should be low because the increase of 10 to 15% of grains smaller than 0.15 mm in the aggregates will decrease the compressive strength of concrete by almost 10%. The higher the softness factor, the less sand is used. The coefficient of softness of the sand used in the research is 2.7.

2.2|Cement

The cement used in the research is Portland Type 2 with a volume level of 3200 cm^2/gr and an autoclave expansion of 0.2. 430 kg/m^3 cement grade was considered in the construction of concretes. The chemical analysis of cement is presented in *Table 1.*

Table 1. Chemical analysis of cement used.

Chemical Composition	Percent Presentintype 2 Portland ement
SiO_2	21.8
Al_2O_3	3.5
Fe_2O_3	4.8
CaO	63.4
MgO	2.1
K_2O	0.6
Na_2O	0.3
So_3	2.5

2.3|Rice Husk Ash

This research used rice husk ash *Fig. 1* as a natural pozzolan with a specific weight of 2.2 gr/[cm]^3, whose chemical compositions are listed in *Table 2*.

Fig. 1. Used rice husk ash.

Table 2. Chemical composition of rice husk ash.

Chemical Composition	D Is Present in Rice Husk Ash
SiO_2	90.9
Al_2O_3	0.83
Fe_2O_3	0.6
CaO	0.8
MgO	0.56
K_2O	0.85
Na_2O	0.5
So_3	-

2.4 | Water

The water used in concrete production is the drinking water of Tankabon city of Mazandaran province, which is also suitable for making concrete due to its potable consumption.

2.5 | Super Lubricant

As the ratio of water to cement decreases, the quality of the concrete will increase, and we will see more resistance; for this purpose, various types of lubricating solutions will be added to the water required to make concrete. In constructing concrete samples, a superfluidizing additive based on polycarboxylate ether was used with a permissible consumption amount of 0.2 to 0.5% [12].

Also, the superfluidizer additive reduces the ratio of water to cement and the uniform and optimal distribution of cement among the constituents of concrete, which increases the specific weight and strength of concrete and also decreases the permeability. The specifications of the superfluidizer are listed in *Table 3*.

Table 3. Specifications of superplasticizers used in concrete.

Specifications	Feature
liquid	physical condition
bright yellow	color
gr/cm3 $\pm$ 0.01 1.04	specific weight
4 to 5	PH
does not have	Chlorine ion

2.6 | Consumable Fibers

Among other concrete additives in this research are metal fibers and polypropylene. Since steel fibers of concrete cause very high resistance in concrete and increase the efficiency of concrete, it can usually be used in all concreting. Concrete steel fibers are produced from low-carbon steel during various operations, and these fibers are produced and supplied in two types of sinusoidal and two hook ends. Considering that the types of concrete steel fibers can be changed according to the consumer's needs, it is possible to change the texture of concrete by changing the length and diameter of concrete steel fibers.

The steel fibers used in fiber concrete, according to ACI 544 standard [13], should have a ratio of length to thickness in the range of 20 to 100 in order to be properly distributed in the concrete, and also the volume percentage of steel fibers added to the in-situ concrete should be in the range of 0.25 to 2% to facilitate concrete making. The optimal consumption of these fibers is 10 to 12 kg/m^3. Steel strands with non-uniform distribution in the concrete reinforce the concrete in all directions (unlike the reinforcement, which only reinforces the concrete in two longitudinal and transverse directions). Steel fibers can be added to concrete at any stage, and the best time to add fibers is in the middle stage of mixing concrete components [14].

Polypropylene fibers are a type of polymer fibers that are added to the concrete mix to control cracks. This material is available as a single strand and in two sizes: the 12 mm type is used for concrete, and the 6 mm type is used for plaster or building mortar. These fibers are used to prevent the formation of fine cracks caused by shrinkage, premature drying, or premature temperature fluctuations. These measures are carried out to exploit the inherent properties of hardened cement materials optimally. These fibers are added to concrete before adding water [15].

2.7| Simple Metal Fibers with Two Hook Ends

This research used two hook fibers with two different diameters of 0.5 and 0.35 mm and a length of 35 mm. The action mechanism of the fibers is stretching or tearing from both sides of the concrete; in the case of metal fibers with two hook ends, the two ends of the fibers act like hooks and make it difficult to pull the fibers out of the concrete core. These fibers improve the parameters of the concrete by engaging and increasing the cohesion stresses inside the concrete. *Fig. 2* and *Fig 3* show Taheri's shape of hooked steel fibers.

Fig. 2. Metal fibers with two hook ends with a diameter of 0.35 mm.

Fig. 3. Metal fibers with two hook ends with a diameter of 0.5 mm.

2.8 | Sinusoidal Steel Fibers with Two Hook Ends

Sinus fibers with a diameter of 0.8 mm and a length of 50 mm were used in the research. Sinusoidal steel fibers create a special resistance in concrete structures and cause the creation of a suitable bed and uniform distribution in the entire concrete structure by sinusoidal concrete steel fibers. In *Fig 4* and *Fig 5*, the used metal fibers can be seen. The specifications of the used fibers are also given in *Table 4*.

Fig. 4. Sinusoidal metal fibers with two hook ends with a diameter of 0.8 mm.

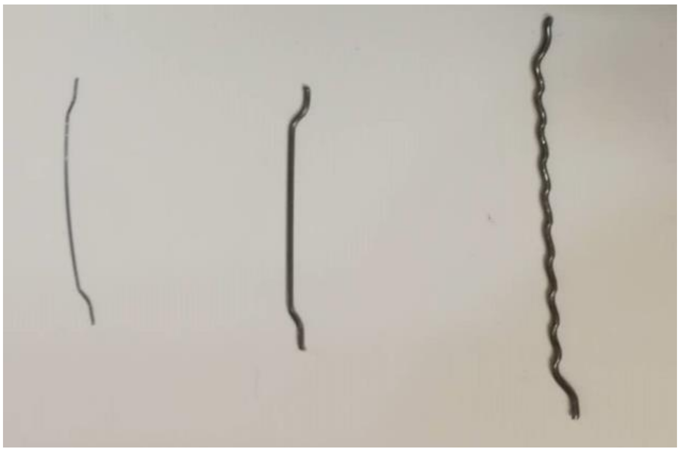

Fig. 5. A view of three types of metal fibers used with different diameters and lengths.

Table 4. Specifications of steel fibers.

Sinusoidal Fibers	Crochet Fibers	Specifications
50	35	Fiber length (mm)
0/8	0/35, 0/5	Fiber diameter (mm)
62/5	100, 70	Length-to-diameter ratio
7850	7850	Density (kg/m3)
1050	1050	Tensile strength (MPa)

2.9|Polypropylene Fibers

The research used polypropylene fibers with a length of 12 mm (*Fig. 6*), whose specifications are available in *Table 5*. These fibers have applications such as crack control in ready-made concrete, prefabricated concrete, conventional shotcrete, implementation of floor coverings, coating, and micro-silica concretes, concrete slabs, implementation of floors, patterned or patterned concrete and walkways, and supporting structures. Water, concreting of coastal structures, repair of stains, implementation of thin blades, dams, water tanks, construction of silos and tunnels, etc.

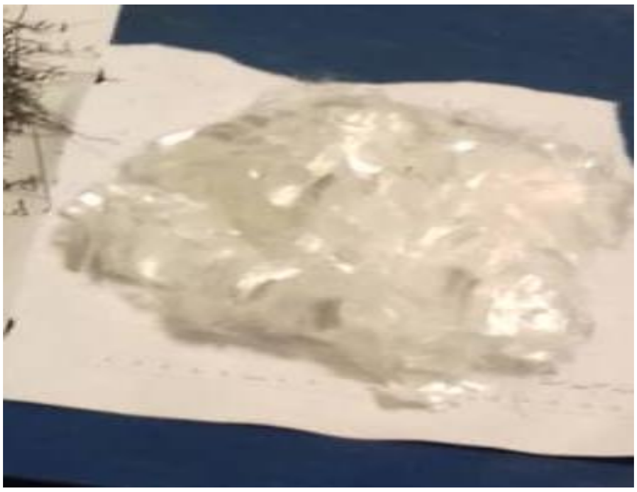

Fig. 6. Used polypropylene fibers.

Table 5. Properties of polypropylene fibers.

Characteristics of Polypropylene Fibers	Feature
white	color
12mm	Qatar
18 to 30 microns	Fiber thickness
gr/cm3 0.91 0.91 gr/cm3	specific weight
165 degrees Celsius	melting temperature
80 %	The rate of increase in length
MPa 400	Tensile strength

3|Concrete Mixing Plant

The material mixing plan includes one concrete plan without fibers and three concrete plans containing steel fibers, polypropylene fibers, and rice husk ash pozzolan. The 28-day characteristic strength of concrete in the research was 20 MPa, and the ratio of water to cement was 0.35. The code of designs with fibers represents the diameter of the steel fibers. The types of steel fibers are different for designs containing all fixed compositions. In constructing all four designs, 1% of steel fibers, 0.5% of superplasticizer, and 0.07% of polypropylene fibers were used, and 10% of the cement weight was replaced with rice husk ash. In *Table 6*, the plans for mixing materials can be seen.

Table 6. Plans for mixing concretes in terms of kilograms per cubic meter.

Mixing Scheme Code	Cement	Water	Sand	Sand	Rice Husk Ash	Super Smooth	Hooked Steel Fibers			Polypropylene Fibers
							0/8 mm	0/5 mm	0/35 mm	
C	430	150	1100	600	-	2/15	-	-	-	-
S 0.8	387	150	1100	600	43	2/15	10	-	-	0/7
S 0.5	387	150	1100	600	43	2/15	-	10	-	0/7
S 0.35	387	150	1100	600	43	2/15	-		10	0/7

4 | Making Samples

The materials used according to the mixing plan were entered into the truck mixer in certain sizes to make the samples. At first, dry materials such as gravel, sand, and cement were mixed after being weighed (*Fig. 7*), and at the end, water and superplasticizer were added, and the concrete mixing process lasted about 10 minutes. After the materials were completely mixed, the concretes were poured into cubic and pre-lubricated cylindrical molds (*Fig. 8*). This operation was done in three stages and, each time, hit 25 times with a rod with a diameter of 16 mm so that the concrete was fully compacted. The samples were placed in the laboratory environment for 24 hours, and after that, they were removed from the molds (*Fig. 9*) and placed in a water basin with a temperature of 20±2 for processing until reaching the desired age (*Fig. 10*).

Fig. 7. Weighing of dry materials.

Fig. 8. A view of concrete poured in standard molds.

Fig. 9. Concrete samples after removing from the molds.

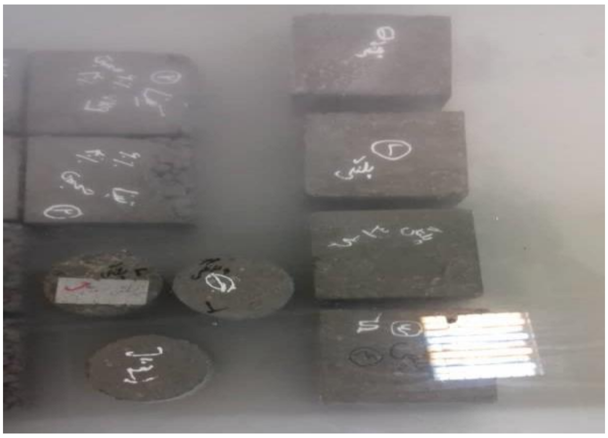

Fig. 10. Processing of concrete samples.

5 | Test Results

5.1 | Compressive Strength of Concrete

The compressive strength of normal concrete and three designs containing fibers at the age of 7 and 28 days are shown in *Table 7*. The resistance results are the average of three concrete samples. Based on the results, the compressive strength of concrete containing steel fibers with a diameter of 0.8 and polypropylene at the age of 28 days is 49.5 MPa and about twice the control sample, which was the highest compressive strength in the designs. For concrete with steel fibers with a diameter of 0.5, the strength increased by 50%, and for concrete containing steel fibers with a diameter of 0.35, this value increased by 25% compared to the control concrete.

The diagram of the compressive strength of the designs (*Fig. 11*) shows the resistance changes in the designs well. The increase in compressive strength at the age of 28 days of the concrete compared to the age of 7 days is 16% for the control sample, 32% for the concrete with sinuous fibers, and 28% and 19% for the concrete containing hooked fibers with a diameter of 0.5 and 0.35, respectively.

Table 7. Results of compressive strength of concrete samples.

Mixing Scheme Code	Compressive Strength (MPa)	
	7 Days	28 Days
C	20.1	24.4
S 0.8	37.9	49.5
S 0.5	28.5	36.9
S 0.35	26.5	30.6

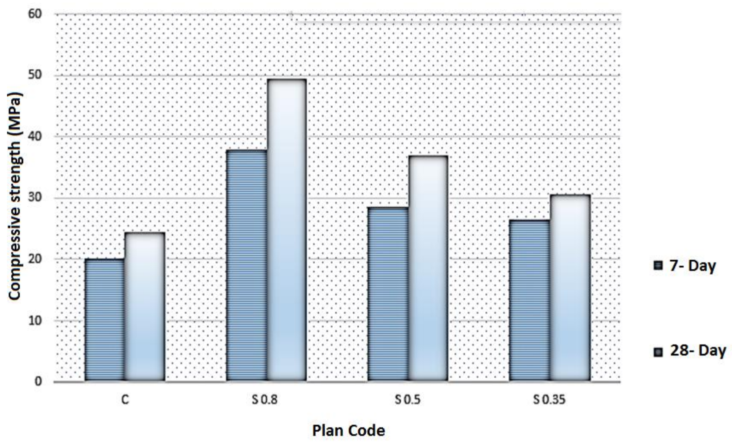

Fig. 11. Compressive strength results of concrete samples at the age of 7 and 28 days.

5.2 | Tensile Strength

The tensile strength results of normal concrete and three designs containing fibers at the age of 28 days are shown in *Table 8* and *Fig. 12*. The resistance results are the average of three concrete samples. The tensile strength of concrete containing fibers increased, and the highest amount of resistance was obtained in concrete containing sinusoidal fibers, which was associated with a 22% increase in strength compared to concrete without fibers. Tensile strength in hook concrete designs with a diameter of 0.5 and 0.35 was 7 and 2.6% higher than the strength of concrete without fibers, respectively.

Table 8. Tensile strength results of concrete samples.

Mixing Scheme Code	Tensile Strength 28 Days (MPa)
C	2.24
S 0.8	2.74
S 0.5	2.40
S 0.35	2.30

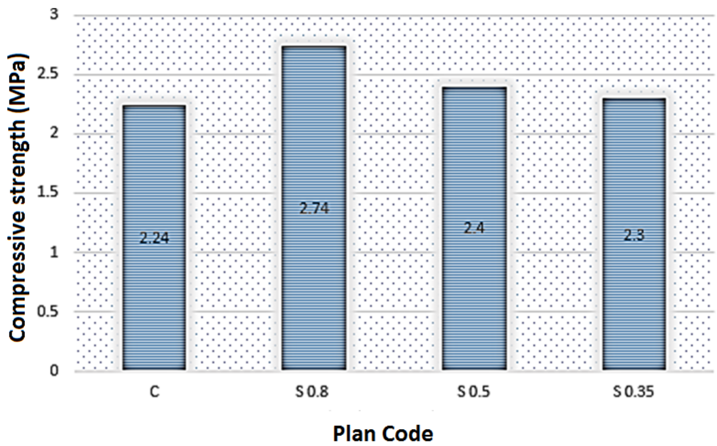

Fig. 12. Tensile strength results of concrete samples at the age of 28 days.

5.3 | Modulus of Elasticity

The results of the modulus of elasticity of concrete samples aged 28 days are described in *Table 9*. Like the compressive strength of concrete, the highest stress-strain ratio in the second mixing design is concrete with sinusoidal steel fibers with a diameter of 0.8. This ratio has grown by 34% in concrete with sinuous hooked fibers, 19% in concrete with hooked fibers with a diameter of 0.5, and 10% in concrete with hooked fibers with a diameter of 0.35 compared to concrete without fibers. Similarly, there is an increase in the compressive strength of concrete, and with the increase of compressive strength, the modulus of elasticity of concrete increases.

Table 9. Results of modulus of elasticity of concrete samples.

Mixing Scheme Code	Modulus of Elasticity 28 Days (GPa)
C	22.05
S 0.8	29.61
S 0.5	26.31
S 0.35	24.38

6 | Conclusion

From the analysis and examination of the results of the samples for the experiments, the following results were obtained:

I. According to the results obtained in the research, the use of steel fibers and, polypropylene and pozzolan of rice husk ash in mixed designs increased the compressive strength, tensile strength, and modulus of elasticity compared to concrete.

II. The addition of fibers reduced the slump and efficiency of concrete, and using a superplasticizer in concrete reduced this effect.

III. The use of rice husk ash as a substitute for part of cement has had a favorable effect on the strength of concrete.

IV. The use of polypropylene fibers in a very small amount in combination with steel fibers resulted in better adhesion of materials with cement and better performance of steel fibers.

V. Slump of concrete samples without fibers and containing zero fibers, and the mixing design is without slump.

VI. The highest compressive strength at the age of 7 days is for concrete containing hooked fibers with a diameter of 0.8 mm, which increased by 42% compared to concrete without fibers, and at the age of 28 days, this increase reached 102%.

VII. The maximum tensile strength at the age of 28 days of concrete with hooked fibers with a diameter of 0.8 mm was 2.74 MPa, which was about a 22% increase in strength compared to concrete without fibers.

VIII. The trend of increasing resistances in tension and compression is similar for the design of mixtures and its value is from high to low for fibers containing sinusoidal fibers, hooked fibers with a diameter of 0.5 and 0.35 mm.

IX. The highest increase in the modulus of elasticity is also seen in sinusoidal fibers with a value of 29.6 GPa with a 19% increase compared to concrete. As the compressive strength increased, the modulus of elasticity also increased.

Author Contributions

Mohammad Baqer Mirzaplangi designed and conducted the study, collected and analyzed data, and drafted the manuscript.

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Data Availability

The data generated and analyzed during this study are available from the author on reasonable request.

Conflicts of Interest

The author declares no conflicts of interest concerning the research, authorship, or publication of this article.

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