World Journal of Advanced Research and Reviews

eISSN: 2581-9615 CODEN (USA): WJARAI

Cross Ref DOI: 10.30574/wjarr

Journal homepage: https://wjarr.com/

(Research Article)

Comparative Mechanical and Durability Performance of Roller Compacted Concrete and Conventional Concrete in Burkina Faso

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World Journal of Advanced Research and Reviews, 2026, 29(01), 660-668

Publication history: Received on 06 November 2025; revised on 06 January 2026; accepted on 09 January 2026

Article DOI: https://doi.org/10.30574/wjarr.2026.29.1.0051

Abstract

The rapid urbanization of Sub-Saharan African cities has intensified traffic loads and stress concentrations in critical pavement zones, such as roundabouts and parking areas. These facilities are frequently exposed to heavy static and dynamic loads, braking and turning stress, and hydrocarbon spills. These situations accelerate the deterioration of conventional pavement material. This study investigates the potential of Roller-Compacted Concrete (RCC) as a sustainable alternative to Conventional Concrete (CC) for such applications in Burkina Faso. Both concrete types were designed with a target compressive strength of 25 MPa using locally available materials. The experimental results revealed that RCC exhibited a higher fresh density (approximately 2500 kg/m^3) than CC (≈2300 kg/m^3). This indicates superior compaction and reduced void content. Despite a 3% lower cement demand, RCC achieved a compressive strength of 27.57 MPa, which is 38% higher than the 20.01 MPa of the CC. RCC nearly doubled the tensile strength of CC (3.12 MPa vs. 1.72 MPa). In addition, its lower sorptivity (0.0964 vs. 0.1632) confirms its reduced porosity and improved resistance to the ingress of water. These findings highlight the suitability of RCC for urban infrastructure subjected to localized heavy stresses. It offers enhanced durability, lower maintenance requirements, and reduced life-cycle costs. The results support the use of RCC as a cost-effective and sustainable solution for roundabouts and parking areas in sub-Saharan Africa.

Keywords: Roller-compacted concrete; Conventional concrete; Mechanical properties; Durability; Sustainable pavement; Local materials

1. Introduction

Urban mobility in Sub-Saharan Africa increasingly depends on the reliability and durability of road infrastructure, particularly at critical nodes, such as roundabouts and parking areas. These facilities play a central role in traffic circulation and accessibility, serving as key connectors between arterial roads, commercial centers and residential zones. However, they are also subject to some of the most demanding service conditions in road networks. Frequent braking, acceleration, and turning maneuvers generate high shear stresses, whereas slow-moving or static loads do not. In particular, heavy vehicles impose severe compressive and tensile stresses on pavement surfaces. Consequently, conventional pavement materials often experience premature degradation, leading to increased maintenance costs and operational disruptions.

In Sub-Saharan cities, bituminous pavements remain the predominant choice for such facilities because of their low initial costs and ease of construction. However, under local climatic conditions characterized by high temperatures,

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intense solar radiation, and seasonal heavy rainfall, bituminous surfaces are prone to rutting, stripping, and oxidation, which significantly reduce their service life [1]. Conversely, conventional concrete pavements offer higher strength and durability but entail greater construction costs, longer curing times, and higher cement requirements. The need for skilled labor and specialized equipment further limits their widespread adoption in resource-constrained settings.

Roller-Compacted Concrete (RCC) has emerged as a promising alternative that bridges the performance gap between these two conventional solutions. RCC is a no-slump, low-water concrete mixture placed using earthmoving equipment and compacted using vibratory rollers. Its dense, well-compacted structure provides excellent mechanical performance and low permeability, resulting in enhanced resistance to wear, rutting, and fuel or oil spillage conditions that are common in parking facilities and roundabouts. The ability to quickly place RCC over large areas also reduces construction time and minimizes traffic disruption, which is an essential advantage in busy urban settings.

From an economic standpoint, RCC offers a favorable life-cycle cost compared to bituminous and conventional concrete pavements. Although its initial construction may require investment in specific compaction equipment and workforce training, its extended service life and reduced maintenance needs translate into substantial savings in the long term. This makes the RCC particularly relevant for cities in developing countries, such as those in Burkina Faso, where budgetary constraints coexist with growing traffic demand and challenging environmental conditions.

The potential of RCC for roundabouts and parking areas extends beyond its mechanical characteristics. These localized infrastructures are highly visible in urban networks. Their premature deterioration often creates negative public perceptions and traffic congestion, whereas their long-term durability directly contributes to safer and more efficient urban mobility. Therefore, adopting RCC for such applications could not only improve pavement longevity, but also demonstrate the feasibility of sustainable construction practices using local materials.

In this context, the present study aims to evaluate the mechanical and durability performance of Roller-Compacted Concrete (RCC) compared to Conventional Concrete (CC) produced using local aggregates from Burkina Faso. Both concrete types were designed with a target compressive strength of 25 MPa. The comparative analysis focused on the fresh density, compressive and tensile strengths, and sorptivity to assess the compaction quality, strength development, and permeability. The results provide new insights into the suitability of RCC for high-stress urban infrastructure, particularly roundabouts and parking areas, in sub-Saharan environments.

2. Materials and Methods

2.1. Materials used

2.1.1. Cement

The cement used was a CEM I – 42.5 of the company CIMTOGO produced in accordance with standard EN 197-1. The cement had a specific density, bulk density, and BET surface area of 3.15 t/m^3, 1.06 t/m3, and 2.96 m^2/g, respectively.

Table 1 Physical and mechanical properties of sand and coarse aggregates

Properties	Sand	Coarse aggregate
Maximum size (mm)	5	20
Bulk Density (kg/m^3)	1530	1350
Specific density (kg/m^3)	2680	2611
Los Angeles abrasion value (%)	-	35.9
Water absorption (24h) (%)	3.4	0.18

2.1.2. Sand and coarsed aggregate

The sand used as a fine aggregate was obtained from a local river. It has a maximum aggregate size of 5 mm. The particle size distribution of the sand shown in **Error! Reference source not found.** presents a poorly graded sand with a coefficient of uniformity Cu=3 and a coefficient of curvature Cc=0.9. A sand equivalent value of 98 indicates that there is less clay-like material in the sand, and it is appropriate for high-quality concrete. The specific density, bulk density, and fineness modulus of the sand were 2680 kg/m^3, 1530 kg/m^3, and 2.90, respectively.

The Physical and mechanical properties of the coarse aggregates are also listed in Table 1.

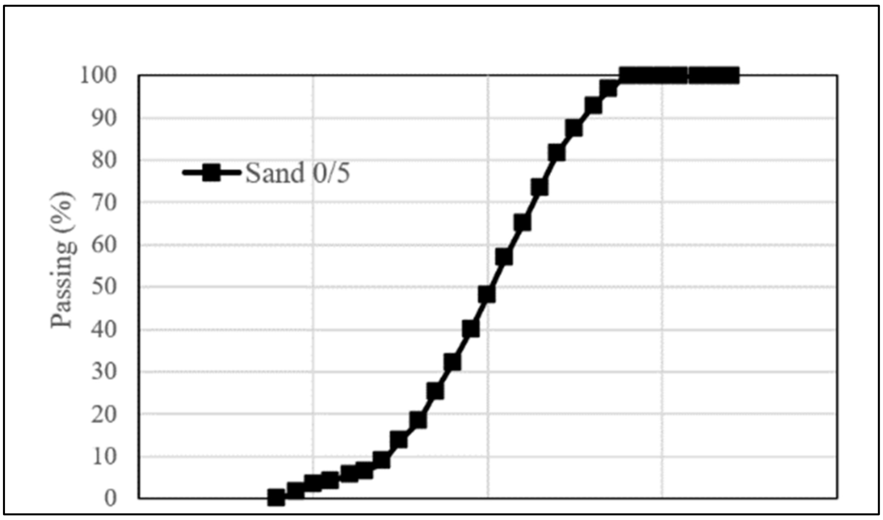

Figure 1 Particle size distribution curve of sand (0/5)

2.2. Concrete mix proportions and manufacture

Roller-compacted concrete (RCC) was designed using a semi-empirical approach based on the Fuller–Thompson grading curve method [2] to determine the optimal aggregate proportions. The required cement paste volume was estimated by quantifying the intergranular voids obtained after the compaction of the aggregate skeleton. This approach ensured an adequate paste content to achieve sufficient cohesion and mechanical performance of the RCC mixture. In contrast, conventional concrete (CC) was formulated according to the Dreux–Gorisse method, targeting a characteristic compressive strength of 25 MPa and medium workability corresponding to a slump class A (approximately 7 cm).

The different mixing proportions investigated in this study are summarized in Table 2.

Table 2 The different formulations

	Aggregate	Sand	Cement	Water	W/C
RCC	933	1032	340	128	0.38
CC	1073	738	350	200	0.57

The RCC specimens were cast in cylindrical molds with dimensions of 100 × 200 mm. Compaction was performed in five successive layers, each subjected to 43 blows using a standard Proctor hammer to simulate the field compaction conditions typical of RCC pavement construction. To avoid premature setting and ensure the consistency of the mixtures, the total duration from mixing to specimen preparation was strictly limited to 20–30 min.

For conventional concrete, mixing and casting were performed in the same cylindrical molds (100 mm × 200 mm), followed by mechanical vibration to ensure proper compaction. All specimens were demoulded after 24 h and subsequently cured by immersion in a water tank until the testing ages of 7 and 28 d.

2.3. Experimental tests

2.3.1. Compressive strength

The compression test was conducted on cylindrical test specimens (100 mm × 200 mm) in accordance with ASTM C39 [3] after 7 and 28 days of curing. This strength was calculated using Equation (1).

$$R_{cj} = \frac{P}{\frac{\pi * D^2}{4}} \quad \text{……….. (1)}$$

R_{cj} : Compressive strength on day j (MPa).

P: Maximum load causing failure under compressive stress (N);

D : Diameter of the specimen (mm^2).

Figure 2 Illustration of the compressive strength test performed on a 100 × 200 mm concrete specimen

2.3.2. Tensile strength

The split tensile strength test, or Brazilian test, is an indirect method used to evaluate the tensile behavior of concrete by applying a diametral compressive load to the specimen. This induces uniform tensile stress along the vertical diameter. The test was conducted in accordance with ASTM C496 on cylindrical specimens with dimensions of 100 mm × 200 mm at curing ages of 7 and 28 d [4]. The split tensile strength was calculated using Equation (2).

$$R_{tj} = 2\frac{P}{\pi * D * H} \tag{2}$$

R_{tj} : Tensile strength on day j (MPa).
P : Maximum compression load causing cylinder bursting by applying tensile stress to the vertical diameter (N).
$\pi * D * H$: Lateral section of the cylinder with diameter D and height H (mm^2).

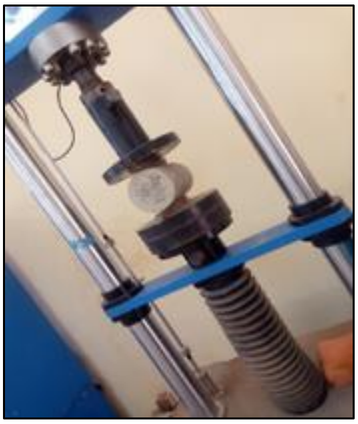

Figure 3 Splitting tensile test on cylindrical concrete specimen (100 mm × 200 mm)

2.3.3. Capillary absorption

The capillary water absorption test involves placing the lower surface of a concrete specimen in contact with water and monitoring the mass increase of the specimen over time. Prior to testing, all specimens were oven-dried at 60 °C until a constant mass was achieved, defined as a mass variation of less than 0.1% between two consecutive measurements taken 24 h apart. The lateral surfaces of the specimens were sealed with waterproof silicone to ensure unidirectional water ingress. Water absorption was determined by weighing the specimens at predefined time intervals (0, 5, 10, 20, 30, 60, 120, 240, 480, and 1440 min). Before each measurement, the surface in contact with water was gently wiped with a damp cloth to remove residual surface water. The test was conducted in accordance with ASTM C1585-04 [5] on cylindrical specimens with dimensions of 100 mm × 200 mm at curing ages of 7 and 28 d.

3. Results and discussion

3.1. Apparent density

The apparent density of fresh RCC was determined from the mass and volume measured after compaction in the molds, whereas that of CC was calculated using the mass and volume recorded after casting and vibration. Figure 4 presents the average fresh densities of RCC and CC, obtained from a total of eighteen (18) test specimens.

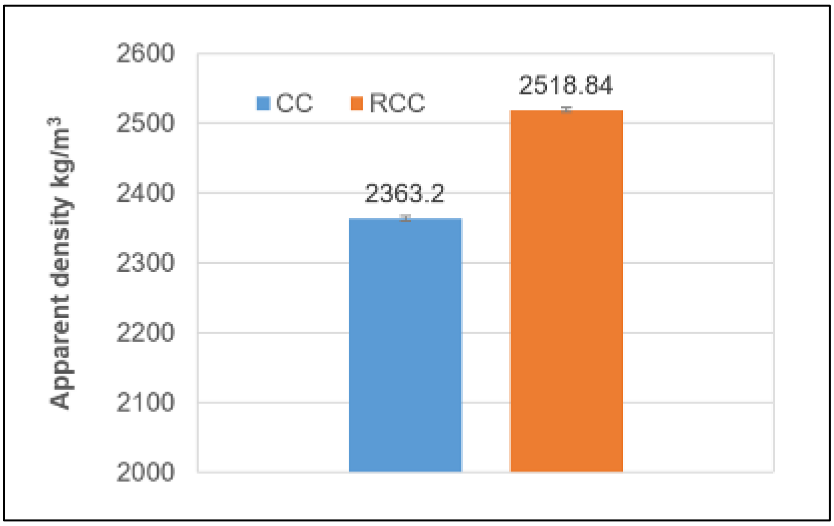

Figure 4 Apparent density of RCC and CC

The results indicated that all RCC specimens exhibited an average fresh density of approximately 2500 kg/m^3, whereas the densities of the CC specimens were approximately 2300 kg/m^3. Overall, the fresh density of roller-compacted concrete was approximately 9% higher than that of conventional concrete.

This increase in density can be attributed to the enhanced densification of the granular skeleton of the RCC mixtures. The application of intensive mechanical compaction significantly reduces the volume of entrapped air and intergranular voids, leading to lower porosity and a more compact internal structure of the material. Similar observations have been reported in the literature, where improved concrete density resulting from optimized compaction and aggregate packing has been highlighted [6].

3.2. Compressive strength

Figure 5 illustrates the compressive strength values and their evolution for the RCC and CC specimens (100 × 200 mm) after 7 and 28 days of curing. Each reported value corresponds to the average of the three tested specimens.

Although both concrete mixtures were designed to achieve a target compressive strength of 25 MPa at 28 d, differences in cement content were observed. Conventional concrete exhibited a slightly higher cement demand than roller-compacted concrete, with cement contents of 350 kg/m^3 and 340 kg/m^3, respectively, corresponding to an increase of approximately 3%.

Despite this higher cement content, the compressive strength of RCC at 28 days was significantly higher than that of CC, with values of 27.57 MPa and 20.01 MPa, respectively, representing an increase of approximately 38%. This superior performance of RCC can be attributed to the application of high compaction energy, which enhances the densification of the concrete matrix, and the higher proportion of aggregates that promotes improved granular interlock.

These findings are consistent with those of previous studies reported in the literature [7,8], which highlighted the enhanced mechanical performance of roller-compacted concrete compared to that of conventional concrete. Moreover, at 7 days of curing, the RCC already achieved a compressive strength of approximately 21 MPa, indicating rapid strength development. This characteristic represents a significant advantage for RCC pavement applications, particularly in projects that require early opening to traffic.

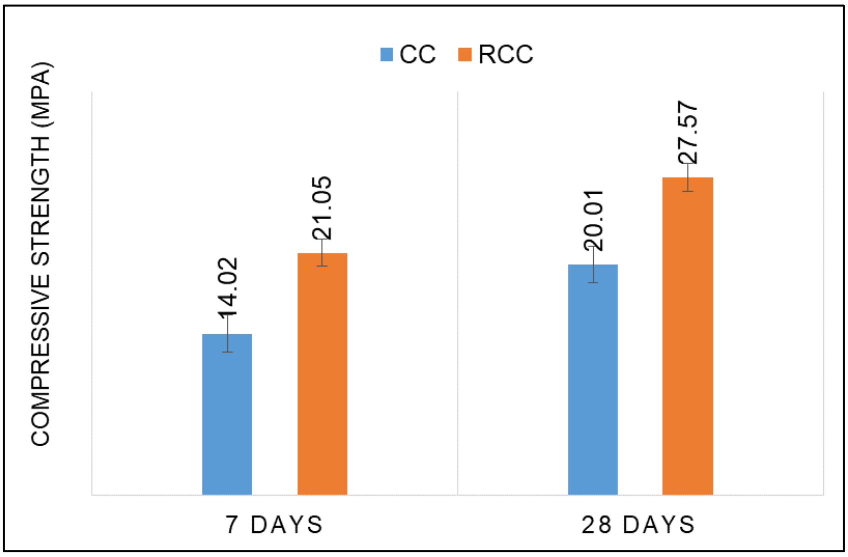

Figure 5 Comparison between conventional concrete and roller-compacted concrete at 7 and 28 days of compressive strength

3.3. Tensile strength

Figure 6 presents the splitting tensile strength results obtained at curing ages of 7 and 28 days. Each value corresponds to the average of three tested specimens.

The results clearly indicate that roller-compacted concrete exhibits a significantly higher tensile performance than conventional concrete. At 28 days, the splitting tensile strength of RCC reached 3.12 MPa, compared to 1.72 MPa for CC. This corresponds to an increase of nearly 80%. This enhanced tensile behavior represents a major advantage of RCC, particularly in pavement applications, where resistance to cracking is critical.

The superior tensile performance of RCC can be attributed to its denser microstructure resulting from intensive compaction, as well as to the higher aggregate content, which improves aggregate interlock and crack-bridging mechanisms. Similar trends have been reported in previous studies [7,9], confirming the enhanced mechanical performance of roller-compacted concrete.

Furthermore, the ratio of compressive strength to splitting tensile strength (Rc/Rt) was approximately 8.86 for RCC, compared to 11.63 for conventional concrete, indicating a more favorable balance between the compressive and tensile properties of RCC. At 7 days of curing, RCC already develops a splitting tensile strength of approximately 2.23 MPa, which contributes to limiting early age cracking and enhances the durability of the concrete at early service stages.

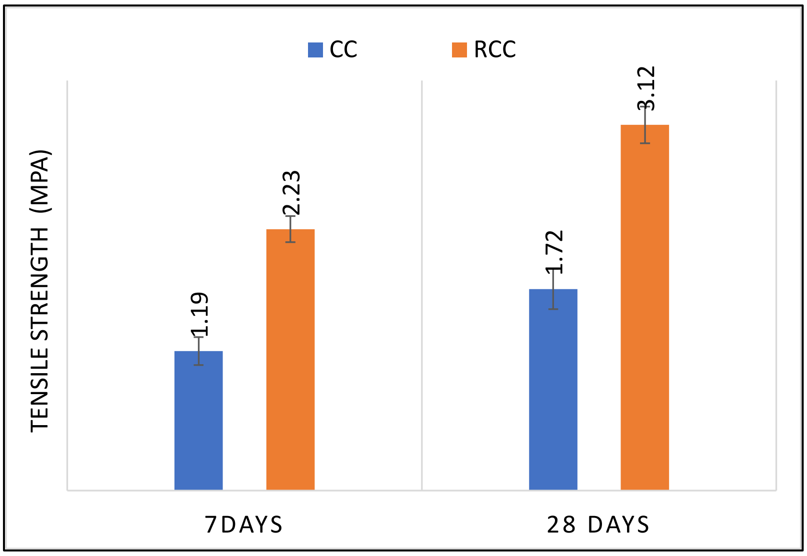

Figure 6 Splitting tensile strength of RCC and CC at 7 and 28 days of curing

3.4. Capillary absorption

Figure 7 illustrates the evolution of capillary water absorption for RCC and CC specimens over a period ranging from 1 to 24 h at 28 days of curing. The results clearly show a significantly lower rate of water uptake for RCC compared to that of CC.

The sorptivity coefficient of RCC was 0.0964, whereas that of CC reached 0.1632, indicating a much faster capillary water rise in conventional concrete. This difference is further reflected in the total water absorption values reported in Table 3, where CC exhibits a total absorption of 4.7% compared to only 3.1% for RCC.

Table 3 Evolution of capillary absorption of RCC and CC between 1 and 24 hours

Samples	Sorptivity [kg.m^2/h$^{1/2}$]	Correlation coefficient [R^2]	Water absorption [%]
RCC	0.0964	0.9167	3.1%
CC	0.1632	0.9453	4.7%

The reduced capillary absorption of RCC can be attributed to the enhanced densification of its granular skeleton, induced by intensive mechanical compaction. This densification leads to a refined pore structure with lower connectivity and reduced capillary porosity, thereby limiting the water ingress. In contrast, the higher porosity of conventional concrete promotes greater permeability and accelerates capillary transport.

These findings are consistent with those of previous studies reported by the Canadian Cement Association (2005), which demonstrated that conventional concrete generally exhibits higher permeability than roller-compacted concrete. The lower capillary absorption observed in RCC is therefore closely linked to its improved mechanical performance and enhanced durability, particularly under aggressive environmental conditions.

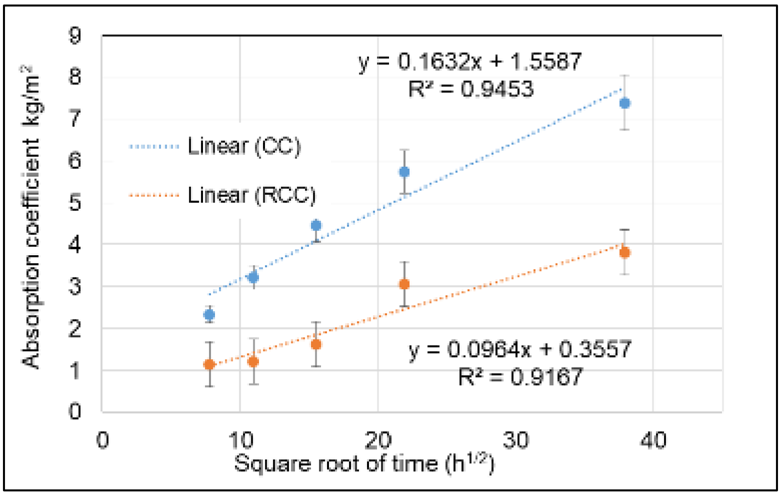

Figure 7 Capillary water absorption of RCC and CC (1 to 24 hours)

4. Conclusions

This study demonstrates that roller-compacted concrete (RCC) is a technically efficient and economically attractive alternative to conventional concrete (CC) for urban pavement applications subjected to severe localized loading conditions, particularly in Sub-Saharan African contexts such as Burkina Faso.

The combined evaluation of the mechanical and durability-related properties highlights a strong link between the microstructural features of RCC and its overall performance. The higher fresh density achieved through optimized granular packing and intensive compaction leads to a denser internal structure, which directly governs both the strength development and resistance to fluid ingress.

From a mechanical perspective, RCC exhibits significantly higher compressive and splitting tensile strengths than CC, despite its slightly lower cement content. This enhanced performance is mainly attributed to the effective densification of the concrete matrix, improved aggregate interlocks, and reduction in interfacial transition zones. The lower compressive-to-tensile strength ratio (Rc/Rt) further confirms the superior tensile behavior of the RCC, which is critical for limiting crack initiation and propagation in pavement structures.

In terms of durability, the reduced capillary water absorption and lower sorptivity coefficient observed for RCC indicate a refined and less-connected pore network. This microstructural refinement restricts water penetration and the transport of aggressive agents, thereby improving the resistance to long-term degradation. The strong correlation between reduced permeability and enhanced mechanical performance underscores the durability of RCC, particularly under combined mechanical and environmental loading.

Early age performance analysis revealed that RCC rapidly develops significant compressive and tensile strengths within the first 7 days, which helps mitigate early age cracking and limits the formation of preferential pathways for moisture ingress. This characteristic is especially beneficial for pavement applications that require early opening to traffic and exposure to harsh climatic conditions.

Overall, the experimental results confirm that RCC offers a more favorable balance between mechanical strength, crack resistance, and durability than conventional concrete does. The combination of superior performance, reduced cement demand, and possibility of incorporating locally available materials positions RCC as a sustainable and cost-effective solution for critical urban infrastructures such as roundabouts, intersections, and parking areas. These findings support the wider adoption of roller-compacted concrete in pavement engineering practices across sub-Saharan Africa, contributing to the development of more durable, resilient, and economically viable urban transport infrastructure.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare no conflicts of interest regarding the publication of this paper.

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