for categorical variables; the t-test was used for continuous normally distributed variables.

To determine the differences in GM graph network parameters between groups, a nonparametric permutation test method was used [52]. First, Cp and Lp of the networks at a given sparsity were computed separately for the AD and control groups. To test the null hypothesis that the observed group differences could occur by chance, we then randomly reallocated each subject's set of regional mean kurtosis measures to one or the other of the two groups and recomputed the correlation matrix for each randomized group. We then obtained corresponding weighted matrix using the same sparsity threshold as in the real brain networks. Next, we calculated the network parameters for each randomized group and obtained their differences between the randomized groups. This randomization procedure was repeated 1000 times.

To determine the between-group differences in the small world properties and network efficiency of the WM networks, an analysis of covariance (ANCOVA) was performed on each diffusion metric. Age and gender were taken as covariates in this model. The relationship between the network metrics and MMSE and MoCA scores in the patient group was analyzed by the partial correlation analysis.

Results

Demographics

There were no significant differences in both age ($p = 0.07$) and gender ($p = 0.8$) of AD patients and controls. For the neuropsychological tests, there were significant differences in MMSE and MoCA scores between the two groups ($p<0.05$, Table 1).

Within group network analysis

Small world analysis of the grey matter networks

The interregional parameter correlation values of the cortical networks were calculated to construct correlation matrices (90 × 90) for the NC and AD groups. The images of the group level interregional correlation matrices using DKI metrics of MK, KFA, AK and RK are shown in Fig. 1, and KFA in the control group presented the strongest positive coordinated effects during observations among these metrics.

Table 1 Demographic and clinical characteristics of subjects

Characteristics	AD Patients	Controls	*P* value
Age	73.57(±6.87)	70 (±8.08)	0.07
Female/male	12/21	9/18	0.8
MMSE	18.71 (±5.9)	28.16 (±1.12)	<0.001
MoCA	15(±6.67)	27.89(±0.14)	<0.001

Scores are shown with mean (±SD)

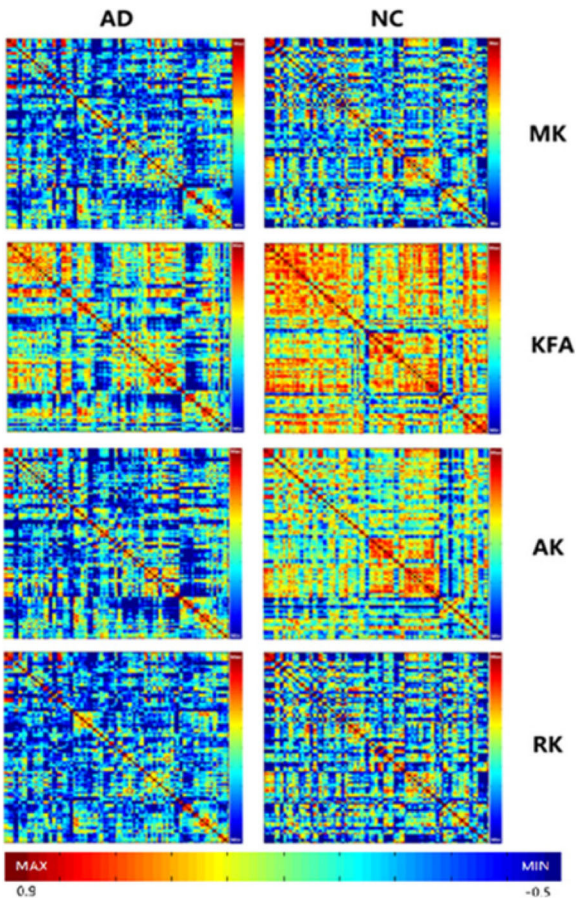

Fig. 1 The interregional correlation matrix (90 × 90) in the AD and NC groups using DKI metrics of MK, KFA, AK and RK. The color bar indicates the value of the interregional parameter correlation. The red color bar represents the higher positive correlation value. The blue color bar represents the higher negative correlation value. From the maps, a great degree of dispersion in DKI could be observed in AD patients. Note more strong positive coordinated effects existing in extensive brain regions labeled by red color for the metric of MK, KFA, AK and RK in the control group vs. AD group, and KFA is the typical. The higher KFA value meant more compact histological structure

We found the small world attributes of GM networks with MK, KFA, AK and RK metric in the normal elder subjects and AD patients over a wide range of sparsity (6% ~ S ~ 40%) (showed in Fig. 2). The small-worldness values ($\sigma = \gamma/\lambda$) calculated from the DKI indices were larger than 1, the values with MK, KFA, AK and RK were 1.57, 1.67, 1.75 and 2.25 in AD patients, respectively, and were 2.88, 2.28, 1.55, 2.24 in controls, respectively.

Small world analysis of the white matter networks

As expected, we also observed that the brains of both the AD patients and controls had prominent small world network properties in WM networks over a wide range