Ball with Hair: Modular functionalization of highly stable G-quadruplex DNA nano-scaffolds through N2-guanine modification

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Supporting Information

Keywords: G-quadruplex, nanoparticle, stability, N2-modifications, functionalization

Running Title: N2-modifications to G-quadruplex

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123 4 5 6 7 89 101112154415161718 192021 22324NativeTTGGGTTAGGGTTAGGGTTAGGGAMet-3TTMGGTTAGGGTTAGGGTTAGGGAMet-4TTGMGTTAGGGTTAGGGTTAGGGAMet-5TTGGMTTAGGGTTAGGGTTAGGGAMet-10TTGGGTTAGGGTTAGGGTTAGGGAMet-11TTGGGTTAGGGTTAGGGTTAGGGAMet-15TTGGGTTAGGGTTAGGGTTAGGGAMet-16TTGGGTTAGGGTTAGGGTTAGGGAMet-21TTGGGTTAGGGTTAGGGTTAGGGAMet-23TTGGGTTAGGGTTAGGGTTAGGGAMet-23TTGGGTTAGGGTTAGGGTTAGGGABen-3TTBGGTTAGGGTTAGGGTTAGGGABen-10TTGGGTTAGGGTTAGGGTTAGGGABen-11TTGGGTTAGGGTTAGGGTTAGGGABen-12TTGGGTTAGGGTTAGGGTTAGGG	Name	Sequence
NativeTTGGGTTAGGGTTAGGGTTAGGGAMet-3TTMGGTTAGGGTTAGGGTTAGGGAMet-3TTGMGTTAGGGTTAGGGTTAGGGAMet-4TTGMGTTAGGGTTAGGGTTAGGGAMet-5TTGGGTTAMGGTTAGGGTTAGGGAMet-10TTGGGTTAGGGTTAGGGTTAGGGAMet-11TTGGGTTAGGGTTAGGGTTAGGGAMet-15TTGGGTTAGGGTTAGGGTTAGGGAMet-16TTGGGTTAGGGTTAGGGTTAGGGAMet-21TTGGGTTAGGGTTAGGGTTAGGGAMet-23TTGGGTTAGGGTTAGGGTTAGGGABen-3TTBGGTTAGGGTTAGGGTTAGGGABen-4TTGGGTTAGGGTTAGGGTTAGGGABen-5TTGGGTTAGGGTTAGGGTTAGGGABen-10TTGGGTTAGGGTTAGGGTTAGGGABen-11TTGGGTTAGGGTTAGGGTTAGGG		1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Met-3TTMGGTTAGGGTTAGGGTTAGGGAMet-4TTGMGTTAGGGTTAGGGTTAGGGAMet-5TTGGGTTAGGGTTAGGGTTAGGGAMet-9TTGGGTTAGGGTTAGGGTTAGGGAMet-10TTGGGTTAGGGTTAGGGTTAGGGAMet-11TTGGGTTAGGGTTAGGGTTAGGGAMet-15TTGGGTTAGGGTTAGGGTTAGGGAMet-16TTGGGTTAGGGTTAGGGTTAGGGAMet-21TTGGGTTAGGGTTAGGGTTAGGGAMet-22TTGGGTTAGGGTTAGGGTTAGGGAMet-23TTGGGTTAGGGTTAGGGTTAGGGABen-3TTGGGTTAGGGTTAGGGTTAGGGABen-5TTGGGTTAGGGTTAGGGTTAGGGABen-10TTGGGTTAGGGTTAGGGTTAGGGABen-11TTGGGTTAGGGTTAGGGTTAGGGABen-12TTGGGTTAGGGTTAGGGTTAGG	Native	TT GGG TTA GGG TTA GGG TTA GGG A
Met-3TTMGGTTAGGGTTAGGGTTAGGGAMet-4TTGMGTTAGGGTTAGGGTTAGGGAMet-5TTGGGTTAGGGTTAGGGTTAGGGAMet-9TTGGGTTAGGGTTAGGGTTAGGGAMet-10TTGGGTTAGGGTTAGGGTTAGGGAMet-11TTGGGTTAGGGTTAGGGTTAGGGAMet-15TTGGGTTAGGGTTAGGGTTAGGGAMet-16TTGGGTTAGGGTTAGGGTTAGGGAMet-21TTGGGTTAGGGTTAGGGTTAGGGAMet-22TTGGGTTAGGGTTAGGGTTAGGGAMet-23TTGGGTTAGGGTTAGGGTTAGGGABen-3TTBGGTTAGGGTTAGGGTTAGGGABen-10TTGGGTTAGGGTTAGGGTTAGGGABen-11TTGGGTTAGGGTTAGGGTTAGGGABen-11TTGGGTTAGGGTTAGGGTTAGGGABen-12TTGGGTTAGGGTTAGGGTTAG		
Met-4TTGMGTTAGGGTTAGGGTTAGGGAMet-5TTGGMTTAGGGTTAGGGTTAGGGAMet-9TTGGGTTAGGGTTAGGGTTAGGGAMet-10TTGGGTTAGGGTTAGGGTTAGGGAMet-11TTGGGTTAGGGTTAGGGTTAGGGAMet-15TTGGGTTAGGGTTAGGGTTAGGGAMet-16TTGGGTTAGGGTTAGGGTTAGGGAMet-17TTGGGTTAGGGTTAGGGTTAGGGAMet-21TTGGGTTAGGGTTAGGGTTAGGGAMet-23TTGGGTTAGGGTTAGGGTTAGGGAMet-23TTGGGTTAGGGTTAGGGTTAGGGABen-3TTBGGTTAGGGTTAGGGTTAGGGABen-10TTGGGTTAGGGTTAGGGTTAGGGABen-11TTGGGTTAGGGTTAGGGTTAGGGABen-12TTGGGTTAGGGTTAGGGTTAGGGABen-13TTGGGTTAGGGTTAGGGTTA	Met-3	TT MGG TTA GGG TTA GGG TTA GGG A
Met-5TTGGMTTAGGGTTAGGGTTAGGGGTAGGGAMet-9TTGGGTTAGMGTTAGGGTTAGGGAMet-10TTGGGTTAGGGTTAGGGTTAGGGAMet-11TTGGGTTAGGGTTAGGGTTAGGGAMet-15TTGGGTTAGGGTTAGGGTTAGGGAMet-16TTGGGTTAGGGTTAGGGTTAGGGAMet-17TTGGGTTAGGGTTAGGGTTAGGGAMet-21TTGGGTTAGGGTTAGGGTTAGGGAMet-22TTGGGTTAGGGTTAGGGTTAGGGAMet-23TTGGGTTAGGGTTAGGGTTAGGGABen-3TTGGGTTAGGGTTAGGGTTAGGGABen-5TTGGGTTAGGGTTAGGGTTAGGGABen-10TTGGGTTAGGGTTAGGGTTAGGGABen-11TTGGGTTAGGGTTAGGGTTAGGGABen-12TTGGGTTAGGGTTAGGGTTAGGGABen-13TTGGGTTAGGGTTA	Met-4	TT GMG TTA GGG TTA GGG TTA GGG A
Met-9 TT GGG TTA MGG TTA GGG A Met-11 TT GGG TTA GGG TTA GGG TTA GGG TTA GGG A Met-15 TT GGG TTA GGG TTA GGG TTA GGG A GGG A Met-17 TT GGG TTA GGG TTA GGG TTA GGG TTA GGG A GGG A Met-17 TT GGG TTA GGG TTA GGG TTA GGG TTA GGG A GGG A <td>Met-5</td> <td>TT GGM TTA GGG TTA GGG TTA GGG A</td>	Met-5	TT GGM TTA GGG TTA GGG TTA GGG A
Met-10TTGGGTTAGMGTTAGGGTTAGGGAMet-11TTGGGTTAGGGTTAGGGTTAGGGAMet-15TTGGGTTAGGGTTAGGGTTAGGGAMet-16TTGGGTTAGGGTTAGGGTTAGGGAMet-17TTGGGTTAGGGTTAGGGTTAGGGAMet-21TTGGGTTAGGGTTAGGGTTAGGGAMet-22TTGGGTTAGGGTTAGGGTTAGGGAMet-23TTGGGTTAGGGTTAGGGTTAGGGABen-3TTGGGTTAGGGTTAGGGTTAGGGABen-4TTGGGTTAGGGTTAGGGTTAGGGABen-5TTGGGTTAGGGTTAGGGTTAGGGABen-10TTGGGTTAGGGTTAGGGAGGABen-11TTGGGTTAGGGTTAGGGTTAGGGABen-12TTGGGTTAGGGTTAGGGTTAGGGABen-21TTGGGTTAGGGTTAGGGTTAGGGABen-22TTGGGTTAGGGTTAGGGTTAGG	Met-9	TT GGG TTA MGG TTA GGG TTA GGG A
Met-11TTGGGTTAGGMTTAGGGTTAGGGAMet-15TTGGGTTAGGGTTAGGGTTAGGGAMet-16TTGGGTTAGGGTTAGGGTTAGGGAMet-17TTGGGTTAGGGTTAGGGTTAGGGAMet-21TTGGGTTAGGGTTAGGGTTAGGGAMet-22TTGGGTTAGGGTTAGGGTTAGGGAMet-23TTGGGTTAGGGTTAGGGTTAGGGABen-3TTGGGTTAGGGTTAGGGTTAGGGABen-4TTGBGTTAGGGTTAGGGTTAGGGABen-5TTGGGTTAGGGTTAGGGTTAGGGABen-10TTGGGTTAGGGTTAGGGTTAGGGABen-11TTGGGTTAGGGTTAGGGTTAGGGABen-12TTGGGTTAGGGTTAGGGTTAGGGABen-22TTGGGTTAGGGTTAGGGTTAGGGABen-23TTGGGTTAGGGTTAGGGTTAGGGABen-23TTGGGTTAGGGTTAGGGTTA <td< td=""><td>Met-10</td><td>TT GGG TTA GMG TTA GGG TTA GGG A</td></td<>	Met-10	TT GGG TTA GMG TTA GGG TTA GGG A
Met-15TTGGGTTAGGGTTAGGGTTAGGGAMet-16TTGGGTTAGGGTTAGGGTTAGGGAMet-17TTGGGTTAGGGTTAGGGTTAGGGAMet-21TTGGGTTAGGGTTAGGGTTAGGGAMet-22TTGGGTTAGGGTTAGGGTTAGGGAMet-23TTGGGTTAGGGTTAGGGTTAGGGABen-3TTBGGTTAGGGTTAGGGTTAGGGABen-4TTGBGTTAGGGTTAGGGTTAGGGABen-5TTGGGTTAGGGTTAGGGTTAGGGABen-10TTGGGTTAGGGTTAGGGTTAGGGABen-11TTGGGTTAGGGTTAGGGTTAGGGABen-12TTGGGTTAGGGTTAGGGAGGABen-21TTGGGTTAGGGTTAGGGTTAGGGABen-22TTGGGTTAGGGTTAGGGTTAGGGABen-23TTGGGTTAGGGTTAGGGTTAGGGAHex-3TTHGGTTAGGGTTAGGGTTAGGG	Met-11	TT GGG TTA GGM TTA GGG TTA GGG A
Met-16TTGGGTTAGGGTTAGGGAMet-17TTGGGTTAGGGTTAGGGTTAGGGAMet-21TTGGGTTAGGGTTAGGGTTAGGGAMet-22TTGGGTTAGGGTTAGGGTTAGGGAMet-23TTGGGTTAGGGTTAGGGTTAGGGABen-3TTBGGTTAGGGTTAGGGTTAGGGABen-4TTGGGTTAGGGTTAGGGTTAGGGABen-5TTGGGTTAGGGTTAGGGTTAGGGABen-10TTGGGTTAGGGTTAGGGTTAGGGABen-11TTGGGTTAGGGTTAGGGTTAGGGABen-15TTGGGTTAGGGTTAGGGTTAGGGABen-16TTGGGTTAGGGTTAGGGTTAGGGABen-21TTGGGTTAGGGTTAGGGTTAGGGABen-23TTGGGTTAGGGTTAGGGTTAGGGABen-21TTGGGTTAGGGTTAGGGTTAGGGABen-23TTGGGTTAGGGTTAGGGTTAGGGA	Met-15	TT GGG TTA GGG TTA MGG TTA GGG A
Met-17TTGGGTTAGGGTTAGGGAMet-21TTGGGTTAGGGTTAGGGTTAGGGAMet-22TTGGGTTAGGGTTAGGGTTAGGGTTAGGGAMet-23TTGGGTTAGGGTTAGGGTTAGGGTTAGGGABen-3TTBGGTTAGGGTTAGGGTTAGGGABen-4TTGGGTTAGGGTTAGGGTTAGGGABen-5TTGGGTTAGGGTTAGGGTTAGGGABen-10TTGGGTTAGGGTTAGGGTTAGGGABen-11TTGGGTTAGGGTTAGGGTTAGGGABen-12TTGGGTTAGGGTTAGGGTTAGGGABen-13TTGGGTTAGGGTTAGGGAABen-14TTGGGTTAGGGTTAGGGABen-15TTGGGTTAGGGTTAGGGABen-16TTGGGTTAGGGTTAGGGABen-21TTGGGTTAGGGTTAGGGABen-23TTGGGTTAGGGTTAGGGAHex -3TTGGGTTAGGGTTAGGG<	Met-16	TT GGG TTA GGG TTA GMG TTA GGG A
Met-21TTGGGTTAGGGTTAGGGTTAGGGAMet-22TTGGGTTAGGGTTAGGGTTAGGGAMet-23TTGGGTTAGGGTTAGGGTTAGGGABen-3TTGGGTTAGGGTTAGGGTTAGGGABen-3TTGGGTTAGGGTTAGGGTTAGGGABen-4TTGGGTTAGGGTTAGGGTTAGGGABen-5TTGGGTTAGGGTTAGGGTTAGGGABen-10TTGGGTTAGGGTTAGGGTTAGGGABen-11TTGGGTTAGGGTTAGGGTTAGGGABen-11TTGGGTTAGGGTTAGGGTTAGGGABen-11TTGGGTTAGGGTTAGGGTTAGGGABen-11TTGGGTTAGGGTTAGGGAABen-12TTGGGTTAGGGTTAGGGTTAGGGABen-21TTGGGTTAGGGTTAGGGTTAGGGABen-22TTGGGTTAGGGTTAGGGTTAGGGAHex-3TTHGGTTAGGGTTAGGGTTAGGGA </td <td>Met-17</td> <td>TT GGG TTA GGG TTA GGM TTA GGG A</td>	Met-17	TT GGG TTA GGG TTA GGM TTA GGG A
Met-22TTGGGTTAGGGTTAGGGTTAGMGAMet-23TTGGGTTAGGGTTAGGGTTAGGGABen-3TTGGGTTAGGGTTAGGGTTAGGGABen-4TTGBGTTAGGGTTAGGGTTAGGGABen-5TTGGBTTAGGGTTAGGGTTAGGGABen-10TTGGGTTAGGGTTAGGGTTAGGGABen-10TTGGGTTAGGGTTAGGGTTAGGGABen-10TTGGGTTAGGGTTAGGGTTAGGGABen-11TTGGGTTAGGGTTAGGGTTAGGGABen-11TTGGGTTAGGGTTAGGGTTAGGGABen-11TTGGGTTAGGGTTAGGGAABen-11TTGGGTTAGGGTTAGGGABen-12TTGGGTTAGGGTTAGGGABen-22TTGGGTTAGGGTTAGGGABen-23TTGGGTTAGGGTTAGGGAHex-3TTHGGTTAGGGTTAGGGAHex-3TTGGGTTAGGGTTAGGGA <td< td=""><td>Met-21</td><td>TT GGG TTA GGG TTA GGG TTA MGG A</td></td<>	Met-21	TT GGG TTA GGG TTA GGG TTA M GG A
Met-23TTGGGTTAGGGTTAGGGTTAGGMABen-3TTBGGTTAGGGTTAGGGTTAGGGABen-4TTGBGTTAGGGTTAGGGTTAGGGABen-5TTGGBTTAGGGTTAGGGTTAGGGABen-5TTGGGTTAGGGTTAGGGTTAGGGABen-10TTGGGTTAGGGTTAGGGTTAGGGABen-10TTGGGTTAGGGTTAGGGAABen-11TTGGGTTAGGGTTAGGGAABen-15TTGGGTTAGGGTTAGGGAABen-16TTGGGTTAGGGTTAGGGAABen-21TTGGGTTAGGGTTAGGGAABen-22TTGGGTTAGGGTTAGGGAABen-23TTGGGTTAGGGTTAGGGAAHex-3TTHGGTTAGGGTTAGGGAAHex-3TTGGGTTAGGGTTAGGGAAHex-3TTGGGTTAGGGTTAGGGAAHex-4TTGGGTTAGGGTTAGGGAA <td< td=""><td>Met-22</td><td>TT GGG TTA GGG TTA GGG TTA GMG A</td></td<>	Met-22	TT GGG TTA GGG TTA GGG TTA G M G A
Ben-3TTBGGTTAGGGTTAGGGTTAGGGABen-4TTGBGTTAGGGTTAGGGTTAGGGABen-5TTGGBTTAGGGTTAGGGTTAGGGABen-5TTGGGTTABGGTTAGGGTTAGGGABen-9TTGGGTTABGGTTAGGGTTAGGGABen-10TTGGGTTAGBGTTAGGGTTAGGGABen-11TTGGGTTAGGGTTAGGGTTAGGGABen-15TTGGGTTAGGGTTAGGGTTAGGGABen-16TTGGGTTAGGGTTAGGGTTAGGGABen-17TTGGGTTAGGGTTAGGGTTAGGGABen-21TTGGGTTAGGGTTAGGGAABen-22TTGGGTTAGGGTTAGGGAABen-23TTGGGTTAGGGTTAGGGAAHex-3TTHGGTTAGGGTTAGGGAAHex-3TTGGGTTAGGGTTAGGGAAHex-4TTGGGTTAGGGTTAGGGAAHex -9TTGGGTTAGGG	Met-23	TT GGG TTA GGG TTA GGG TTA GGM A
Ben-3TTBGGTTAGGGTTAGGGTTAGGGABen-4TTGBGTTAGGGTTAGGGTTAGGGABen-5TTGGBTTAGGGTTAGGGTTAGGGABen-9TTGGGTTABGGTTAGGGTTAGGGABen-10TTGGGTTAGGBTTAGGGTTAGGGABen-10TTGGGTTAGGBTTAGGGTTAGGGABen-11TTGGGTTAGGGTTAGGGTTAGGGABen-15TTGGGTTAGGGTTAGGGTTAGGGABen-16TTGGGTTAGGGTTAGGBTTAGGGABen-17TTGGGTTAGGGTTAGGBTTAGGGABen-21TTGGGTTAGGGTTAGGGTTAGGGABen-22TTGGGTTAGGGTTAGGGTTAGGGABen-23TTGGGTTAGGGTTAGGGTTAGGGAHex-3TTGGGTTAGGGTTAGGGAAHex-3TTGGGTTAGGGTTAGGGAAHex -9TTGGGTTAGGGTTAGGGTTAGGGA		
Ben-4TTGBGTTAGGGTTAGGGTTAGGGABen-5TTGGBTTAGGGTTAGGGTTAGGGABen-9TTGGGTTABGGTTAGGGTTAGGGABen-10TTGGGTTAGGGTTAGGGTTAGGGABen-10TTGGGTTAGGGTTAGGGTTAGGGABen-11TTGGGTTAGGGTTAGGGTTAGGGABen-15TTGGGTTAGGGTTAGGGTTAGGGABen-16TTGGGTTAGGGTTAGGBTTAGGGABen-17TTGGGTTAGGGTTAGGBTTAGGGABen-21TTGGGTTAGGGTTAGGGTTAGGGABen-22TTGGGTTAGGGTTAGGGTTAGGGABen-23TTGGGTTAGGGTTAGGGAAHex-3TTGGGTTAGGGTTAGGGAAHex-3TTGGGTTAGGGTTAGGGAAHex -9TTGGGTTAGGGTTAGGGTAGGGAHex -10TTGGGTTAGGGTTAGGGTTAGGGAHex -11<	Ben-3	TT B GG TTA GGG TTA GGG TTA GGG A
Ben-5TTGGBTTAGGGTTAGGGTTAGGGABen-9TTGGGTTABGGTTAGGGTTAGGGABen-10TTGGGTTAGBGTTAGGGTTAGGGABen-11TTGGGTTAGGGTTAGGGTTAGGGABen-11TTGGGTTAGGGTTAGGGTTAGGGABen-15TTGGGTTAGGGTTAGGGTTAGGGABen-16TTGGGTTAGGGTTAGGGTTAGGGABen-17TTGGGTTAGGGTTAGGGTTAGGGABen-21TTGGGTTAGGGTTAGGGTTAGGGABen-22TTGGGTTAGGGTTAGGGTTAGGGABen-23TTGGGTTAGGGTTAGGGAAHex -3TTHGGTTAGGGTTAGGGAAHex -9TTGGGTTAGGGTTAGGGTTAGGGAHex -10TTGGGTTAGGGTTAGGGTTAGGGAHex -11TTGGGTTAGGGTTAGGGTTAGGGAHex -16TTGGGTTAGGGTTAGGGTTAGGGA<	Ben-4	TT G B G TTA GGG TTA GGG TTA GGG A
Ben-9TTGGGTTABGGTTAGGGTTAGGGABen-10TTGGGTTAGBGTTAGGGTTAGGGABen-11TTGGGTTAGGGTTAGGGTTAGGGABen-15TTGGGTTAGGGTTABGGTTAGGGABen-16TTGGGTTAGGGTTAGGGTTAGGGABen-17TTGGGTTAGGGTTAGGGTTAGGGABen-21TTGGGTTAGGGTTAGGGTTAGGGABen-22TTGGGTTAGGGTTAGGGTTAGGGABen-23TTGGGTTAGGGTTAGGGTTAGGGAHex-3TTHGGTTAGGGTTAGGGAGGGAHex -10TTGGGTTAGGGTTAGGGTTAGGGAHex -11TTGGGTTAGGGTTAGGGTTAGGGAHex -16TTGGGTTAGGGTTAGGGTTAGGGAHex -17TTGGGTTAGGGTTAGGGTTAGGGAHex -21TTGGGTTAGGGTTAGGGTTAGGGAHex -22TTGGGTTAGGGTTAGGGTTA <td>Ben-5</td> <td>TT GGB TTA GGG TTA GGG TTA GGG A</td>	Ben-5	TT GG B TTA GGG TTA GGG TTA GGG A
Ben-10TTGGGTTAGBGTTAGGGTTAGGGABen-11TTGGGTTAGGBTTAGGGTTAGGGABen-15TTGGGTTAGGGTTAGGGTTAGGGABen-16TTGGGTTAGGGTTAGGGTTAGGGABen-16TTGGGTTAGGGTTAGGGTTAGGGABen-17TTGGGTTAGGGTTAGGGTTAGGGABen-21TTGGGTTAGGGTTAGGGTTAGGGABen-22TTGGGTTAGGGTTAGGGTTAGGGABen-23TTGGGTTAGGGTTAGGGAAHex-3TTHGGTTAGGGTTAGGGAAHex -1GGGTTAGGGTTAGGGAAHex -2TTGGGTTAGGGTTAGGGAHex -10TTGGGTTAGGGTTAGGGAAHex -11TTGGGTTAGGGTTAGGGAAHex -16TTGGGTTAGGGTTAGGGAAHex -17TTGGGTTAGGGTTAGGGAAHex -21TTGGGTTAGGGTTAGGGA <td< td=""><td>Ben-9</td><td>TT GGG TTA BGG TTA GGG TTA GGG A</td></td<>	Ben-9	TT GGG TTA B GG TTA GGG TTA GGG A
Ben-11TTGGGTTAGGBTTAGGGTTAGGGABen-15TTGGGTTAGGGTTAGGGTTAGGGABen-16TTGGGTTAGGGTTAGGGTTAGGGABen-17TTGGGTTAGGGTTAGGGTTAGGGABen-21TTGGGTTAGGGTTAGGGTTAGGGABen-22TTGGGTTAGGGTTAGGGTTAGBGABen-23TTGGGTTAGGGTTAGGGAAHex-3TTHGGTTAGGGTTAGGGAAHex -4TTGHGTTAGGGTTAGGGAAHex -5TTGGGTTAGGGTTAGGGAAHex -10TTGGGTTAGGGTTAGGGAAHex -11TTGGGTTAGGGTTAGGGAAHex -16TTGGGTTAGGGTTAGGGAAHex -17TTGGGTTAGGGTTAGGGTTAGGGAHex -21TTGGGTTAGGGTTAGGGTTAGGGAAHex -22TTGGGTTAGGGTTAGGGTTAGGGAAHex -23TTGGG	Ben-10	TT GGG TTA G B G TTA GGG TTA GGG A
Ben-15TTGGGTTAGGGTTAGGGTTAGGGABen-16TTGGGTTAGGGTTAGGGTTAGGGABen-17TTGGGTTAGGGTTAGGBTTAGGGABen-21TTGGGTTAGGGTTAGGGTTABGGABen-22TTGGGTTAGGGTTAGGGTTAGGGABen-23TTGGGTTAGGGTTAGGGTTAGGGAHex-3TTHGGTTAGGGTTAGGGTTAGGGAHex-3TTGHGTTAGGGTTAGGGTAGGGAHex -4TTGHGTTAGGGTTAGGGTAGGGAHex -5TTGGHTTAGGGTTAGGGTAGGGAHex -9TTGGGTTAGGGTTAGGGAAHex -10TTGGGTTAGGGTTAGGGAAHex -11TTGGGTTAGGGTTAGGGAAHex -15TTGGGTTAGGGTTAGGGAAHex -16TTGGGTTAGGGTTAGGGAAHex -21TTGGGTTAGGGTTAGGGAAHex -22TTGGGTTA <td< td=""><td>Ben-11</td><td>TT GGG TTA GGB TTA GGG TTA GGG A</td></td<>	Ben-11	TT GGG TTA GG B TTA GGG TTA GGG A
Ben-16TTGGGTTAGGGTTAGGGTTAGGGABen-17TTGGGTTAGGGTTAGGBTTAGGGABen-21TTGGGTTAGGGTTAGGGTTABGGABen-22TTGGGTTAGGGTTAGGGTTAGBGABen-23TTGGGTTAGGGTTAGGGTTAGGGAHex-3TTHGGTTAGGGTTAGGGTTAGGGAHex-4TTGHGTTAGGGTTAGGGTAGGGAHex -5TTGGHTTAGGGTTAGGGAAHex -9TTGGGTTAGGGTTAGGGAAHex -10TTGGGTTAGGGTTAGGGAAHex -11TTGGGTTAGGGTTAGGGAAHex -15TTGGGTTAGGGTTAGGGAAHex -16TTGGGTTAGGGTTAGGGAAHex -21TTGGGTTAGGGTTAGGGAAHex -22TTGGGTTAGGGTTAGGGAAHex -23TTGGGTTAGGGTTAGGGAA	Ben-15	TT GGG TTA GGG TTA B GG TTA GGG A
Ben-17TTGGGTTAGGGTTAGGGTTAGGGABen-21TTGGGTTAGGGTTAGGGTTABGGABen-22TTGGGTTAGGGTTAGGGTTAGBGABen-23TTGGGTTAGGGTTAGGGTTAGGGAHex-3TTHGGTTAGGGTTAGGGTTAGGGAHex -4TTGHGTTAGGGTTAGGGTAGGGAHex -5TTGGHTTAGGGTTAGGGAAHex -9TTGGGTTAGHGTTAGGGAAHex -10TTGGGTTAGHGTTAGGGAAHex -11TTGGGTTAGGGTTAGGGAAHex -15TTGGGTTAGGGTTAGGGAAHex -16TTGGGTTAGGGTTAGGGAAHex -21TTGGGTTAGGGTTAGGGAAHex -22TTGGGTTAGGGTTAGGGTTAGHGAHex -23TTGGGTTAGGGTTAGGGAAA	Ben-16	TT GGG TTA GGG TTA G B G TTA GGG A
Ben-21TTGGGTTAGGGTTAGGGTTABGGABen-22TTGGGTTAGGGTTAGGGTTAGBGABen-23TTGGGTTAGGGTTAGGGTTAGGGAHex-3TTHGGTTAGGGTTAGGGTTAGGGAHex -4TTGHGTTAGGGTTAGGGTAGGGAHex -5TTGGHTTAGGGTTAGGGAAHex -9TTGGGTTAGHGTTAGGGAAHex -10TTGGGTTAGHGTTAGGGAAHex -11TTGGGTTAGGGTTAGGGAAHex -15TTGGGTTAGGGTTAGGGAAHex -16TTGGGTTAGGGTTAGGGAAHex -21TTGGGTTAGGGTTAGGGAAHex -22TTGGGTTAGGGTTAGGGTTAGGGAHex -23TTGGGTTAGGGTTAGGGTTAGGGA	Ben-17	TT GGG TTA GGG TTA GG B TTA GGG A
Ben-22TTGGGTTAGGGTTAGGGTTAGGGABen-23TTGGGTTAGGGTTAGGGTTAGGGAHex-3TTHGGTTAGGGTTAGGGTTAGGGAHex -4TTGHGTTAGGGTTAGGGTTAGGGAHex -5TTGGHTTAGGGTTAGGGTAGGGAHex -9TTGGGTTAHGGTTAGGGTAGGGAHex -10TTGGGTTAGHGTTAGGGAAHex -11TTGGGTTAGGGTTAGGGAAHex -15TTGGGTTAGGGTTAGGGAAHex -16TTGGGTTAGGGTTAGGGAAHex -21TTGGGTTAGGGTTAGGGAAHex -22TTGGGTTAGGGTTAGGGTAGHGAHex -23TTGGGTTAGGGTTAGGGTAGHGA	Ben-21	TT GGG TTA GGG TTA GGG TTA B GG A
Ben-23TTGGGTTAGGGTTAGGGTTAGGBAHex-3TTHGGTTAGGGTTAGGGTTAGGGAHex -4TTGHGTTAGGGTTAGGGTTAGGGAHex -5TTGGHTTAGGGTTAGGGTTAGGGAHex -9TTGGGTTAHGGTTAGGGTTAGGGAHex -10TTGGGTTAGHGTTAGGGTAGGGAHex -11TTGGGTTAGGGTTAGGGAAHex -15TTGGGTTAGGGTTAGGGAHex -16TTGGGTTAGGGTTAGGGAHex -21TTGGGTTAGGGTTAGGGAHex -22TTGGGTTAGGGTTAGGGAHex -23TTGGGTTAGGGTTAGGGA	Ben-22	TT GGG TTA GGG TTA GGG TTA G B G A
Hex-3TTHGGTTAGGGTTAGGGTTAGGGAHex -4TTGHGTTAGGGTTAGGGTTAGGGAHex -5TTGGHTTAGGGTTAGGGTTAGGGAHex -9TTGGGTTAHGGTTAGGGTTAGGGAHex -10TTGGGTTAGHGTTAGGGTTAGGGAHex -11TTGGGTTAGGGTTAGGGTTAGGGAHex -15TTGGGTTAGGGTTAGGGAAHex -16TTGGGTTAGGGTTAGGGAHex -21TTGGGTTAGGGTTAGGGAHex -22TTGGGTTAGGGTTAGGGTTAGGGAHex -23TTGGGTTAGGGTTAGGGTTAGGHA	Ben-23	TT GGG TTA GGG TTA GGG TTA GG B A
Hex-3TTHGGTTAGGGTTAGGGTTAGGGAHex -4TTGHGTTAGGGTTAGGGTTAGGGAHex -5TTGGHTTAGGGTTAGGGTTAGGGAHex -9TTGGGTTAHGGTTAGGGTTAGGGAHex -10TTGGGTTAGHGTTAGGGTTAGGGAHex -11TTGGGTTAGGGTTAGGGTAGGGAHex -15TTGGGTTAGGGTTAGGGAAHex -16TTGGGTTAGGGTTAGGGAAHex -21TTGGGTTAGGGTTAGGGAAHex -22TTGGGTTAGGGTTAGGGTTAGGGAHex -23TTGGGTTAGGGTTAGGGTAGGHA		
Hex -4TTGHGTTAGGGTTAGGGTTAGGGAHex -5TTGGHTTAGGGTTAGGGTTAGGGAHex -9TTGGGTTAHGGTTAGGGTTAGGGAHex -10TTGGGTTAGHGTTAGGGTTAGGGAHex -10TTGGGTTAGHGTTAGGGTTAGGGAHex -11TTGGGTTAGGHTTAGGGAAHex -15TTGGGTTAGGGTTAHGGAHex -16TTGGGTTAGGGTTAGGGAHex -17TTGGGTTAGGGTTAGGGAHex -21TTGGGTTAGGGTTAGGGTTAGHGAHex -22TTGGGTTAGGGTTAGGGTTAGGHAAHex -23TTGGGTTAGGGTTAGGGTTAGGHA	Hex-3	TT HGG TTA GGG TTA GGG TTA GGG A
Hex -5TTGGHTTAGGGTTAGGGTTAGGGAHex -9TTGGGTTAHGGTTAGGGTTAGGGAHex -10TTGGGTTAGHGTTAGGGTTAGGGAHex -11TTGGGTTAGGHTTAGGGTTAGGGAHex -15TTGGGTTAGGGTTAHGGTTAGGGAHex -16TTGGGTTAGGGTTAGGHTTAGGGAHex -17TTGGGTTAGGGTTAGGGTAGGGAHex -21TTGGGTTAGGGTTAGGGTTAGHGAHex -22TTGGGTTAGGGTTAGGGTTAGGHAHex -23TTGGGTTAGGGTTAGGGTTAGGHA	Hex -4	TT GHG TTA GGG TTA GGG TTA GGG A
Hex -9TTGGGTTAHGGTTAGGGTTAGGGAHex -10TTGGGTTAGHGTTAGGGTTAGGGAHex -11TTGGGTTAGGHTTAGGGTTAGGGAHex -15TTGGGTTAGGGTTAGGGTTAGGGAHex -16TTGGGTTAGGGTTAGGGAGGGAHex -17TTGGGTTAGGGTTAGGGAAHex -21TTGGGTTAGGGTTAGGGTTAGGGAHex -22TTGGGTTAGGGTTAGGGTTAGGHAHex -23TTGGGTTAGGGTTAGGGTTAGGHA	Hex -5	TT GGH TTA GGG TTA GGG TTA GGG A
Hex -10TTGGGTTAGHGTTAGGGTTAGGGAHex -11TTGGGTTAGGGTTAGGGTTAGGGAHex -15TTGGGTTAGGGTTAGGGTTAGGGAHex -16TTGGGTTAGGGTTAGGGTTAGGGAHex -17TTGGGTTAGGGTTAGGGTTAGGGAHex -21TTGGGTTAGGGTTAGGGTTAGGGAHex -22TTGGGTTAGGGTTAGGGTTAGGGAHex -23TTGGGTTAGGGTTAGGGTTAGGHA	Hex -9	TT GGG TTA H GG TTA GGG TTA GGG A
Hex -11TTGGGTTAGGHTTAGGGTTAGGGAHex -15TTGGGTTAGGGTTAGGGTTAGGGAHex -16TTGGGTTAGGGTTAGHGTTAGGGAHex -17TTGGGTTAGGGTTAGGGTTAGGGAHex -21TTGGGTTAGGGTTAGGGTTAGGGAHex -22TTGGGTTAGGGTTAGGGTTAGGGAHex -23TTGGGTTAGGGTTAGGGTTAGGHA	Hex -10	TT GGG TTA G H G TTA GGG TTA GGG A
Hex -15TTGGGTTAGGGTTAGGGAHex -16TTGGGTTAGGGTTAGHGTTAGGGAHex -17TTGGGTTAGGGTTAGGHTTAGGGAHex -21TTGGGTTAGGGTTAGGGTTAGGGAHex -22TTGGGTTAGGGTTAGGGTTAGHGAHex -23TTGGGTTAGGGTTAGGGTTAGGHA	Hex -11	TT GGG TTA GG H TTA GGG TTA GGG A
Hex -16TTGGGTTAGGGTTAGHGTTAGGGAHex -17TTGGGTTAGGGTTAGGHTTAGGGAHex -21TTGGGTTAGGGTTAGGGTTAHGGAHex -22TTGGGTTAGGGTTAGGGTTAGHGAHex -23TTGGGTTAGGGTTAGGGTTAGGHA	Hex -15	TT GGG TTA GGG TTA HGG TTA GGG A
Hex -17TTGGGTTAGGGTTAGGGAHex -21TTGGGTTAGGGTTAGGGTTAHGGAHex -22TTGGGTTAGGGTTAGGGTTAGHGAHex -23TTGGGTTAGGGTTAGGGTTAGGHA	Hex -16	TT GGG TTA GGG TTA G H G TTA GGG A
Hex -21TTGGGTTAGGGTTAHGGAHex -22TTGGGTTAGGGTTAGGGTTAGHGAHex -23TTGGGTTAGGGTTAGGGTTAGGHA	Hex -17	TT GGG TTA GGG TTA GG H TTA GGG A
Hex -22TTGGGTTAGGGTTAGHGAHex -23TTGGGTTAGGGTTAGGHA	Hex -21	TT GGG TTA GGG TTA GGG TTA H GG A
Hex -23 TT GGG TTA GGG TTA GGG TTA GGH A	Hex -22	TT GGG TTA GGG TTA GGG TTA GHG A
	Hex -23	TT GGG TTA GGG TTA GGG TTA GG H A

Table S1. DNA Sequences explored in systematic study of N2-modification of (3+1) G-quadruplex nano-scaffold

Position of N2-modified-guanines are indicated as such: N2-Methyl-Guanine (**M**), N2-benzyl-guanine (**B**), N2-6-amino-hexyl-guanine (**H**),

	NMR ^a			UV (°C)		
Sequence	Single Major Species	Minor Population	Multiple Major Species	Tm ^b	ΔTm	
Native	•	I		54.4 ± 0.4	-	
Met-3				59.7 ± 0.2	5.3	
Met-4	•			60.1 ± 0.7	5.7	
Met-5	•			58.4 ± 0.5	4.0	
Met-9		•		62.7 ± 0.8	8.3	
Met-10	•			58.5 ± 0.4	4.1	
Met-11	•			57.8 ± 0.6	3.5	
Met-15	•			59.9 ± 0.4	5.6	
Met-16	•			57.5 ± 0.1	3.1	
Met-17		•		57.2 ± 0.3	2.8	
Met-21	•			59.6 ± 0.3	5.2	
Met-22		•		59.9 ± 0.5	5.5	
Met-23	•			56.9 ± 0.2	2.5	
Ben-3		•		60.7 ± 0.1	6.3	
Ben-4	•			64.0 ± 0.5	9.6	
Ben-5			•	-	-	
Ben-9	•			67.7 ± 0.5	13.3	
Ben-10	•			61.3 ± 0.4	6.9	
Ben-11	•			61.9 ± 0.3	7.5	
Ben-15	•			57.4 ± 0.1	3.0	
Ben-16			•	-	-	
Ben-17		•		58.9 ± 0.5	4.5	
Ben-21	•			62.3 ± 0.7	8.0	
Ben-22	•			59.6 ± 0.3	5.2	
Ben-23		•		57.2 ± 0.3	2.8	
Hex-3	•			63.6 ± 0.4	9.2	
Hex-4	•			62.7 ± 0.4	8.3	
Hex-5			•	-	-	
Hex-9	•			63.5 ± 0.5	9.1	
Hex-10			•	-	-	
Hex-11	•			59.0 ± 0.4	4.6	
Hex-15	•			59.7 ± 0.1	5.3	
Hex-16			•	-	-	
Hex-17	•			56.4 ± 0.3	2.0	
Hex-21			•	-	-	
Hex-22	•			62.3 ± 0.1	7.9	
Hex-23	•			57.5 ± 0.0	3.1	

Table S2. Classification of G-quadruplex conformation and stability

[a] Determination of the same (3+1) conformation being adopted is based off a qualitative analysis of the amount of minor conformation present in NMR spectra and the similarity of NMR and CD spectra between the modified and unmodified sequences.

[b] The \pm values indicated the hysteresis observed between heating and cooling curved in UV melting experiments

	Sequence							
1 2	3 4 5	6	789	10	11 12 13	14	15 16 17	18
ΤT	GGG	Т	GGG	Т	GGG	Т	GGG	Т
TT	GGG	Т	MGG	Т	GGG	Т	GGG	Т
ΤT	GGG	Т	GMG	Т	GGG	Т	GGG	Т
TT	GGG	Т	GGM	Т	GGG	Т	GGG	Т
TT	GGG	Т	BGG	Т	GGG	Т	GGG	Т
1.1.	GGG	Т	G B G	Т	GGG	Т	GGG	Т
TT	GGG	Т	GG B	Т	GGG	Т	GGG	Т
TT	GGG	Т	HGG	Т	GGG	Т	GGG	Т
ΤT	GGG	Т	GHG	Т	GGG	Т	GGG	Т
TT	GGG	Т	GGH	Т	GGG	Т	GGG	Т

Table S3. Single N2-substitutions into a parallel G-quadruplex nano-scaffold construct

The position of N2-modified-guanines are indicated as such: N2-Methyl-Guanine (**M**), N2-benzyl-guanine (**B**), N2-6-amino-hexyl-guanine (**H**)

Name	Sequence ^[a]	$T_m^{\ b}$	$\Delta T_{\rm m}$
Native	TT GGG TTA GGG TTA GGG TTA GGG A	45.5 ± 0.2	_
N2-One-Groove	TT GGG TTA G <u>MM</u> TTA GGG TTA GGG A	52.4 ± 1.0	6.9
N2-Two-Groove	TT <u>H</u> GG TTA <u>H</u> GG TTA GGG TTA GGG A	63.8 ± 0.3	18.2
N2-All-Groove	TT <u>H</u> GG TTA <u>H</u> G <u>M</u> TTA <u>M</u> GG TTA GGG A	72.1 ± 0.2	26.6
N2-Ball-with-Hair	ТТ <u>НН</u> G ТТА <u>Н</u> G <u>H</u> ТТА <u>Н</u> G <u>H</u> TTA G <u>H</u> H A	91.7 ± 0.1 ^c	46.2

Table S4. Nano-scaffold sequences containing multiple N2-modivitaions and their stabilities

Samples were examined in "Low Salt" conditions (1 mM KPi + 1 mM KCl).

[a] The position of N2-modified guarines is given by the following notation: " $\underline{\mathbf{M}}$ " for ^{Met}G; " $\underline{\mathbf{H}}$ " for ^{Hex}G

 $[b] \pm$ indicate the hysteresis between heating and cooling curves in CD melting experiments

[c] Incomplete melting transition observed. Tm determined by single base line correction with high temperature baseline set to a constant of ≈ 0 absorbance

Name	Sequence ^[a]	$T_m^{\ b}$	$\Delta T_{\rm m}$
Native	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 24 TT GGG TTA GGG TTA GGG A GGG A	54.4 ± 0.4	
Bio-22 Bio-11-22	TT GGG TTA GGG TTA GGG TTA G Q G A TT GGG TTA GG Q TTA GGG TTA G Q G A	$\begin{array}{c} 56.0\pm0.6\\ 57.8\pm0.2\end{array}$	1.7 3.4

Table S5. Nano-scaffold sequences containing functional N2-modifications

Samples were examined in "Moderate Salt" conditions (10 mM KPi + 10 mM KCl).

[a] The position of N2-modified-guarines are indicated as such: N2-Biotin-Guarine ($\underline{\mathbf{0}}$) [b] \pm indicate the hysteresis between heating and cooling curves in UV melting experiments



Figure S1. NMR spectra of single N2-methyl-guanine modifications (*MET*) to the (3+1) G-quadruplex nano-scaffold



Figure S2. NMR spectra of single N2-benzyl-guanine modifications (*BEN*) to the (3+1) G-quadruplex nano-scaffold



Figure S3. NMR spectra of single N2-6-amino-hexyl-guanine modifications (*HEX*) to the (3+1) G-quadruplex nano-scaffold



Figure S4. CD spectra of single N2-methyl-guanine (*MET*) modifications to the (3+1) Gquadruplex nano-scaffold. Modified sequences are shown in black. The *Native* reference sequence is shown in grey.



Figure S5. CD spectra of single N2-benzyl-guanine (*BEN*) modifications to the (3+1) Gquadruplex nano-scaffold. Modified sequences are shown in black. The *Native* reference sequence is shown in grey



Figure S6. CD spectra of single N2-6-amino-hexyl-guanine (*HEX*) modifications to the (3+1) Gquadruplex nano-scaffold. Modified sequences are shown in black. The *Native* reference sequence is shown in grey



G3

G13

G

G7

G9

Figure S7. NMR spectra of single substations of N2-methyl-guanine (M), N2-benzyl-guanine (B), or N2-6-amino-hexyl-guanine (H) into the parallel G-quadruplex nano-scaffold formed by the $d[T_2(G_3T)_4]$ sequence. Substitution position indicated in red. Black dots indicate imino proton resonances of the monomer G-quadruplex.



Figure S8. Fraction folded curves from UV melting experiments of modified (3+1) Gquadruplex forming sequences containing single MET substitutions



Figure S9. Fraction folded curves from UV melting experiments of modified (3+1) Gquadruplex forming sequences containing single BEN substitutions



Figure S10. Fraction folded curves from UV melting experiments of modified (3+1) Gquadruplex forming sequences containing single HEX substitutions



Α

Figure S11. Design of a ^{Hex}G modified "Ball-with-hair" G-quadruplex nano-scaffold: (**A**) NMR spectra of N2-Ball-with-Hair sequence in "low" and "physiological" salt conditions shows the same structure is formed. (**B**) Temperature dependent CD spectra demonstrate the incredible stability of the "Ball-with-hair" nano-scaffold in physiological salt conditions. (**C**) Projection of CD intensity at 290 nm over varying temperatures.



Figure S12. Non-denaturing PAGE investigating G-quadruplex nano-scaffold stoichiometry: (lane 1) *Native* sequence and known monomer, (lane 2) *N2-One groove*, (lane 3) *N2-Two Groove*, (lane 4) *N2-All Groove*, (lane 5) Reference sequence $d(G_3T)_4$ known to form a dimer G-quadruplex. Monomer (M) and Dimer (D) migration rates are indicated at right