

Synthesis and styrene copolymerization of novel trisubstituted ethylenes:

1. Alkyl ring-substituted 2-methoxyethyl phenylcyanoacrylates

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Abstract

Novel trisubstituted ethylenes, alkyl ring-substituted 2-methoxyethyl phenylcyanoacrylates, $RPhCH=C(CN)CO_2CH_2CH_2OCH_3$ (where R is H, 2-methyl, 3-methyl, 4-methyl, 4-ethyl, 4-propyl, 4-*i*-propyl, 4-butyl, 4-*i*-butyl, 4-*t*-butyl) were prepared and copolymerized with styrene. The ethylenes were synthesized by the piperidine catalyzed Knoevenagel condensation of ring-substituted benzaldehydes and 2-methoxyethyl cyanoacetate, and characterized by CHN analysis, IR, 1H and ^{13}C NMR. All the ethylenes were copolymerized with styrene in solution with radical initiation (ABCN) at 70°C. The compositions of the copolymers were calculated from nitrogen analysis.

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1. Introduction

Cyanoacrylates is family of vinyl monomers renowned for their high reactivity, instant adhesive properties, and wide-ranging applications [1–3]. Trisubstituted ethylenes (TSE), ring-functionalized (R^1) alkyl (R^2) phenylcyanoacrylates, $R^1\text{PhCH} = \text{C}(\text{CN})\text{CO}_2\text{R}^2$ (PCA) continue to attract attention as compounds with variety of applications [4–11]. Thus, methoxy ring-substituted methyl phenylcyanoacrylate, MPCA was used in synthesis of pyridotriazines and triazolopyridines [4]. Dimethylamino ring-substituted MPCA was examined among other cyanovinylheteroaromatics in relation to organic nonlinear optics [5]. There are a number of applications of ethyl phenylcyanoacrylate, EPCA and its ring-substituted derivatives which include studies of catalysis [6] and potential antimicrobial and antioxidant agents [7]. 2,4-Dimethoxyphenyl EPCA was used in design, synthesis and study of anticancer activity of novel benzothiazole analogues [8], in synthesis of thiazacridine derivatives as anticancer agents against breast and hematopoietic neoplastic cells [9] and in DABCO-catalyzed Knoevenagel condensation using hydroxy ionic liquid as a promoter [10]. This EPCA was involved in catalysis study of N,N' -dialkylimidazolium dimethyl phosphates [11], in synthesis and study of antimicrobial activity of some cyanoacrylates [12], as well as in synthesis of antiproliferative active 2-aminobenzimidazole derivatives [13].

In regards to polymerization reactivity, previous studies showed that PCAs as all TSE monomers containing double bond substituents larger than fluorine have very low reactivity in radical homopolymerization due to polar and steric reasons [14]. Although steric difficulties preclude homopolymerization of such monomers, their copolymerization with a monosubstituted alkenes makes it possible to overcome these steric problems. Thus, copolymerization of electrophilic TSE monomers having double bonds substituted with halo, cyano, and carbonyl groups and electron-rich monosubstituted ethylenes such as styrene, N-vinylcarbazole, and vinyl acetate [15-17] show a tendency toward the formation of alternating copolymers - thus suggesting a way of functionalization of commercial polymers via introduction of isolated monomer units in copolymers. Earlier we have reported synthesis and styrene copolymerization of a number of alkyl ring-substituted methyl [18, 19], ethyl [20, 21], propyl [22], isopropyl [23], butyl [24], and isobutyl [25, 26] PCAs.

Our objectives in exploration of novel 2-methoxyethyl phenylcyanoacrylates (MEPA) were twofold: (1) to utilize Knoevenagel condensation for synthesis of MEPA compounds with a variety of potentially reactive functional groups and (2) to explore feasibility of radical copolymerization with a commercial monomer styrene.

Thus, in continuation of our investigation of novel TSE compounds we have prepared 2-methoxyethyl alkyl phenylcyanoacrylates, $R\text{PhCH}=\text{C}(\text{CN})\text{CO}_2\text{CH}_2\text{CH}_2\text{OCH}_3$, where R is H, 2-methyl, 3-methyl, 4-methyl, 4-ethyl, 4-propyl, 4-*i*-propyl, 4-butyl, 4-*i*-butyl, 4-*t*-butyl, and explored the feasibility of their copolymerization with styrene. To the best of our

knowledge, there have been no reports on either synthesis of these compounds, nor their copolymerization with styrene [27].

2. Experimental

2.1. Materials

Benzaldehyde ($\geq 99\%$), 2-methyl ($\geq 96.5\%$), 3-methyl (97%), 4-methyl (97%), 4-ethyl (97%), 4-propyl (95%), 4-*i*-propyl ($\geq 98\%$), 4-butyl (90%), 4-*i*-butyl (97%), 4-*t*-butyl (97%) benzaldehydes, 2-methoxyethyl cyanoacetate ($\geq 98.0\%$), piperidine (99%), styrene ($\geq 99\%$), 1,1'-azobis(cyclohexanecarbonitrile) (98%), (ABCN), and toluene (98%) supplied from Sigma-Aldrich Co., were used as received.

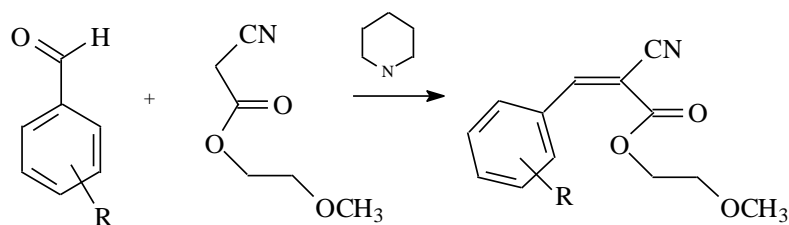
2.2. Instrumentation

Infrared spectra of the MEPA compounds and polymers (NaCl plates) were determined with an ABB FTLA 2000 FT-IR spectrometer. The melting points of the MEPA compounds were measured with TA (Thermal Analysis, Inc.) Model Q10 differential scanning calorimeter (DSC). ^1H and ^{13}C NMR spectra were obtained on 10-25% (w/v) MEPA solutions in CDCl_3 at ambient temperature using Avance 300 MHz spectrometer. CHN-elemental analyses of MEPA compounds and nitrogen analysis of the copolymers were performed by Midwest Microlab, LLC (IN).

3. Results and discussion

3.1. Synthesis and characterization of 2-methoxyethyl phenylcyanoacrylates

All 2-methoxyethyl phenylcyanoacrylates (MEPA) compounds were synthesized by Knoevenagel condensation [28] of appropriate benzaldehydes with 2-methoxyethyl cyanoacetate, catalyzed by base, piperidine (Scheme 1).



Scheme 1. Synthesis of 2-methoxyethyl phenylcyanoacrylates where R is H, 2-methyl, 3-methyl, 4-methyl, 4-ethyl, 4-propyl, 4-*i*-propyl, 4-butyl, 4-*i*-butyl, 4-*t*-butyl.

The preparation procedure was essentially the same for all the monomers. In a typical synthesis, equimolar amounts of 2-methoxyethyl cyanoacetate and an appropriate benzaldehyde were mixed in equimolar ratio in a 20 mL vial. A few drops of piperidine were added with stirring. The product of the reaction was isolated by filtration and purified by crystallization from 2-propanol. The condensation reaction proceeded smoothly, yielding products, which were purified by conventional techniques. The compounds were characterized by IR, ^1H and ^{13}C NMR spectroscopies. No stereochemical analysis of the novel alkyl ring-substituted MEPA was performed since no stereoisomers (*E* or/and *Z*) of known configuration were available.

3.1.1. 2-Methoxyethyl phenylcyanoacrylate

Yield 85%; ^1H NMR δ 8.3 (s, 1H, CH=), 8.1-7.1 (s, 5H, Ph), 4.5 (t, 2H, CO_2CH_2), 3.7 (t, 2H, OCH_2); ^{13}C NMR δ 164 (C=O), 156 (HC=), 136, 133, 131, 130, 128 (Ph), 116 (CN), 103 (C=), 70 (OCH_2), 66 (CO_2CH_2), 59 (CH_3); IR (cm^{-1}): 3082-2825 (m, C-H), 2223 (m, CN), 1741 (s, C=O), 1272 (s, C-O- CH_3), 882 (s, C-H out of plane). Anal. Calcd. for $\text{C}_{13}\text{H}_{13}\text{NO}_3$: C, 67.52; H, 5.67; N, 6.06; Found: C, 67.44; H, 5.85; N, 6.29.

3.1.2. 2-Methoxyethyl 2-methylphenylcyanoacrylate.

Yield 77%; mp 51°C; ^1H NMR δ 8.6 (s, 1H, CH=), 8.1-7.0 (m, 4H, Ph), 4.5 (t, 2H, CO_2CH_2), 3.7 (t, 2H, OCH_2), 3.6 (s, 3H, OCH_3), 2.3 (Ph CH_3); ^{13}C NMR δ 167 (C=O), 154 (HC=), 149, 140, 139, 133, 132, 128 (Ph), 115 (CN), 104 (C=), 70 (OCH_2), 66 (CO_2CH_2), 59 (CH_3), 23 (Ph CH_3); IR (cm^{-1}): 3028 (m, C-H), 2224 (m, CN), 1734 (s, C=O), 1224 (s, C-O- CH_3), 882 (s, C-H out of plane). Anal. Calcd. for $\text{C}_{14}\text{H}_{15}\text{NO}_3$: C, 68.56; H, 6.16; N, 5.71; Found: C, 65.47; H, 6.16; N, 6.15.

3.1.3. 2-Methoxyethyl 3-methylphenylcyanoacrylate.

Yield 77%; ^1H NMR δ 8.3 (s, 1H, CH=), 7.8-7.1 (m, 4H, Ph), 4.5 (t, 2H, CO_2CH_2), 3.7 (t, 2H, OCH_2), 3.4 (s, 3H, OCH_3), 2.4 (Ph CH_3); ^{13}C NMR δ 163 (C=O), 155 (HC=), 151, 139, 135, 134, 132, 129 (Ph), 115 (CN), 102 (C=), 70 (OCH_2), 65 (CO_2CH_2), 59 (CH_3), 23 (Ph CH_3); IR (cm^{-1}): 3008 (m, C-H), 2215 (m, CN), 1726 (s, C=O), 1269 (s, C-O- CH_3), 887 (s, C-H out of plane). Anal. Calcd. for $\text{C}_{14}\text{H}_{15}\text{NO}_3$: C, 68.56; H, 6.16; N, 5.71; Found: C, 64.75; H, 6.08; N, 6.04.

3.1.4. 2-Methoxyethyl 4-methylphenylcyanoacrylate.

Yield 77%; ^1H NMR δ 8.2 (s, 1H, CH=), 7.9-7.1 (m, 4H, Ph), 4.5 (t, 2H, CO_2CH_2), 3.7 (t, 2H, OCH_2), 3.5 (s, 3H, OCH_3), 2.4 (Ph CH_3); ^{13}C NMR δ 168 (C=O), 155 (HC=), 151, 145, 131, 130, 128, 127 (Ph), 116 (CN), 101 (C=), 70 (OCH_2), 65 (CO_2CH_2), 59 (CH_3), 23 (Ph CH_3); IR (cm^{-1}): 3026 (m, C-H), 2214 (m, CN), 1726 (s, C=O), 1607 (s, C=C), 1269 (s, C-O- CH_3), 854 (s, C-H out of plane). Anal. Calcd. for $\text{C}_{14}\text{H}_{15}\text{NO}_3$: C, 68.56; H, 6.16; N, 5.71; Found: C, 66.04; H, 6.05; N, 5.94.

3.1.5. 2-Methoxyethyl 2-ethylphenylcyanoacrylate.

Yield 82%; $^1\text{H NMR}$ δ 8.2 (s, 1H, CH=), 7.9, 7.2 (m, 4H, Ph), 4.4 (t, 2H, CO₂CH₂), 3.6 (t, 2H, OCH₂), 3.5 (s, 3H, OCH₃), 2.7 (q, 2H, CH₃CH₂Ph), 1.2 (PhCH₂CH₃); $^{13}\text{C NMR}$ δ 162 (C=O), 155 (HC=), 151, 132, 130, 129, 128 (Ph), 115 (CN), 101 (C=), 70 (OCH₂), 66 (CO₂CH₂), 59 (OCH₃), 29 (PhCH₂); 15 (PhCH₂CH₃); IR (cm⁻¹): 2968 (m, C-H), 2224 (m, CN), 1732 (s, C=O), 1595 (C=C), 1238 (s, C-O-CH₃), 864 (s, C-H out of plane).
Anal. Calcd. for C₁₅H₁₇NO₃: C, 69.48; H, 6.61; N, 5.40; Found: C, 67.62; H, 6.85; N, 5.90.

3.1.6. 2-Methoxyethyl 4-ethylphenylcyanoacrylate.

Yield 77%; $^1\text{H NMR}$ δ 8.2 (s, 1H, CH=), 8.0, 7.3 (m, 4H, Ph), 4.4 (t, 2H, CO₂CH₂), 3.7 (t, 2H, OCH₂), 3.5 (s, 3H, OCH₃), 2.7 (q, 2H, CH₃CH₂Ph), 1.2 (PhCH₂CH₃); $^{13}\text{C NMR}$ δ 163 (C=O), 155 (HC=), 151, 132, 130, 129 (Ph), 116 (CN), 101 (C=), 70 (OCH₂), 66 (CO₂CH₂), 59 (OCH₃), 28 (PhCH₂); 16 (PhCH₂CH₃); IR (cm⁻¹): 2934 (m, C-H), 2210 (m, CN), 1728 (s, C=O), 1597 (C=C), 1265 (s, C-O-CH₃), 833 (s, C-H out of plane). Anal. Calcd. for C₁₅H₁₇NO₃: C, 69.48; H, 6.61; N, 5.40; Found: C, 66.30; H, 6.75; N, 5.64.

3.1.7. 2-Methoxyethyl 4-propylphenylcyanoacrylate.

Yield 79%; $^1\text{H NMR}$ δ 8.2 (s, 1H, CH=), 8.0-7.2 (m, 4H, Ph), 4.4 (t, 2H, OCOCH₂), 3.6 (t, 2H, OCH₂), 3.4 (s, 3H, OCH₃), 2.7 (t, 2H, CH₃CH₂CH₂Ph), 1.7 (m, 2H, CH₃CH₂CH₂Ph), 0.9 (t, 3H, CH₃CH₂CH₂Ph); $^{13}\text{C NMR}$ δ 163 (C=O), 155 (HC=), 135, 130, 129, 128, 127 (Ph), 116 (CN), 101 (C=), 70 (OCH₂), 66 (OCOCH₂), 60 (OCH₃), 38 (CH₃CH₂CH₂Ph), 25 (CH₃CH₂CH₂Ph), 14 (Ph-CH₂CH₂CH₃); IR (cm⁻¹): 2934 (m, C-H),

2224 (m, CN), 1728 (s, C=O), 1599 (C=C), 1267 (s, C-O-CH₃), 845, 808, 760 (s, C-H out of plane). Anal. Calcd. for C₁₆H₁₉NO₃: C, 70.31; H, 7.01; N, 5.12; Found: C, 71.51; H, 7.23; N, 5.36.

3.1.8. 2-Methoxyethyl 4-*i*-propylphenylcyanoacrylate.

Yield 84%; ¹H NMR δ 8.2 (s, 1H, CH=), 8.0-7.0 (m, 4H, Ph), 4.4 (t, 2H, OCOCH₂), 3.7 (t, 2H, OCH₂), 3.4 (s, 3H, OCH₃), 2.9 (m, 1H, CHPh), 1.3 (d, 6H, (CH₃)₂CH); ¹³C NMR δ 163 (C=O), 155 (HC=), 135, 131, 127, 125 (Ph), 116 (CN), 109 (C=), 68 (OCH₂), 65 (CO₂CH₂), 58 (OCH₃), 34 ((CH₃)₂C), 24 (CHCH₃); IR (cm⁻¹): 2962 (m, C-H), 2224 (m, CN), 1728 (s, C=O), 1599 (C=C), 1265 (s, C-O-CH₃), 848 (s, C-H out of plane). Anal. Calcd. for C₁₆H₁₉NO₃: C, 70.31; H, 7.01; N, 5.12; Found: C, 69.22; H, 7.15; N, 5.89.

3.1.9. 2-Methoxyethyl 4-*butyl*phenylcyanoacrylate.

Yield 82%; ¹H NMR δ 8.2 (s, 1H, CH=), 7.9-7.2 (m, 4H, Ph), 4.3 (t, 2H, OCOCH₂), 3.6 (t, 2H, OCH₂), 3.4 (s, 3H, OCH₃), 2.7 (t, 2H, C₃H₇CH₂Ph), 1.6 (q, 2H, C₂H₅CH₂CH₂Ph), 1.2 (m, CH₃CH₂CH₂CH₂Ph), 0.9 (t, 3H, CH₃CH₂CH₂CH₂Ph); ¹³C NMR δ 165 (C=O), 155 (HC=), 134, 132, 130, 128 (Ph), 116 (CN), 102 (C=), 70 (OCH₂), 65 (OCOCH₂), 59 (OCH₃), 36 (C₃H₇CH₂Ph), 33 (C₂H₅CH₂CH₂Ph), 22 (CH₃CH₂CH₂CH₂Ph), 14 (CH₃CH₂CH₂CH₂Ph); IR (cm⁻¹): 3024-2813 (m, C-H), 2224 (m, CN), 1722 (s, C=O), 1561 (C=C), 1258 (s, C-O-CH₃), 924 (s, C-H out of plane). Anal. Calcd. for C₁₇H₂₁NO₃: C, 71.06; H, 7.37; N, 4.87; Found: C, 70.87; H, 7.42; N, 4.93.

3.1.10. 2-Methoxyethyl 4-*t*-butylphenylcyanoacrylate.

Yield 89%; $^1\text{H NMR}$ δ 8.2 (s, 1H, CH=), 8.0-7.3 (s, 4H, Ph), 4.5 (t, 2H, OCOCH₂), 3.7 (t, 2H, OCH₂), 3.1 (s, 3H, OCH₃), 1.3 (s, 9H, (CH₃)₃C-Ph); $^{13}\text{C NMR}$ δ 163 (C=O), 155 (HC=), 134, 131, 130, 129, 127, 126 (Ph), 116 (CN), 102 (C=), 70 (OCH₂), 66 (OCOCH₂), 59 (OCH₃), 34 (CH₃)₃C-Ph, 31 (CH₃)₃C-Ph; IR (cm⁻¹): 2938 (m, C-H), 2224 (m, CN), 1730 (s, C=O), 1634 (C=C), 1265 (s, C-O-CH₃), 936, 847 (s, C-H out of plane). Anal. Calcd. for C₁₇H₂₁NO₃: C, 71.06; H, 7.37; N, 4.87; Found: C, 68.17; H, 7.59; N, 5.01.

3.1.11. 2-Methoxyethyl 4-*i*-butylphenylcyanoacrylate.

Yield 73%; $^1\text{H NMR}$ δ 8.2 (s, 1H, CH=), 7.9-7.0 (m, 4H, Ph), 4.4 (t, 2H, OCOCH₂), 3.5 (t, 2H, OCH₂), 3.1 (s, 3H, OCH₃), 2.3 (d, (CH₃)₂CHCH₂-Ph), 1.8 (m, (CH₃)₂CHCH₂-Ph), 0.9 (CH₃)₂CHCH₂-Ph); $^{13}\text{C NMR}$ δ 163 (C=O), 155 (HC=), 142, 136, 135, 131, 126, 125 (Ph), 116 (CN), 109 (C=), 70 (OCH₂), 65 (OCOCH₂), 59 (OCH₃), 45 (CH₃)₂CHCH₂-Ph, 30 (CH₃)₂CHCH₂-Ph, 22 (CH₃)₂CHCH₂-Ph; IR (cm⁻¹): 2953 (m, C-H), 2224 (m, CN), 1730 (s, C=O), 1560 (C=C), 1312 (s, C-O-CH₃), 949, 849 (s, C-H out of plane). Anal. Calcd. for C₁₇H₂₁NO₃: C, 71.06; H, 7.37; N, 4.87; Found: C, 72.26; H, 7.77; N, 4.95.

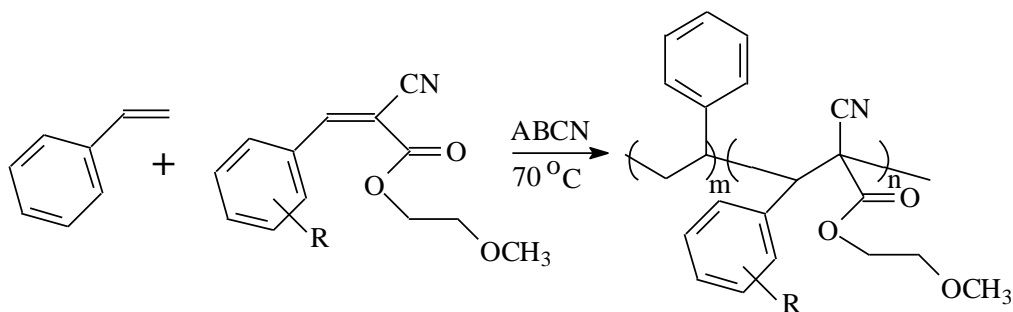
3.2. Homopolymerization

An attempted homopolymerization of the MEPA compounds in the presence of ABCN did not produce any polymer as indicated by the lack of a precipitate in methanol. The inability of the monomers to polymerize is associated with steric difficulties encountered in homopolymerization of 1,1- and 1,2-disubstituted ethylenes [14]. Homopolymerization

of ST under conditions identical to those in copolymerization experiments yielded 18.3% of polystyrene, when polymerized for 30 min.

3.3. Synthesis and characterization of styrene – MEPA copolymers

Copolymers of the ST and the MEPA compounds, P(ST-co-MEPA) were prepared in 25-mL glass screw cap vials at ST/MEPA = 3 (mol) the monomer feed using 0.12 mol/L of ABCN at an overall monomer concentration 2.44 mol/L in 10 mL of toluene. The copolymerization was conducted at 70°C. After a predetermined time, the mixture was cooled to room temperature, and precipitated dropwise in methanol. The composition of the copolymers was determined based on the nitrogen content (cyano group in MEPA). The novel synthesized MEPA compounds copolymerized readily with ST under free-radical conditions (Scheme 2) forming white flaky precipitates when their solutions were poured into methanol. The conversion of the copolymers was kept between 10 and 20% to minimize compositional drift (Table 1).



Scheme 2. Copolymerization of ST and the ring-substituted 2-methoxyethyl phenylcyanoacrylates, where R is H, 2-methyl, 3-methyl, 4-methyl, 4-ethyl, 4-propyl, 4-*i*-propyl, 4-butyl, 4-*i*-butyl, 4-*t*-butyl.

Table 1. Copolymerization of Styrene and 2-Methoxyethyl phenylcyanoacrylates.

R	Yield ^a (wt%)	N (wt%)	ST in copol. (mol%)	MEPA in copol. (mol%)
H	12.3	3.47	62.4	37.6
2-Methyl	11.1	2.87	70.0	30.0
3-Methyl	15.2	2.82	70.7	29.3
4-Methyl	13.9	2.70	72.5	27.5
2-Ethyl	13.4	2.49	74.5	25.5
4-Ethyl	13.5	2.76	70.5	29.5
4-Propyl	14.0	2.53	72.9	27.1
4-Isopropyl	17.4	2.55	72.6	27.4
4-Butyl	15.5	2.45	73.2	26.8
4-t-Butyl	10.9	2.45	73.2	26.8
4-i-Butyl	14.1	2.37	74.5	25.5

Nitrogen elemental analysis showed that between 25.5 and 37.6 mol% of MEPA is present in the copolymers prepared at ST/MEPA = 3 (mol), which is indicative of relatively high reactivity of the MEPA monomers towards ST radical which is typical of alkyl ring-substituted MEPA [18-26]. Since MEPA monomers do not homopolymerize, the most likely structure of the copolymers would be isolated MEPA monomer units alternating with short ST sequences (Scheme 2).

The copolymers prepared in the present work are all soluble in ethyl acetate, THF, DMF and CHCl₃ and insoluble in methanol, ethyl ether, and petroleum ether.

4 Conclusions

Novel trisubstituted ethylenes, alkyl ring-substituted 2-methoxyethyl phenylcyanoacrylates, RPhCH=C(CN)CO₂CH₂CH₂OCH₃ (where R is H, 2-methyl, 3-methyl, 4-methyl, 4-ethyl, 4-

propyl, 4-i-propyl, 4-butyl, 4-i-butyl, 4-t-butyl) were prepared and copolymerized with styrene.

Acknowledgments

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