Polymer-Supported Triazenes as Smart Reagents for the Alkylation of Carboxylic Acids

Bernhard Erb,[a] Jean-Philippe Kucma,[b] Sandrine Mourey,[c] and Fritz Struber*[a]

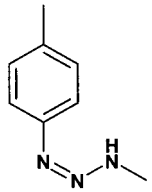
Abstract: Starting from polystyrene, a simple four-step synthesis of polymer-supported alkyltriazenes (alkyl = Me, Et, benzyl) is described. With this synthesis, a loading capacity of 2.2 mmol g^{-1} can be reached. The most prominent application of these polymer-supported reagents is the rapid, highly selective and high-yielding esterification of carboxylic acids, which involves a simple "mix and filter off" procedure at room temperature. If stored in a refrigerator, these reagents are stable for many months and they can be recycled several times.

Keywords: alkylation · combinatorial chemistry · diazo compounds · polymers · solid-phase synthesis

Introduction

Alkylating agents are among the classes of reagents most commonly used in organic synthesis. In addition to the known reagents (e.g. alkyl halides, alkyl triflates, Meerwein salts and diazoalkanes) there is still a demand for less toxic, more stable, more selective, easier to handle and recyclable alkylating agents. 3-Alkyl-1-aryltriazenes[1] are known for the low-temperature alkylation of acidic substances (carboxylic acids, phenols, enols) under mild conditions, but so far they have not reached widespread application in synthesis.

3-Methyl-1-*p*-tolyltriazene **1** is a commercially available but toxic solid that can replace the far more toxic and explosive diazomethane in many methylation reactions.[2] Polymer-supported reagents have become state-of-the-art tools in organic synthesis because of their easy handling, easy work-up and their increased safety compared with classical reagents.[3] In the polymer-supported triazenes (PSTs) the advantages of triazenes[4] and polymer-supported reagents are unified. The synthesis of methyl esters directly from carboxylic acids by using polymer-supported *O*-methylisourea has recently been described by Linclau.[5] Rademann's group[6] have found PSTs to be excellent reagents for this purpose, which react well at room temperature and which are commercially available.[7] PSTs have also been used by Bräse et al. for the synthesis of alkyl halides and esters,[8] as well as for alkyl sulfonates.[9] Furthermore, PSTs have been used as cleavable supports for solid-phase synthesis.[10, 11] We describe here further examples of the synthetic scope of PSTs as alkylating agents, and in particular we describe an improved procedure for their preparation. It involves an efficient four-step synthesis starting from simple polystyrene rather than from the more expensive chloromethyl polystyrene used by Rademann and Bräse. This new methodology was optimized with ecological and safety criteria, as well as the economical aspect in mind.



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Results and Discussion

Synthesis of polymer-supported triazenes: Starting from commercially available polystyrene 1% cross-linked with divinylbenzene, the PSTs were synthesized in four simple steps (Scheme 1).

The nitration of polystyrene to poly(*p*-nitrostyrene) **2** was best performed with 94% HNO_3 at 0 °C, under which conditions elemental analysis indicated 100% nitration.[12]

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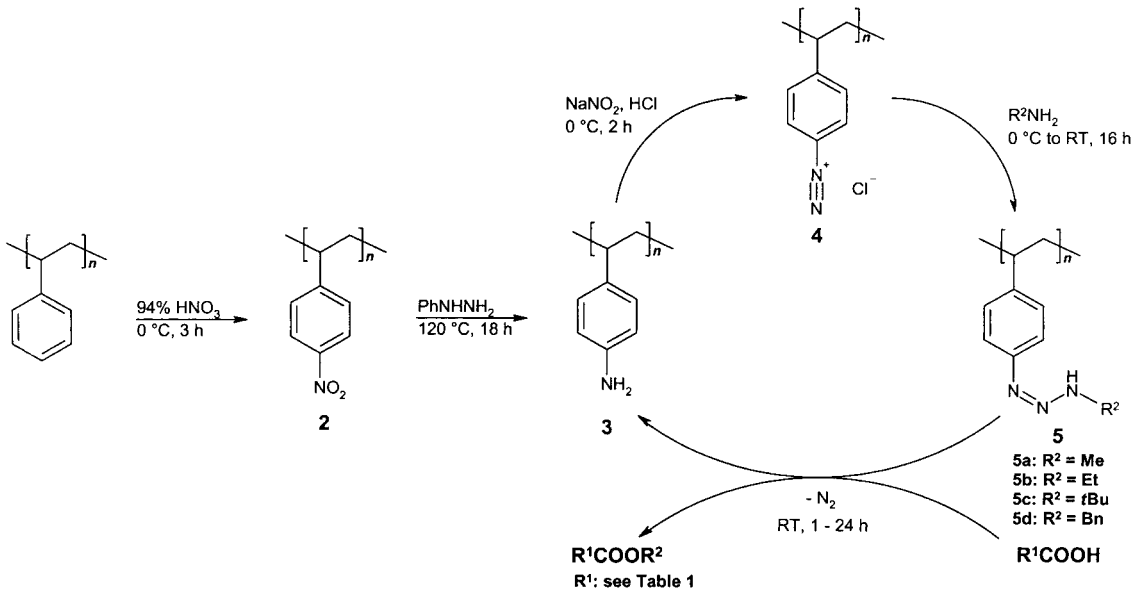


Scheme 1. Synthesis of polymer-supported triazenes (PSTs) **5a–d** from polystyrene and their application in the esterification of carboxylic acids at room temperature.

Nitration was also possible with a mixture of 65% HNO_3 and H_2SO_4, however the product was agglutinated and could not be reduced fully in the next step. The reduction of **2** to the poly(*p*-aminostyrene) **3** was successful with pure phenyl hydrazine at 160 °C.[13] The use of xylene as a cosolvent led to incompletely reduced material. However pure phenyl hydrazine showed a strong exothermic decomposition above 160 °C according to differential scanning calorimetry. At 120 °C the reduction was still effective, and the safety risk could thus be minimized, but for the routine use of this procedure on a larger scale more detailed calorimetric measurements have to be carried out. The reaction was monitored by IR spectroscopy and elemental analysis. Other reducing agents ($Na_2S_2O_4/H_2O$[14] at 70 °C, $Na_2S/S/H_2O$[15] at 150 °C and 6 bar or $SnCl_2 \cdot 2H_2O/EtOH$[16] at 70 °C) were ineffective according to elemental analysis. Classical aqueous diazotation[14] with $HCl/NaNO_2$ led successfully to the polymer-bound diazonium salt **4**, whilst diazotation with *tert*-butylnitrite/$BF_3 \cdot Et_2O$[11, 17] or $NOBF_4$[18] in organic solvents was less successful. The diazotation reaction was best monitored by quenching samples of **4** with amine and checking the activity of the resulting PST **5**. The amination of **4** to the desired poly(*p*-alkyltriazenestyrenes) **5a–5d** was best performed with aqueous solutions of the corresponding amine. The *tert*-butyl derivative **5c** decomposed during isolation or use as reagent, with the release of 2-methylprop-1-ene, presumably in a reaction initiated by the protonation of the triazene moiety involving the *tert*-butyl cation.[19] The loading of the PSTs was easily determined by esterification of an excess of benzoic acid in $CDCl_3$; after an aliquot had been decanted, an NMR spectra was taken. From the extent of conversion to the corresponding benzoate ester, the loadings were calculated as follows: 1.7–2.2 mmol g^{-1} for Me-PST **5a**, 0.9 mmol g^{-1} for Et-PST **5b** and 0.8 mmol g^{-1} for Bn-PST **5d** (Bn = benzyl). It has to be mentioned that the maximum loading for noncopolymerized **5a** should be 6.2 mmol g^{-1}. One explanation for the lower loading could be the intramolecular coupling of two equivalents of the diazonium salt with the amine to yield pentazenes.

The preparation described above is a simple approach to the desired functionalized reagents. The synthesis shows economical merits in comparison with the existing syntheses of PSTs on Merrifield resin and was done on larger scale starting from 750 g polystyrene.

Applications of polymer-supported triazenes: The outstanding feature of PSTs was shown to be the esterification of carboxylic acids, which can be done in a simple "mix and filter off" procedure at room temperature. In order to study the scope and limitations of the PSTs, 20 acids with different structural and electronic features were alkylated, mainly with Me-PST **5a** (Table 1). As seen from the table, phenyl groups, double bonds, asymmetric centres, amino groups, aliphatic and aromatic hydroxy groups were not affected. In most cases stirring the carboxylic acid solution with 1.2 equivalents of PST for 1 to 24 h is sufficient for complete esterification. After filtration of the resin and evaporation of the solvent, the pure ester was obtained. Although N-protected α-amino acids (entry 23) worked well, unprotected amino acids failed to react. Et-PST **5b** (entry 2) and Bn-PST **5d** (entry 3) were tested only with benzoic acid, and also showed a clean and high-yielding conversion. A broad range of solvents like CH_2Cl_2, DME, MeCN, THF or DMF was successful for esterification with PSTs, but CH_2Cl_2 was the solvent of choice due to reaction speed and ease of product isolation.

As indicated above, the reaction is initiated with the protonation of the triazene moiety, and therefore the pK_a value of the acid greatly influences the reaction time. Whereas treatment of benzoic acid **6** (pK_a = 4.2)[20] in DME with 1.2 equiv of **5a** for 1 h gave a conversion of 35%, 4-nitrobenzoic acid **7** (pK_a = 3.4)[20] gave a conversion of 94% according to HPLC. The high selectivity of PSTs for

Table 1 Alkylation of carboxylic acids with Me-PST **5a**, Et-PST **5b** or Bn-PST **5d** at room temperature.

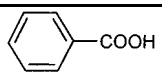
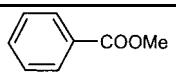
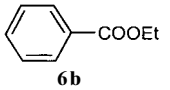
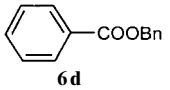
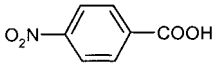
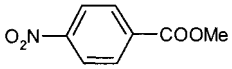
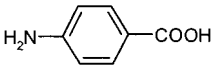
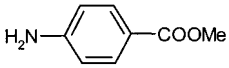
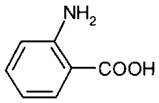
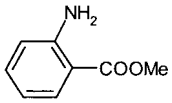
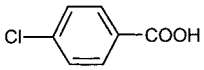
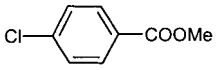
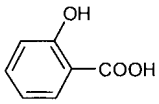
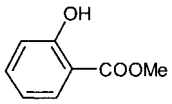
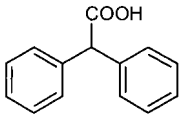
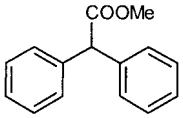
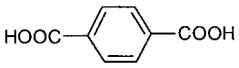
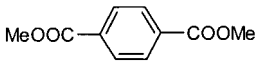
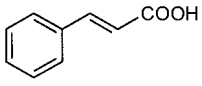
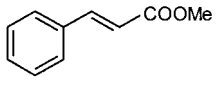
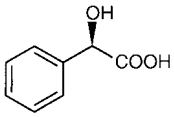
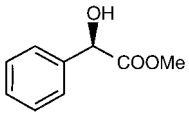
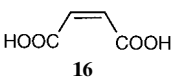
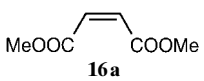
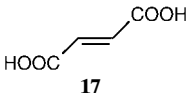
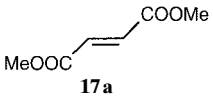
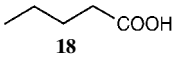
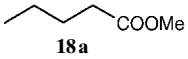
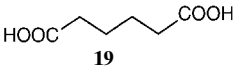
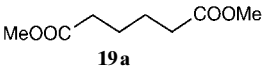
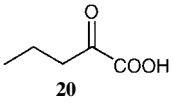
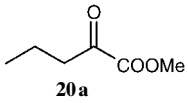
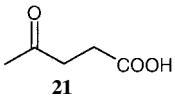
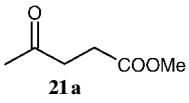
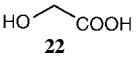
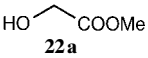
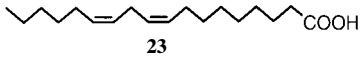
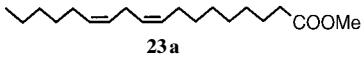
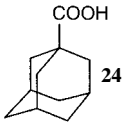
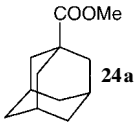
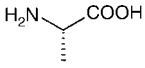
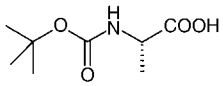
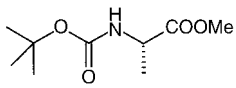
	Acid	Product	Conditions	Purity (GC)	Isolated Yield
1	 **6**	 **6a**	1.2 equiv **5a** CH_2Cl_2, 3 h	98.9%	83%
2	**6**	 **6b**	1.2 equiv **5b** CH_2Cl_2, 4 h	99.3%	79%
3	**6**	 **6d**	2 equiv **5d** CH_2Cl_2, 6 h	89.3%	99%
4	 **7**	 **7a**	1.5 equiv **5a** DME, 16 h	99.2%	97%
5	 **8**	 **8a**	2 equiv **5a** DME, 4 d	98.9%	100%
6	 **9**	 **9a**	2 equiv **5a** DME, 22 h	96.0%	87%
7	 **10**	 **10a**	1.2 equiv **5a** DME, 21 h	99.4%	93%
8	 **11**	 **11a**	1.2 equiv **5a** DME, 22 h	98.1%	89%
9	 **12**	 **12a**	1.2 equiv **5a** DME, 4 d	98.3%	100%
10	 **13**	 **13a**	2.4 equiv **5a** DMF, 5 d	100%	66%
11	 **14**	 **14a**	1.2 equiv **5a** CH_2Cl_2, 24 h	99.9%	86%
12	 **15**	 **15a**	1.2 equiv **5a** MeCN, 6 h	99.5%	91%
13	 **16**	 **16a**	2.4 equiv **5a** DME, 1 h	95.4%	81%
14	 **17**	 **17a**	2.4 equiv **5a** DME, 1.5 h	96.1%	85%

Table 1 (continued).

	Acid	Product	Conditions	Purity (GC)	Isolated Yield
15	 **18**	 **18a**	1.2 equiv **5a** CH_2Cl_2, 3 h	98.4%	42%
16	 **19**	 **19a**	4 equiv **5a** DME, 17 h	98.0%	93%
17	 **20**	 **20a**	1.2 equiv **5a** CH_2Cl_2, 1 h	80.0%	55%
18	 **21**	 **21a**	1.2 equiv **5a** CH_2Cl_2, 2 h	95.6%	88%
19	 **22**	 **22a**	1.2 equiv **5a** DME, 3 h	99.0%	34%
20	 **23**	 **23a**	2 equiv **5a** CH_2Cl_2, 24 h	96.6%	94%
21	 **24**	 **24a**	1.2 equiv **5a** CH_2Cl_2, 20 h	98.9%	94%
22	 **25**	no significant reaction	1.2 equiv **5a** H_2O or 1M HCl/THF (1:1)	–	–
23	 **26**	 **26a**	2 equiv **5a** CH_2Cl_2, 3 h	98.8%	92%

carboxylic hydroxy groups is a result of this fact. Other less acidic hydroxy groups like phenols, alcohols or enolizable carbonyl functions are barely affected in the presence of a carboxylic acid. However phenols also react with PSTs and, as expected, the pK_a is a crucial parameter. Phenol **27** ($pK_a = 10.0$)[21] treated with 2 equiv of Me-PST in CH_2Cl_2 showed 8% conversion to anisole **27a** after 1 d (Table 2, entry 1), whereas 4-nitrophenol **28** ($pK_a = 7.2$)[21] was converted with 74% to the corresponding ether **28a** after only 7 h (Table 2, entry 2). Interestingly, addition of HCl or an acidic ion exchanger did not reduce the reaction time. For the synthesis of **28a**, DME was the solvent of choice because of the higher product solubility (Table 2, entry 3). Acetophenone ($pK_a = 19.1$)[21] in $CDCl_3$ stirred for 3 h with 2 equivalents of **5a** showed no enolether formation according to NMR spectra. Aliphatic alcohols did not react with PSTs.

Table 2 Alkylation of phenols with Me-PST **5a** at room temperature.

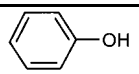
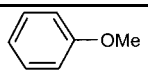
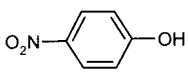
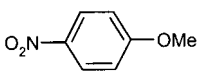
	Phenol	Product	Conditions	Conversion (HPLC)	Isolated yield
1	 **27**	 **27a**	2 equiv **5a** CH_2Cl_2	1 d: 8% 3 d: 21% 14 d: 44% 77 d: 57%	–
2	 **28**	 **28a**	2 equiv **5a** CH_2Cl_2	1 h: 46% 4 h: 60% 7 h: 74%	–
3	**28**	**28a**	2 equiv **5a** DME	1 h: 83% 1 d: 98% 3 d: 99%	– – 94%

Table 3 Decrease of loading from Me-PST **5a**, Et-PST **5b** and Bn-PST **5d** at various temperatures in relation to time.

	Me-PST **5a**			Et-PST **5b**			Bn-PST **5d**		
T	+4 °C	RT	+40 °C	+4 °C	RT	+40 °C	+4 °C	RT	+40 °C
Initial loading [mmol g^{-1}]	1.7	1.7	1.7	0.9	0.9	0.9	0.8	0.8	0.8
4 weeks	1.6	1.5	1.3	0.9	0.8	0.7	0.8	0.7	0.6
8 weeks	1.5	1.5	1.2	0.9	0.8	0.6	0.8	0.7	0.4
12 weeks	1.5	1.4	1.1	0.9	0.7	0.6	0.8	0.6	0.3
2 years	1.2	0.7	–	0.7	0.3	–	0.4	0.1	–

Stability of polymer-supported triazenes: 3-Alkyl-1-aryltriazenes are known to decompose when treated with acids[1, 22, 23] or metal ions.[24] As stated above *t*Bu-PST **5c** decomposed during isolation or use at room temperature. Me-, Et- and Bn-PST (**5a, 5b, 5d**) are only moderately stable at elevated temperatures (Table 3). This is in agreement with the differential scanning calorimetry.[25] Me-PST **5a** begins to decompose exothermically at 55 °C (Figure 1), whereas decomposition of the monomolecular 3-methyl-1-*p*-tolyltriazene **1** starts after melting at 85 °C (Figure 2). Et-PST **5b** starts to decompose at 70 °C and Bn-PST **5d** at 60 °C. PSTs suffer minimal loss of activity when stored in the dark at +4 °C, however Bn-PST **5d** is more temperature sensitive than **5a** or **5b**. These data are insufficient to assess the *safety* of storing large amounts of PSTs, and a detailed thermal analysis of the decomposition is necessary.

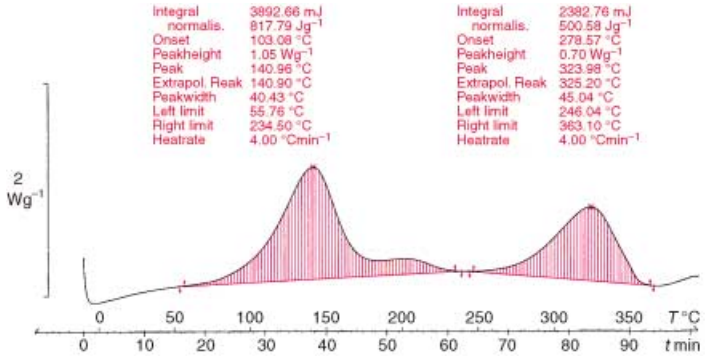


Figure 1. Differential scanning calorimetry thermogram of Me-PST **5a** (loading: 1.6 mmol g^{-1}). Gold-plated steel crucible sealed under argon; test: 4.76 mg, dynamic.

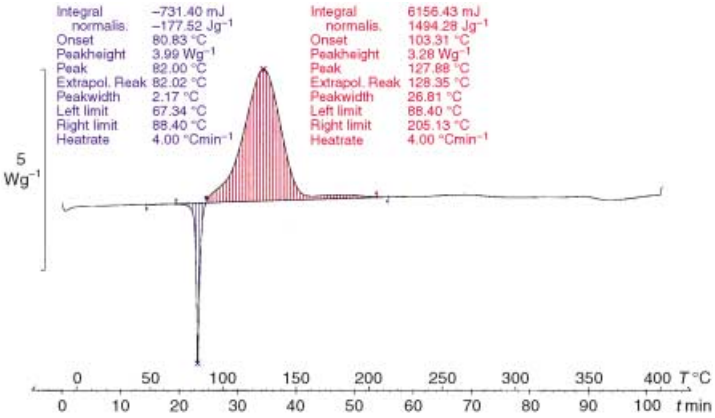


Figure 2. Differential scanning calorimetry thermogram of 3-methyl-1-*p*-tolyltriazene **1**. Gold-plated steel crucible sealed under argon; test: 4.12 mg, dynamic.

Recycling of polymer-supported triazenes: The recyclability of Me-PST **5a** was examined. After reaction with a large excess of benzoic acid, the resulting poly(*p*-aminostyrene) **2** was diazotized, aminated again, and the activity was checked by NMR spectroscopy. Me-PST **5a** with an initial loading of 2.0 mmol g^{-1} was treated in this manner six times (Table 4). With a relative loss of 10–20% loading per cycle, the reagent can be reasonably recycled several times.

Table 4 Decrease of loading from Me-PST **5a** after several recycling steps.

No. of recycling steps	0	1	2	3	4	5	6
Loading (mmol g^{-1})	2.0	1.7	1.5	1.2	0.8	0.8	0.7

Conclusion

In the present paper we describe a new, simple four-step synthesis of polymer-supported triazenes (PSTs) applicable to larger scale preparation. Starting from polystyrene beads, this synthesis is economically superior to the synthesis of PSTs on Merrifield resin. The outstanding feature of PSTs **5a, 5b** and **5d** was demonstrated to be the esterification of carboxylic acids, which can be done in a simple "mix and filter off" procedure at room temperature. Twenty acids with different structural features were esterified with high yield and purity in most cases. Phenols were alkylated much more slowly with Me-PST **5a**. PSTs are only moderately stable at room temperature, but can be stored in a refrigerator for many months. Furthermore it was shown that Me-PST **5a** can be reasonably recycled several times. PSTs are thus attractive reagents whenever an easy, safe, clean and high-yielding esterification of an carboxylic acid is required in a research lab, for the derivatization of analytical samples or for high throughput synthesis.

Experimental Section

General

Starting materials and reagents: Polystyrene beads 100–200 mesh (75–150 μm), cross-linked with 1% divinylbenzene, were purchased from Purolite (IP 1130). These and all other chemicals were used as received. Products obtained from alkylations with PSTs were compared with commercially available samples with a purity mostly >98% according GC, ^{1}H NMR, melting point or refractive index.

Equipment: IR: Midac FTIR M-series, Spectacle software, KBr pellets. ^{1}H NMR: Varian Gemini 200 (200 MHz for ^{1}H); δ in ppm downfield from TMS ($\delta = 0$). Capillary gas chromatography (CGC): Hewlett–Packard HP 6890 series, FID detector; column: Macherey–Nagel 726821 Optima-1; carrier gas: H_2; oven: initial temperature 50 °C for 3 min, final temperature 250 °C (rate 10 °C min^{-1}). HPLC: Hewlett–Packard series 1050 with a detector HP series II 1040M (210 nm); column: Macherey–Nagel CC 125/4 Nucleosil 100–5 C8, temperature 35 °C; eluent: 50% phase A (MeCN/H_2O 1:9 with phosphate buffer solution, pH 5.1), 50% phase B (MeCN/H_2O 9:1) for 15 min and after 100% B with a flow of 1 mL min^{-1}. Elemental analysis: ECO 800 system. Melting points: open glass capillaries, Büchi 535 (Tottoli apparatus), uncorrected. Refractive index: ABBE Mark II, digital refractometer (Reichert Jung) at 20 °C. $[\alpha]_D$ at 20 °C on Perkin–Elmer 241 polarimeter. TLC: sheets from Merck (1.05719; silica gel 60 F_{254}). Differential scanning calorimetry (DSC): Mettler–Toledo STAR with STAR 5.12 software and DSC-821 cells.

Activity checks of PSTs with NMR: Benzoic acid (100 mg, 0.819 mmol) was added to Me-PST **5a** (50.0 mg) in $CDCl_3$ (8 mL) in a round-bottom flask equipped with a magnetic stirrer. The mixture was stirred overnight at room temperature, after which a ^{1}H NMR spectrum of the decanted and clear solution was taken. Integration then established the extent of conversion of benzoic acid to methyl benzoate. Thus from a conversion of 13% the loading of Me-PST **5a** could be calculated as 2.1 mmol g^{-1}. The activity checks of Et-PST **5b** and Bn-PST **5d** were performed in the same manner.

Poly(*p*-nitrostyrene) (2): Nitric acid (94%, 10 L) was chilled to 0 °C before polystyrene beads (750 g, 7.21 mol) were added portion-wise with stirring. First the polymer turned black, then orange. The slurry was stirred at 0 °C for 3 h. Then the resin was filtered on a sintered glass funnel, poured into ice water (10 L), filtered again and washed with EtOH (3 × 2 L) and TBME (2 × 2 L). The product was dried in vacuo at 50 °C overnight to yield yellowish beads (1110 g, 7.45 mol, 103%). IR (KBr): 2926, 1595, 1518, 1344, 855; elemental analysis calcd (%) for $C_8H_7NO_2$ (149.15): C 64.42, H 4.73, N 9.39, O 21.45; found: C 62.13, H 5.08, N 9.58, O 23.45.

Poly(*p*-aminostyrene) 3: Poly(*p*-nitrostyrene) **2** (1100 g, 7.38 mol) was added to phenylhydrazine (22 L), and the mixture was stirred at 120 °C internal temperature for 18 h. The product was filtered and washed with water (10 L). Then the polymer was stirred in EtOH (25 L) at 40 °C for 15 min, filtered and washed with EtOH (3 × 25 L). The product was dried in vacuo at 50 °C for 3 d to yield dark brown beads (867 g, 7.29 mol, 99%). IR (KBr): 3354, 2914, 1618, 1510, 1518, 1340, 1263; elemental analysis calcd (%) for C_8H_9N (119.17): C 80.63, H 7.61, N 11.76; found: C 75.7, H 6.8, N 11.6, O 5.8, H_2O 1.06.

Poly(*p*-methyltriazenestyrene), 5a (Me-PST): Poly(*p*-aminostyrene) **3** (550 g, 4.61 mol) was added to a chilled solution of $NaNO_2$ (830 g, 12.0 mol) in H_2O (10 L). The mixture was stirred at −5 °C while 37% aq. HCl (1 L, 12.0 mol) was added in portions over 30 min. Then the slurry was stirred at 0 °C for a further 2 h, filtered and washed with chilled water (40 L). The resulting polymer-bound diazonium salt **4** was transferred into ice water (5 L). Then 40% aq. $MeNH_2$ (5 L, 59 mol) was added in portions at 0 °C over 30 min. The reaction mixture was stirred at 0 °C for 12 h and for 1 h at room temperature. After filtration, the polymer was washed with H_2O (10 L) and stirred in EtOH (6 L) for 1 h, filtered again and washed with EtOH (8 L) and CH_2Cl_2 (8 L) until the washing solution became colourless. The product was dried in vacuo at 30 °C for 4 d to yield brown beads of Me-PST **5a** (605 g, 3.76 mol, 82%) with a loading of 1.7 mmol g^{-1}. This procedure was repeated several times also on smaller scale, when loadings up to 2.2 mmol g^{-1} were typical. Me-PST **5a** is best stored in the dark at +4 °C. IR (KBr): 2915, 1518, 1433, 1379, 1341, 1240, 1175, 828; elemental analysis calcd (%) for $C_9H_{11}N_3$ (161.21): C 67.06, H 6.88, N 26.07; found: C 67.7, H 6.3, N 18.5, O 6.6, H_2O 0.75.

Poly(*p*-ethyltriazenestyrene), 5b (Et-PST): Poly(*p*-aminostyrene) **3** (80 g, 0.67 mol) was diazotized as described for **5a**. The resulting polymer-bound diazonium salt **4** was transferred into ice water (1 L). Then 70% aq. $EtNH_2$ (690 mL, 8.60 mol) was added in portions at 0 °C over 30 min. The reaction mixture was stirred at 0 °C for 12 h and for 1 h at room temperature. After filtration the polymer was washed with H_2O (2 L) and stirred in EtOH (2 L) for 1 h, filtered again and washed with EtOH (2 L) and CH_2Cl_2 (2 L) until the washing solution became colourless. The product was dried in vacuo at 30 °C for 4 d to yield brown beads of Et-PST **5b** (86 g, 0.49 mol, 73%) with a loading of 0.9 mmol g^{-1}. Et-PST **5b** is best stored in the dark at +4 °C. IR (KBr): 2919, 1518, 1440, 1399, 1341, 1236, 1175, 828; elemental analysis calcd (%) for $C_{10}H_{13}N_3$ (175.23): C 68.54, H 7.48, N 23.98; found: C 70.0, H 6.4, N 15.2, O 7.8, H_2O 0.96.

Poly(*p*-benzyltriazenestyrene), 5d (Bn-PST): Poly(*p*-aminostyrene) **3** (60 g, 0.50 mol) was diazotized as described for **5a**. The resulting polymer-bound diazonium salt **4** was transferred into ice water (1.7 L). Then $BnNH_2$ (720 mL, 6.45 mol) was added at 0 °C over 15 min. The reaction mixture was stirred at 0 °C for 12 h and for 1 h at room temperature. After filtration the polymer was washed with H_2O (3 L) and stirred in EtOH (2 L) for 1 h, filtered again and washed with EtOH (2 L) and CH_2Cl_2 (2 L) until the washing solution became colourless. The product was dried in vacuo at 25 °C for 4 d to yield brown beads of Bn-PST **5d** (81 g, 0.34 mol, 68%) with a loading of 0.8 mmol g^{-1}. Bn-PST **5d** is best stored in the dark at +4 °C. IR (KBr): 2911, 1514, 1449, 1391, 1341, 1163, 692; elemental analysis calcd (%) for $C_{15}H_{15}N_3$ (237.31): C 75.92, H 6.37, N 17.71; found: C 75.0, H 6.2, N 13.7, O 4.7, H_2O 0.78.

Alkylation of Carboxylic Acids:

*Methyl benzoate (**6a**)*: Me-PST **5a** (2.90 g, loading 1.7 mmol g^{-1}, 4.93 mmol) was added to a solution of benzoic acid **6** (500 mg, 4.09 mmol) in CH_2Cl_2 (13 mL), and the reaction mixture was stirred at room temperature for 3 h. Then the polymer was filtered off on a sintered glass funnel and washed with CH_2Cl_2. Evaporation under vacuum afforded **6a** (457 mg, 3.38 mmol, 83%) with a purity of 98.9% (GC and ^{1}H NMR). n_D = 1.5131 (1.5170[26]).

*Ethyl benzoate (**6b**)*: Benzoic acid **6** (200 mg, 1.64 mmol) in CH_2Cl_2 (10 mL) was treated with Et-PST **5b** (2.20 g, loading 0.9 mmol g^{-1}, 1.98 mmol) for 4 h as described for **6a** to afford **6b** (194 mg, 1.29 mmol, 79%) with a purity of 99.3% (GC and ^{1}H NMR). n_D = 1.5028 (1.5050[26]).

*Benzyl benzoate (**6d**)*: Benzoic acid **6** (214 mg, 1.75 mmol) in CH_2Cl_2 (10 mL) was treated with Bn-PST **5d** (4.38 g, loading 0.8 mmol g^{-1}, 3.50 mmol) for 6 h as described for **6a** to afford **6d** (369 mg, 1.74 mmol, 99%) with a purity of 89.3% (GC and ^{1}H NMR). n_D = 1.5635 (1.5680[26]).

*Methyl 4-nitrobenzoate (**7a**)*: 4-Nitrobenzoic acid **7** (512 mg, 3.06 mmol) in DME (14 mL) was treated with Me-PST **5a** (2.70 g, loading 1.7 mmol g^{-1}, 4.59 mmol) for 16 h as described for **6a** to afford **7a** (540 mg, 2.98 mmol, 97%) with a purity of 99.2% (GC and ^{1}H NMR). M.p. 94.5–95.2 °C (94–96 °C[26]).

*Methyl 4-aminobenzoate (**8a**)*: 4-Aminobenzoic acid **8** (107 mg, 0.78 mmol) in DME (5 mL) was treated with Me-PST **5a** (0.92 g, loading 1.7 mmol g^{-1}, 1.56 mmol) for 4 d as described for **6a** to afford **8a** (118 mg, 0.78 mmol, 100%) with a purity of 98.9% (GC and ^{1}H NMR). M.p. 110.0–110.6 °C (111–113 °C[26]).

*Methyl anthranilate (**9a**)*: Anthranilic acid **9** (1018 mg, 7.42 mmol) in DME (50 mL) was treated with Me-PST **5a** (9.89 g, loading 1.5 mmol g^{-1}, 14.8 mmol) for 22 h as described for **6a** to afford **9a** (980 mg, 6.48 mmol, 87%) with a purity of 96.0% (GC and ^{1}H NMR). n_D = 1.5735 (1.5830[26]).

*Methyl 4-chlorobenzoate (**10a**)*: 4-Chlorobenzoic acid **10** (1023 mg, 6.53 mmol) in DME (50 mL) was treated with Me-PST **5a** (5.22 g, loading 1.5 mmol g^{-1}, 7.83 mmol) for 21 h as described for **6a** to afford **10a** (1037 mg, 6.08 mmol, 93%) with a purity of 99.4% (GC and ^{1}H NMR). M.p. 35.5–36.4 °C (42–44 °C[26]).

*Methyl salicylate (**11a**)*: Salicylic acid **11** (1018 mg, 7.37 mmol) in DME (50 mL) was treated with Me-PST **5a** (5.90 g, loading 1.5 mmol g^{-1}, 8.85 mmol) for 22 h as described for **6a** to afford **11a** (1002 mg, 6.59 mmol, 89%) with a purity of 98.1% (GC and ^{1}H NMR). n_D = 1.5307 (1.5360[26]).

*Methyl diphenylacetate (**12a**)*: Diphenylacetic acid **12** (202 mg, 0.95 mmol) in DME (10 mL) was treated with Me-PST **5a** (765 mg, loading 1.5 mmol g^{-1}, 1.15 mmol) for 4 d as described for **6a** to afford **12a** (215 mg, 0.95 mmol, 100%) as an oil with a purity of 98.3% (GC and ^{1}H NMR).

*Dimethyl terephthalate (**13a**)*: Me-PST **5a** (4.84 g, loading 1.5 mmol g^{-1}, 7.26 mmol) was added to a solution of terephthalic acid **13** (502 mg, 3.02 mmol) in DMF (25 mL), and the reaction mixture was stirred at room temperature for 5 d. Then the polymer was filtered off on a sintered glass funnel and washed with DMF. H_2O (25 mL) was added to the filtrate, and the mixture was kept in the refrigerator for 2 h. After the precipitate was collected and evaporated under vacuum to afford **13a** (385 mg, 1.98 mmol, 66%) with a purity of 100% (GC and ^{1}H NMR). M.p. 139.8–140.7 °C (140–142 °C[26]).

*Methyl cinnamate (**14a**)*: Cinnamic acid **14** (107 mg, 0.72 mmol) in CH_2Cl_2 (5 mL) was treated with Me-PST **5a** (554 mg, loading 1.6 mmol g^{-1}, 0.88 mmol) for 24 h as described for **6a** to afford **14a** (100 mg, 0.62 mmol, 86%) with a purity of 99.9% (GC and ^{1}H NMR). M.p. 34.4–34.9 °C (36–38 °C[26]).

*Methyl (R)-(−)-mandelate (**15a**)*: (*R*)-(−)-Mandelic acid **15** (203 mg, 1.34 mmol) in MeCN (10 mL) was treated with Me-PST **5a** (1.07 g, loading 1.5 mmol g^{-1}, 1.60 mmol) for 6 h as described for **6a** to afford **15a** (202 mg, 1.22 mmol, 91%) with a purity of 99.5% (GC and ^{1}H NMR). M.p. 53.3–53.9 °C (56–58 °C[26]); $[\alpha]_D$ at 20 °C = −138.6 (c = 1 in MeOH) (−144.0[26]).

*Dimethyl maleate (**16a**)*: Maleic acid **16** (509 mg, 4.39 mmol) in DME (25 mL) was treated with Me-PST **5a** (7.05 g, loading 1.5 mmol g^{-1}, 10.57 mmol) for exactly 1 h as described for **6a** to afford **16a** (510 mg, 3.54 mmol, 81%) with a purity of 95.4% (GC and ^{1}H NMR). If the reaction mixture was stirred for longer than 1 h, a partial isomerization to dimethyl fumarate **17a** occurred, which reached 2.3% (4 h), 18% (21 h), 47% (4 d) or 62% (11 d) according HPLC and NMR. n_D = 1.4326 (1.4410[26]).

*Dimethyl fumarate (**17a**)*: Fumaric acid **16** (501 mg, 4.32 mmol) in DME (40 mL) was treated with Me-PST **5a** (6.91 g, loading 1.5 mmol g^{-1}, 10.37 mmol) for 1.5 h as described for **6a** to afford **17a** (526 mg, 3.65 mmol, 85%) with a purity of 96.1% (GC and ^{1}H NMR). M.p. 100.1–101.3 °C (103–104 °C[26]).

*Methyl valerate (**18a**)*: Valeric acid **18** (1043 mg, 10.21 mmol) in CH_2Cl_2 (50 mL) was treated with Me-PST **5a** (8.16 g, loading 1.5 mmol g^{-1}, 12.24 mmol) for 3 h as described for **6a** to afford **18a** (495 mg, 4.27 mmol, 42%) with a purity of 98.4% (GC and ^{1}H NMR). n_D = 1.3981 (1.3970[26]).

*Dimethyl adipate (**19a**)*: Adipic acid **19** (202 mg, 1.38 mmol) in DME (10 mL) was treated with Me-PST **5a** (3.70 g, loading 1.5 mmol g^{-1}, 5.55 mmol) for 17 h as described for **6a** to afford **19a** (223 mg, 1.28 mmol, 93%) with a purity of 98.0% (GC and ^{1}H NMR). n_D = 1.4257 (1.4280[26]).

*Methyl 2-oxopentanoate (**20a**)*: Freshly distilled 2-oxopentanoic acid **20** (209 mg, 1.80 mmol) in CH_2Cl_2 (10 mL) was treated with Me-PST **5a** (1.44 g, loading 1.5 mmol g^{-1}, 2.16 mmol) for 1 h as described for **6a** to afford **20a** (129 mg, 0.99 mmol, 55%) with a purity of 80.0% (GC). The ^{1}H NMR spectrum corresponded to the literature.[27]

*Methyl levulinate (**21a**)*: Levulinic acid **21** (109 mg, 0.94 mmol) in CH_2Cl_2 (5 mL) was treated with Me-PST **5a** (660 mg, loading 1.7 mmol g^{-1}, 1.12 mmol) for 2 h as described for **6a** to afford **21a** (108 mg, 0.83 mmol, 88%) with a purity of 95.6% (GC and ^{1}H NMR). n_D = 1.4230 (1.422[28]).

*Methyl glycolate (**22a**)*: Glycolic acid **22** (212 mg, 2.79 mmol) in DME (10 mL) was treated with Me-PST **5a** (2.23 g, loading 1.5 mmol g^{-1}, 3.35 mmol) for 3 h as described for **6a** to afford **22a** (85 mg, 0.94 mmol, 34%) with a purity of 99.0% (GC and ^{1}H NMR). n_D = 1.4136 (1.4170[26]).

*Methyl linoleate (**23a**)*: Linoleic acid **23** (216 mg, 0.77 mmol) in CH_2Cl_2 (10 mL) was treated with Me-PST **5a** (1.03 g, loading 1.5 mmol g^{-1}, 1.55 mmol) for 24 h as described for **6a** to afford **23a** (213 mg, 0.72 mmol, 94%) with a purity of 96.6% (GC and ^{1}H NMR). n_D = 1.4625 (1.4620[26]).

*Methyl 1-adamantaneoate (**24a**)*: 1-Adamantanecarboxylic acid **24** (102 mg, 0.57 mmol) in CH_2Cl_2 (5 mL) was treated with Me-PST **5a** (400 mg, loading 1.7 mmol g^{-1}, 0.68 mmol) for 20 h as described for **6a** to afford **24a** (103 mg, 0.53 mmol, 94%) with a purity of 98.9% (GC). The ^{1}H NMR spectrum corresponded to the literature.[29]

N-*(*tert*-Butyloxycarbonyl)*-L-*alanine methylester (**26a**)*: *N*-(*tert*-Butyloxycarbonyl)-L-alanine **26** (208 mg, 1.10 mmol) in CH_2Cl_2 (10 mL) was treated with Me-PST **5a** (1.41 g, loading 1.5 mmol g^{-1}, 2.11 mmol) for 3 h as described for **6a** to afford **26a** (206 mg, 1.01 mmol, 92%) with a purity of 98.8% (GC and ^{1}H NMR).

Alkylation of phenols

*4-Nitroanisole (**28a**)*: 4-Nitrophenol **28** (110 mg, 0.79 mmol) in DME (5 mL) was treated with Me-PST **5a** (940 mg, loading 1.7 mmol g^{-1}, 1.60 mmol) for 3 d as described for **6a** to afford **28a** (113 mg, 0.74 mmol, 94%) with a purity of 96.0% (GC and ^{1}H NMR). M.p. 49.3–50.6 °C (54 °C[30]).

Recycling of Me-PST 5a: Me-PST **5a** (6.3 g, loading 2.0 mmol g^{-1}, 12.6 mmol) was added to a solution of excess benzoic acid **6** (7.1 g, 58.2 mmol) in CH_2Cl_2 (70 mL), and the reaction mixture was stirred at room temperature until the gas evolution finished. Then the polymer was filtered off on a sintered glass funnel, washed with CH_2Cl_2 and dried. The resulting poly(*p*-aminostyrene) **3** was diazotized and aminated as described for **5a**. An activity check with 50 mg of this recycled material showed a loading of 1.7 mmol g^{-1}. The alkylation of benzoic acid and recycling was repeated five times with the following decrease of loading: 1.5 mmol g^{-1} (2nd cycle), 1.2 mmol g^{-1} (3rd cycle), 0.8 mmol g^{-1} (4th cycle), 0.8 mmol g^{-1} (5th cycle), 0.7 mmol g^{-1} (6th cycle).

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