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Xanthates and solid-phase chemistry. A new soluble polymer analogue of Wang resin

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Abstract—The straightforward synthesis of a new soluble polymer containing a Wang type linker is described. Inter-molecular radical additions of xanthates onto olefins were performed with this new resin in comparison with a classical Wang resin. The new soluble polymer analogue of Wang resin allows easy ^{1}H monitoring of the reactions and gives better results for the radical transfer while preserving the efficient cleavage conditions of the Wang linker. © 2002 Published by Elsevier Science Ltd.

1. Introduction

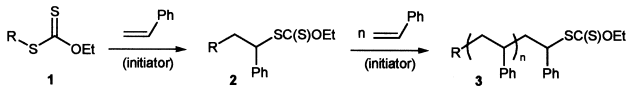
The use of radical reactions in organic synthesis has been extensively developed over the past 20 years. Notably, they offer one of the most powerful routes to C–C bond formation under mild conditions.[1] However, in contrast with other C–C bond-forming methods,[2] radical reactions have not yet been widely applied to solid support chemistry.[3] Until the blossoming of combinatorial chemistry in the last decade, research directed toward the development of new reactions on solid-support has greatly increased, especially for the synthesis of pharmaceutically relevant non-oligomeric small organic molecules.[4] Most of the examples regarding solid-support radical reactions deal with cyclization reactions, while inter-molecular reactions have been less well explored. In general, compared to solution-phase reactions, a large amount of radical initiator and propagator must be used, in accordance with the well-established lower rate of solid-phase reactions. The heterogeneous nature of reactions on solid-support is thought to be responsible for this change in kinetics and, in order to restore homogeneous reaction conditions, various soluble polymer supports have been developed over the past few years.[5] Yet, to our knowledge, the use of these kinds of supports for the study of radical chemistry has been described generally in the case of radical allyl transfers.[6] In the field of free radical chemistry, xanthates have proved to be convenient precursors of a variety of radicals that can add to olefins in an inter- or intramolecular fashion.[7] We now report our studies on the radical inter-molecular addition reactions of xanthates on solid support. Taking into account the afore-mentioned difficulties due to lowered solid-phase kinetics, we wanted to compare a commercially available standard polymer (1% divinylbenzene cross-linked polystyrene) and a soluble polymer support. Within the framework of xanthate transfer technology, we recently described a new practical process for preparing soluble styrene oligomers and this technology looked particularly attractive for our study.[8] In order to make a comparison with Wang resin, we engaged in the synthesis of a new soluble resin containing a *p*-alkoxybenzyl alcohol linker. Herein, we present the straightforward preparation and application of the first soluble analogue of the classical Wang resin.

2. Results

2.1. Synthesis of a new soluble resin containing a *p*-alkoxybenzyl alcohol linker (10-b)

The radical transfer reaction of a xanthate can be easily applied to the formation of oligomers of styrene, leading to new soluble materials for polymer-supported synthesis as depicted in Scheme 1.[8]

In a general procedure, heating a mixture of xanthate **1** and styrene in toluene in the presence of small amounts of a radical initiator gives an adduct **2**. This adduct, being itself



Scheme 1.

Keywords: soluble polystyrene resin; Wang resin; solid phase synthesis; free radical addition; xanthate.

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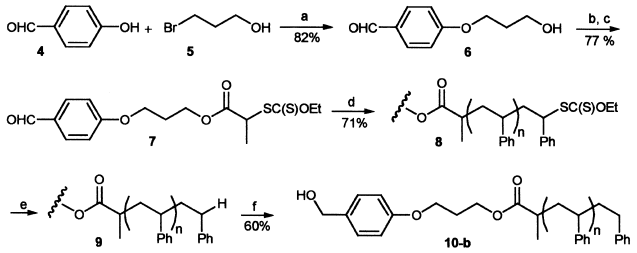


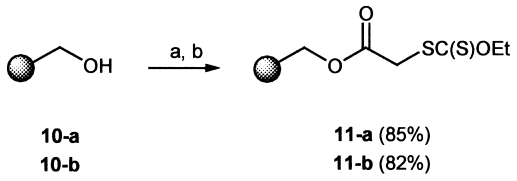
Scheme 2. (a) K_2CO_3, DMF, reflux, 8 h, 82%; (b) CH_2Cl_2, 2-chloropropionyl chloride, pyridine, room temperature, 2 h; (c) KSC(S)OEt, acetone, room temperature, 2 h, 77%; (d) styrene (20 equiv.), toluene, 90°C, 13 mol% DLP, 71%; (e) Bu_3SnH, AIBN, C_6H_6, reflux, 30 min; (f) $NaBH_4$, THF, EtOH, room temperature, 1 h, 60% from **8**.

a xanthate, can act as a starting point for another addition to styrene, resulting in the formation of polymer **3**. As already described, a ratio of substrate to styrene of about 1:15 leads to easily handlable, powdery solids that are soluble in many of the common organic solvents and may be precipitated in methanol. For a substrate of molecular weight of about 300, this gives a loading of approximately 0.5 mmol g^{-1}.[8]

During our investigation of supported xanthate radical chemistry, we were interested in making a comparison between the classical Wang resin and a soluble version. To this end, the use of this new styrene polymerization process was particularly attractive. Several attempts to synthesize a soluble resin containing a *p*-alkoxybenzyl alcohol linker by different methods were conducted. Finally, the reactions outlined in Scheme 2 led successfully to the formation of resin **10-b**.

The synthesis began with the condensation of *p*-hydroxybenzaldehyde **4** with 3-bromopropanol **5** as already described.[9] The resulting alcohol **6** was then converted into xanthate **7** via a chloroacetate ester derivative. Heating this xanthate with 20 equiv. of styrene in toluene at 90°C with 13 mol% of lauroyl peroxide (DLP), followed by concentration under vacuum and precipitation in methanol gave the corresponding polymeric derivative **8** in 71% yield. It is noteworthy that the polymerization conditions are especially mild and compatible with the presence of the aldehyde moiety. In order to obtain a polymer suitable for a further utilization in radical chemistry, the terminal xanthate moiety of resin **8** had to be cleanly removed. After several attempts,[8] the complete elimination of the xanthate moiety was finally cleanly achieved by a tributyltin hydride reduction to give polymer **9**. The tin residues were very easily eliminated during the precipitation of this polymer in methanol. The last step of the preparation was the borohydride reduction of the aldehyde, performed in a mixture of THF and ethanol to give the new soluble polymer **10-b** containing the Wang linker.

As all resins are readily soluble in chloroform-*d*, the ^1H NMR characterizations of these transformations were particularly expedient because with those polymers, the wide region between the aromatic and aliphatic hydrogens of the styrene units remains useful. For example, characteristic signals of the xanthate moiety [4.60–4.20 (m, 3H)] of resin **8** disappeared in compound **9**, and the signals of the aldehyde in **8** or **9** [9.86 (s, 1H); 7.81 (m, 2H)] vanished in



Scheme 3. (a) $ClCOCH_2Cl$ or $BrCOCH_2Cl$, CH_2Cl_2, NEt_3, room temperature, 2 h; (c) KSC(S)OEt, acetone, room temperature, 2 h.

compound **10-b** in favor of those of the benzylic methylene [4.60 (s, 2H)]. The loading of resin **10-b** was evaluated at 0.24 mmol g^{-1} by ^1H NMR (see Section 5). Determination of loading can be performed with each polymer giving a truly efficient method to follow each step of transformation.

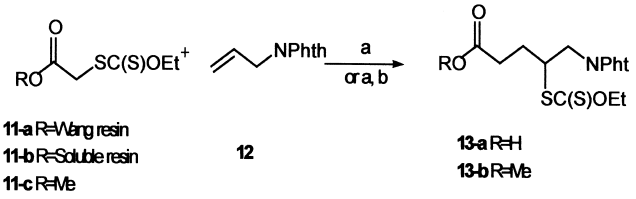
The viability of a radical inter-molecular addition of a xanthate to an olefin on solid phase can be checked in two different manners: (i) addition of a resin-bonded xanthate to an olefin in solution; (ii) addition of a xanthate in solution to an immobilized olefin.

2.2. Radical additions of resin-bound xanthates to *N*-allylphtalimide 12

Starting from Wang resin **10-a** or from the soluble analogue **10-b**, the xanthates **11-a** and **11-b** were easily prepared by chloroacetylation followed by the displacement of the chlorine with *O*-ethyl xanthate (Scheme 3).

The xanthates **11-a** and **11-b** were used to check the intermolecular addition to *N*-allylphtalimide **12** in refluxing 1,2-dichloroethane (1,2-DCE). These reactions were compared with the reaction performed in solution with xanthate **11-c** (Scheme 4).

The results are summarized in Table 1. As shown in this table, with the Wang resin (entries 1, 2), a large excess of reagent must be used to perform the reaction. On one hand, under conditions analogous to the solution reaction, the reaction fails to go to completion even with a large excess of radical initiator (entry 1 vs entry 4). On the other hand, even with a large excess of olefin **12**, about 30 mol% of DLP must still be used to accomplish 100% conversion (entry 2 vs entry 4). The reactions with xanthate **11-a** were not clean, various by-products were formed, and the adduct **13-a** could be obtained only in 26% yield.[10] With soluble resin **11-b**, it was possible to find conditions in order to bring the reaction to completion with only a three-fold excess of olefin **12**, though about 40 mol% of DLP had to be used. In this case, the reaction was cleaner than with Wang resin and the adduct **13-a** could be isolated in 54% yield after chromatography.



Scheme 4. (a) 1,2-DCE, reflux, DLP; (b) 10% TFA/CH_2Cl_2, room temperature, 30 min.

Table 1. Radical additions with resin-bound xanthates **11-a** and **11-b**

Entry	Conditions[a]	Xanthate	Molar ratio **12/11**	DLP (mol%)	Conversion[b] (%)	**13** Yield[c] (%)
1	a, b	**11-a**	1.3	108	60	N.d.
2	a, b	**11-a**	10	32	100	26
3	a, b	**11-b**	3.3	40	100	54
4	a	**11-c**	1.3	5	100	83

N.d.—not determined.
[a] See Scheme 4.
[b] Determined by ^{1}H NMR on crude product or after TFA cleavage for supported reactions (entries 1–3).
[c] Determined after silica gel chromatography.

It is noteworthy that the addition reaction to *N*-allylphtalimide **12** with the soluble resin **11-b** was very easily monitored. In comparison, with the classical Wang resin **11-a**, an aliquot of the reaction mixture had to be removed, washed several times, cleaved (30 min) then analyzed by TLC or ^{1}H NMR. The same monitoring with the soluble resin **11-b** was greatly simplified, with a very quick and simple ^{1}H NMR analysis of an aliquot of the reaction medium using a standard NMR apparatus. An example of such a monitoring is shown in Fig. 1. The full spectrum corresponds to the starting mixture of compounds **11-b** and **12**, before the addition of the radical initiator. One can observe, in the expanded spectra (6.10–3.80 ppm) the formation of the adduct (5.04 ppm) and the complete disappearance of the starting material (5.11 ppm).

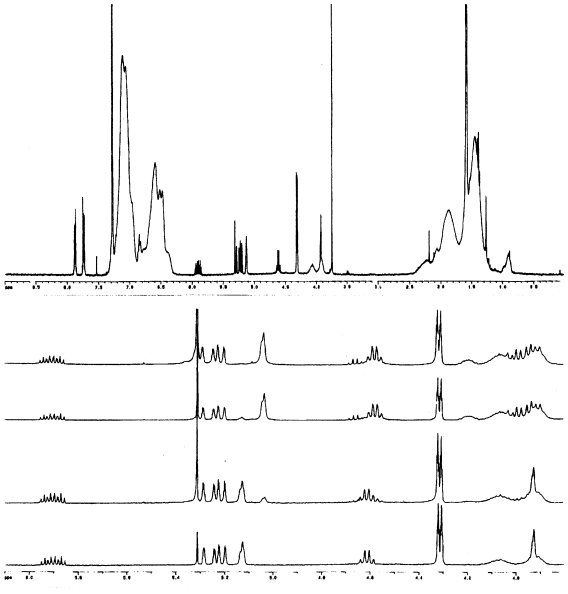
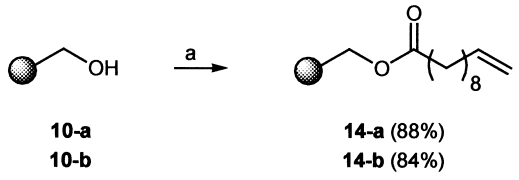


Figure 1.

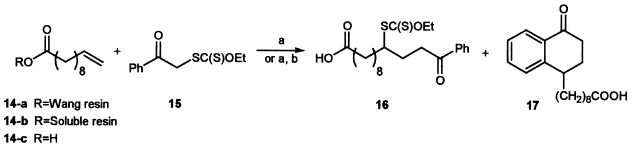
2.3. Radical additions to immobilized olefins 14-a and 14-b

Wang resin **10-a** and the soluble analogue **10-b** were efficiently acylated by 10-undecenoyl chloride (Scheme 5).



Scheme 5. (a) 10-undecenoyl chloride, NEt_3 or pyridine, room temperature, 2 h.

We examined the conditions of the addition of the acetophenone-derived xanthate **15** on the resin bound olefins **14-a** and **14-b**, in comparison with the corresponding reaction in solution with 10-undecenoic acid **14-c** (Scheme 6).



Scheme 6. (a) 1,2-DCE, reflux, DLP; (b) 10% TFA/CH_2Cl_2, room temperature, 30 min.

The results are summarized in Table 2. In reactions with immobilized olefins **14-a** and **14-b**, xanthate **16** was obtained as a 9:1 mixture with the corresponding tetralone **17**.[11] The formation of this latter compound was not observed when the reaction was performed in solution with olefin **14-c**. The formation of the tetralone **17** with supported olefins shows that the intra-molecular addition to the aryl ring is now competing with the bimolecular chain transfer of the alkyl radical. The similar ratio of **16** to **17**, observed with resins **14-a** and **14-b** indicates that the

Table 2. Radical additions to immobilized olefins **14-a** and **14-b**

Entry	Conditions[a]	Olefin	Molar ratio **15/14**	DLP (mol%)	Conversion[b] (%)	Yield[c] (%)
1	a, b	**14-a**	5.0	54	80	52[d]
2	a, b	**14-b**	3.6	50	75	70[d]
3	a	**14-c**	3.0	12	100	80[e]

[a] See Scheme 6.
[b] Determined by ^{1}H NMR on crude product, after TFA cleavage for supported reactions (entries 1 and 2).
[c] Determined after silica gel chromatography, corrected for conversion.
[d] Yield of the mixture of compounds **16** and **17** (9:1 molar ratio).
[e] Yield of adduct **16**.

intra-molecular cyclization reaction does not depend on the mobility of the polymer radical. With immobilized olefins **14-a** and **14-b**, it was not possible to bring the reaction to completion, even with large excess of radical initiator. In comparison with the results of Table 1, the reactions were always clean, the only products obtained in the crude mixture after TFA cleavage being the xanthate **16**, the tetralone **17** and the starting olefin **14-c**. A better yield, closer to that of the reaction in solution was obtained with soluble resin **14-b**.

3. Discussion

In comparison with the results depicted in the literature, the majority of radical reactions, excepting two studies,[12] have involved organotin reagents.[3b,6,13] In all experiments, large amounts of radical initiator and propagator were used to afford good yields for the inter-molecular radical additions. Our results are in agreement with this statement, especially with the classical Wang resin. In the case of the soluble polymer, we found conditions that permit to use less than 1 equiv. of radical initiator. Even if this amount is still much greater than for the corresponding reactions performed in solution, we demonstrate for the first time a radical chain reaction on a solid support.

In our case, with the Wang resin-bound xanthates **11-a** and **11-b**, it was not possible to find reaction conditions that brought the reactions to completion cleanly (Table 1). In fact, to add further complication in comparison with the reactions studied in the literature where the products formed cannot react further, the desired product in our case can be consumed when large amounts of radical initiator are used. As our product is also a xanthate, it can react with DLP to generate a radical species, finally leading to a complex mixture of compounds. This problem does not exist when the starting xanthate is used in large excess, as in the reactions with immobilized olefins (Table 2). In this latter case, the starting xanthate itself is used in excess and in solution phase, and is thus more accessible than the immobilized product. The starting xanthate then 'protects' the final adduct from other radical reactions even when large amounts of radical initiator are used. The reactions are thus clean but on the other hand, it is not possible to obtain 100% conversion. Since the quantity of the olefin decreases during the course of the reaction, the rate determining step of the inter-molecular addition also decreases in rate until it becomes negligible, a problem that is exacerbated with an immobilized olefin. It seems then that radical additions of a resin-bound xanthate to an olefin cannot be easily carried out in such heterogeneous medium with Wang resin. In particular, it seems clear in the light of these results that xanthate radical additions need to be properly and carefully monitored in order to prevent the consumption of the adduct and the formation of various by-products.

Thus, the use of a soluble resin presents a tremendous advantage lying in the particularly easy monitoring of the reaction. Moreover, working with the soluble analogue of Wang resin partially restricts the problems of kinetics inherent to solid-phase reactions, and the reaction conditions become more compatible with the radical chemistry of xanthates.

4. Conclusion

In conclusion, we have examined with two different polymers the feasibility of inter-molecular xanthate additions onto olefins. We have thus shown that the reactions with immobilized olefins and a xanthate in solution are cleaner than in the inverse case. Furthermore, the results obtained with a soluble resin are better than those obtained in heterogeneous medium with Wang resin. In order to perform these comparative studies, we have developed the preparation of a new soluble resin bearing a Wang type linker. This new resin, which is easily prepared, avoids the difficulties of solid-phase support, while preserving its positive aspects: the easy cleavage conditions are conserved and the solubility of this support in a large spectrum of organic solvents allows homogeneous reaction conditions and ^{1}H NMR monitoring of the reactions. We believe that this new soluble resin could be developed successfully in many other reactions already described with Wang resin.

5. Experimental

^{1}H and ^{13}C NMR spectra were recorded in $CDCl_3$ using a Bruker AM-400 at 400 and 100 MHz, respectively. The chemical shifts are expressed in parts per million (ppm) referenced to residual chloroform. ^{1}H NMR data are reported as follows: δ, chemical shift; multiplicity (recorded as: s, singlet; d, doublet; t, triplet; q, quadruplet; qt, quintuplet; m, multiplet), coupling constants (J are given in Hertz, Hz) and integration. Infrared spectra were obtained on a Perkin–Elmer FT-1600 instrument and are reported in terms of frequency of absorption (ν, cm^{-1}). Mass spectra were obtained either on a Hewlett–Packard HP 5989B spectrometer via either direct introduction or GC/MS coupling with a Hewlett–Packard HP 5890 chromatograph for chemical positive ionization with ammonia (IC^+, NH_3) and on a Micromass Platform-LC for LC-MS electrospray ionization (ES). Mass spectral data are reported as *m/z*. HPLC was performed on Dionex apparatus with a Kromasil C18 50×2.1 mm 5 μm column (H_2O/CH_3CN, 1%TFA). Thin layer chromatography (TLC) were performed on precoated plate of silica gel $60F_{254}$ staining with anisaldehyde or CAM reagent. Flash chromatography were performed on silica gel 60, 230–400 mesh. Microanalyses were performed by the Service de Microanalyse, Institut de Chimie des Substances Naturelles, C.N.R.S., F-91198, Gif-sur-Yvette. Wang resin was purchased from Novabiochem (l=1.29 mmol g^{-1}). Cleavages from Wang resin were carried out by treatment with CH_2Cl_2/TFA (9:1) for 30 min at room temperature (100 mg of resin for 1 ml).

5.1. Synthesis of the soluble polymers. General procedures with the new soluble polymers

^{1}H NMR spectra. For all polymers, the following signals corresponding to the polystyrene backbone are always present and are not described in each spectrum: 7.50–6.20 (m, aromatic H), 2.50–1.00 (m, aliphatic H). The multiplicities are given without coupling constants because of the breadth of peaks. *Loadings*. The loadings of the resin were determined by ^{1}H NMR from integration curves relative to an internal reference [triphenylmethane (TPM),

δ 5.55 ppm in $CDCl_3$ (s, 1H); 20 mg of resin and 10 mg of TPM in 0.5 ml of $CDCl_3$; standard ^1H NMR spectrum, n_s=128 scans, D_1=10 s]. *Precipitation*. The solvents of the reaction medium were evaporated under vacuum and the residue, dissolved in CH_2Cl_2, was added dropwise under vigorous stirring at room temperature to methanol (1 g of resin for 100 ml of methanol). After about 1 h of stirring at room temperature, the resin is filtered on a Büschner funnel then dried several hours in vacuo at 50°C. *Cleavage*. A solution of 1 g of resin in 5 ml of 10% TFA solution in CH_2Cl_2 was stirred at room temperature for 30 min then the solvents are evaporated under vacuum and the residue was precipitated in methanol. The resulting resin is filtered over a celite pad and the solvents are evaporated in vacuo.

5.1.1. Synthesis of the soluble polymer 10-b (Scheme 2). *4-(3-Hydroxypropoxy) benzaldehyde* ***6***. The title compound was synthesized using an already described procedure in 82% yield.[9]

2-Ethoxyxanthate-propionic acid 3-(4-formyl-phenoxy)-propyl ester ***7***. To a solution of **6** (3.8 g, 21.11 mmol) and pyridine (2.1 ml, 25.96 mmol, 1.2 equiv.) in dichloromethane (20 ml) cooled to 0°C was added dropwise under stirring 2-chloropropionyl chloride (2.5 ml, 25.75 mmol, 1.2 equiv.). The reaction mixture was stirred at room temperature for 2 h and then diluted with 200 ml of ether. The organic layer was washed with portions of 100 ml of water, 5% HCl aqueous solution, water and brine. The organic phase was then dried ($MgSO_4$), filtered and concentrated to dryness under vacuum. The residue was dissolved in acetone (50 ml) and ethylxanthic acid potassium salt (4.1 g, 25.60 mmol, 1.2 equiv.) was added portionwise under stirring at room temperature. After 2 h, the reaction mixture was poured into 100 ml of water and extracted three times with CH_2Cl_2 (50 ml). The combined organic layers were dried ($MgSO_4$), filtered and the solvents were evaporated in vacuo to give 6.02 g of crude **7** as a yellow oil. Silica gel chromatography (ether/petroleum ether 1:1 to 3:2) furnished 5.82 g (77% yield) of pure **7** as a pale yellow oil. ^1H NMR: 9.90 (s, 1H); 7.85 (d, J=8.7 Hz, 2H); 7.00 (d, J=8.7 Hz, 2H); 4.58 (q, J=7.1 Hz, 2H); 4.45–4.30 (m, 3H); 4.14 (t, J=6.1 Hz, 2H); 2.19 (qt, J=6.1 Hz, 2H); 1.58 (d, J=7.4 Hz, 3H); 1.39 (t, J=7.1 Hz, 3H). ^{13}C NMR: 212.05 (CS); 190.85 (CHO); 171.39 (CO); 163.75 (C); 132.04 (CH); 130.04 (C); 114.77 (CH); 70.40 (CH_2); 64.52 (CH_2); 62.20 (CH_2); 47.16 (CH); 28.36 (CH_2); 16.79 (CH_3); 13.70 (CH_3). IR: 2979, 2738, 1735, 1690, 1601, 1577, 1509, 1311, 1218, 1160, 1046. MS(IC^+): 357 $(M+H)^+$, 374 $(M+NH_4)^+$. Anal. calcd for $C_{16}H_{20}O_5S_2$: C 53.91%; H 5.66%. Found: C 53.87%; H 5.61%.

Polymer ***8***. To a degassed solution of xanthate **7** (5.35 g, 15.34 mmol) in toluene (15 ml) and styrene (35 ml, 20 equiv.) heated at 90°C under argon was added lauroyl peroxide (DLP) (60 mg, 1 mol%) every 1.5 h. After 13 mol% of DLP added, the polymer was precipitated to give 32.13 g (l=0.34 mmol g^{-1}, 71% yield) of polymer **8**. ^1H NMR: 9.86 (s, 1H, CHO); 7.85 (m, 2H); 4.60–4.20 (m, 3H); 4.20–4.00 (m, 2H); 4.00–3.80 (m, 2H). IR: 3025, 2926, 1732, 1696, 1601, 1493, 1452, 1217, 1054, 761, 700.

Polymer ***10-b***. A degassed solution of **8** (32.0 g, 10.88 mmol), tributyltin hydride (3.5 ml, 13.01 mmol, 1.2 equiv.) and AIBN (90 mg, 0.55 mmol, 0.05 equiv.) in benzene (28 ml) was heated for 30 min before adding chloroform, cooling to room temperature and precipitation of the polymer **9**. This reaction was performed twice. ^1H NMR: 9.86 (s, 1H); 7.81 (m, 2H); 4.20–4.00 (m, 2H); 4.00–3.80 (m, 2H). To a solution of this former polymer in THF (80 ml) cooled to 0°C was added dropwise an ethanol (20 ml) solution of $NaBH_4$ (500 mg, 13.21 mmol). The reaction mixture was allowed to reach room temperature and was stirred an hour before precipitation to give 26.6 g (l=0.24 mmol g^{-1}, 60% from polymer **8**) of Wang-like resin **10-b**. ^1H NMR: 4.60 (s, 2H); 4.20–4.00 (m, 2H); 4.00–3.80 (m, 2H). IR: 3025, 2922, 1732, 1601, 1493, 1452, 1245, 1028, 760, 700. The ^1H NMR loading determination of resin **10-b** was validated by preparation and cleavage of the corresponding benzoic acid derivative.

5.1.2. Preparation of immobilized xanthates 11-a and 11-b (Scheme 3). Bromoacetyl chloride or chloroacetyl chloride (3 equiv.) was added dropwise at 0°C to a mixture of the resin and triethylamine (3 equiv.) in dichloromethane. The reaction medium was then allowed to reach room temperature and was stirred for 2 h before work up and analysis of the supported products. To an acetone solution (suspension) of the resin was then added 2–3 equiv. of ethylxanthic acid potassium salt and the reaction was stirred for 2 h before work up.

Xanthate ***11-a***. Wang resin **10-a** (5.0 g, 6.45 mmol), triethylamine (2.7 ml, 19.40 mmol), bromoacetyl chloride (1.6 ml, 19.20 mmol), CH_2Cl_2 (40 ml) furnished 5.55 g of chloroacetylated resin. This was treated in acetone (40 ml) with ethylxanthic acid potassium salt (2.75 g, 17.15 mmol) to give 6.0 g (85% yield based on cleavage experiment) of resin **11-a**. IR: 3026; 2924; 1740; 1612; 1513; 1493; 1452; 1377; 1227; 1150; 1113; 1050; 824.

Xanthate ***11-b***. Resin **10-b** (5 g, 1.20 mmol), triethylamine (0.55 ml, 3.95 mmol), chloroacetyl chloride (0.3 ml, 3.77 mmol), CH_2Cl_2 (12 ml) gave 5.78 g of chloroacetylated resin. This was treated with ethylxanthic acid potassium salt (400 mg, 2.5 mmol) in acetone (10 ml) to give 4.90 g (82% yield, l=0.2 mmol g^{-1}) of resin **11-b**. ^1H NMR: 5.11 (s, 2H); 4.60 (q, 2H); 4.20–4.00 (m, 2H); 4.00–3.80 (m, 2H); 3.90 (s, 2H). IR: 3025, 2925, 1733, 1601, 1493, 1452, 1238, 1050, 1028, 758, 700.

5.1.3. Preparation of immobilized olefins 14-a and 14-b (Scheme 5). To a mixture of the resin and triethylamine or pyridine (3 equiv.) was added dropwise at 0°C 10-undecenoyl chloride (3 equiv.). The reaction mixture was allowed to reach room temperature and was stirred for 2 h before work up.

Resin ***14-a***. Wang resin **10-a** (2 g, 2.58 mmol), triethylamine (1.1 ml, 7.90 mmol), 10-undecenoyl chloride (1.7 ml, 7.90 mmol), CH_2Cl_2 (10 ml) furnished 2.42 g (88% yield based on cleavage experiment) of immobilized olefin **14-a**. IR: 2925; 2854; 1734; 1608; 1513; 1493; 1453; 1241; 1168; 1015; 821.

*Resin **14-b***. Resin **10-b** (5.0 g, 1.2 mmol), pyridine (0.32 ml, 3.96 mmol), 10-undecenoyl chloride (0.8 ml, 3.72 mmol), CH_2Cl_2 (10 ml) gave 5.05 g (84% yield, l=0.2 mmol g^{-1}) of resin **14-b**. ^{1}H NMR: 5.80 (m, 1H); 5.02 (s, 2H); 5.05–4.95 (dd, 2H); 4.20–4.00 (m, 2H); 4.00–3.80 (m, 2H). IR: 3025, 2926, 1734, 1601, 1493, 1542, 1246, 908, 760, 700.

5.2. Radical additions. General procedure and work up for radical additions

A mixture of the xanthate and the olefin in 1,2-dichloroethane (1,2-DCE) was degassed under argon for 30 min at reflux then catalytic amounts (5–10 mol%) of DLP were added every 2 h. The reactions with Wang resin were monitored by TLC and/or ^{1}H NMR on cleaved aliquots of the reaction medium. The reactions with the soluble analogue of Wang resin were monitored by ^{1}H NMR (n_s=128 or 256 scans, D_1=0.5 s) of aliquots of the reaction medium. The conversions were determined by ^{1}H NMR analysis of crude products after TFA cleavage. For the reference reactions in solution, the resulting adducts were purified after evaporation of the solvent by silica gel chromatography. For reactions with Wang polymer, the resin was filtered and washed several times with CH_2Cl_2, CH_2Cl_2/pentane (1:1), THF and ether then dried several hours under vacuum at 50°C before cleavage and silica gel chromatography. For reactions with soluble analogue of Wang resin, the 1,2-dichloroethane (1,2-DCE) was evaporated in vacuo before precipitation, drying, cleavage and silica gel chromatography. The carboxylic adducts (**13-a** and **16**) obtained from supported radical additions were compared with the corresponding methyl ester derivative **13-b** for compound **13-a**, and with authentic sample obtained from reference reactions in solution for adduct **16**.

5.2.1. Radical additions to *N*-allylphtalimide 12 (Scheme 4, Table 1). *Table 1*, *entry 1*. Resin **11-a** (200 mg, 0.21 mmol), olefin **12** (51 mg, 0.27 mmol, 1.3 equiv.), 1,2-DCE (1 ml), DLP (92 mg, 108 mol%). ^{1}H NMR analysis of the crude product after cleavage (32 mg) showed a conversion of 60% and the presence of different by-products.

Table 1, *entry 2*. Resin **11-a** (400 mg, 0.43 mmol), olefin **12** (800 mg, 4.28 mmol, 10 equiv.), 1,2-DCE (2 ml). Addition of DLP (55 mg, 32 mol%) until complete disappearance of the starting xanthate observed by ^{1}H NMR. Silica gel chromatography (ether, 1–2% MeOH) followed by preparative TLC (ether, 2% MeOH) furnished 51 mg (32% yield) of adduct **13-a** of approximately 80% purity checked by LC-MS (26% corrected yield).

Table 1, *entry 3*. Resin **11-b** (1.0 g, 0.20 mmol); olefin **12** (132 mg, 0.66 mmol, 3.3 equiv.), 1,2-DCE (1 ml). Addition of DLP (40 mg, 40 mol%) until complete disappearance of the starting xanthate observed by ^{1}H NMR. Cleavage and silica gel chromatography (ether/petroleum ether 1:1, 1% AcOH) furnished 50 mg (68% yield) of adduct **13-a** of approximately 80% purity checked by ^{1}H NMR with TPM as internal reference (54% corrected yield). *Adduct **13-a***. ^{1}H NMR: 7.87 (m, 2H); 7.74 (m, 2H); 4.60 (m, 2H); 4.18 (m, 1H); 4.05–3.90 (m, 2H); 2.70–2.49 (m, 2H); 2.13 (m, 1H); 1.92 (m, 1H); 1.42 (t, J=7.1 Hz, 3H). ^{13}C NMR: 212.15 (CS); 178.83 (COOH); 168.26 (NCO); 134.30 (CH); 131.85 (C); 123.61 (CH); 70.48 (CH_2); 48.77 (CH); 41.00 (CH_2); 31.23 (CH_2); 26.93 (CH_2); 13.72 (CH_3). MS(IC^+): 368 $(M+H)^+$, 385 $(M+NH_4)^+$.

Table 1, *entry 4*. Xanthate **11-c** (3 g, 15.46 mmol), olefin **12** (3.82 g, 20.42 mmol, 1.3 equiv.), 1,2-DCE (15 ml), DLP (330 mg, 5 mol%). Silica gel chromatography (petroleum ether/ether 4:1 to 1:1) furnished 4.91 g (83% yield) of adduct **13-b**. ^{1}H NMR: 7.86 (m, 2H); 7.74 (m, 2H); 4.61 (m, 2H); 4.18 (m, 1H); 4.04–3.91 (m, 2H); 3.67 (s, 3H); 2.63–2.47 (m, 2H); 2.15 (m, 1H); 1.93 (m, 1H); 1.42 (t, J=7.1 Hz, 3H). ^{13}C NMR: 212.24 (CS); 173.01 (COOMe); 168.11 (NCO); 134.22 (CH); 131.85 (C); 123.51 (CH); 70.37 (CH_2); 51.83 (CH_3); 48.84 (CH); 40.98 (CH_2); 31.20 (CH_2); 26.82 (CH_2); 13.70 (CH_3). IR: 2951, 1773, 1714, 1434, 1393, 1361, 1219, 1112, 1046, 714. MS(IC^+): 382 $(M+H)^+$, 399 $(M+NH_4)^+$. Anal. calcd for $C_{17}H_{19}NO_5S_2$: C 53.53%; H 5.02%. Found: C 53.52%; H 4.97%.

5.2.2. Radical additions to immobilized olefins 14-a and 14-b (Scheme 6, Table 2). *Table 2*, *entry 1*. Resin **14-a** (400 mg, 0.42 mmol), xanthate **15** (500 mg, 2.08 mmol, 5.0 equiv.), 1,2-DCE (2 ml), DLP (89 mg, 54 mol%). The ^{1}H NMR analysis of the crude product after cleavage showed a conversion of 80% and the presence of adduct **16** and tetralone **17** in a 9:1 ratio. Silica gel chromatography (petroleum ether/ether 7:3, 1% AcOH) furnished 72 mg of products **16** and **17** in 9:1 ratio (42% yield, 52% corrected for conversion).

Table 2, *entry 2*. Resin **14-b** (900 mg, 0.18 mmol), xanthate **15** (156 mg, 0.65 mmol, 3.6 equiv.), 1,2-DCE (0.5 ml), DLP (45 mg, 50 mol%). The ^{1}H NMR analysis of the crude product after cleavage showed a conversion of 75% and the presence of adduct **16** and tetralone **17** in a 9:1 ratio. Silica gel chromatography (petroleum ether/ether 7:3, 1% AcOH) furnished 39 mg of products **16** and **17** in 9:1 ratio (52% yield, 70% corrected for conversion).

Table 2, *entry 3*. 10-Undenenoic acid **14-c** (185 mg, 1.0 mmol), xanthate **15** (734 mg, 3.05 mmol), 1,2-DCE (1 ml), DLP (47 mg, 12 mol%). Silica gel chromatography (petroleum ether/ether 7:3, 1% AcOH) furnished 338 mg (80% yield) of adduct **16**. ^{1}H NMR: 7.95 (m, 2H); 7.57 (m, 1H); 7.47 (m, 2H); 4.61 (m, 2H); 3.83 (m, 1H); 3.15 (m, 2H); 2.35 (t, J=7.5 Hz, 2H); 2.26 (m, 1H); 1.99(m, 1H); 1.72 (m, 2H); 1.64 (m, 2H); 1.46 (m, 2H); 1.39 (t, J=7.1 Hz, 3H) 1.37–1.28 (m, 8H). ^{13}C NMR: 214.61 (CS); 199.61 (CO); 180.10 (COOH); 136.86 (C); 133.21 (CH); 128.69 (CH); 128.16 (CH); 69.96 (CH_2); 51.19 (CH); 35.91 (CH_2); 34.82 (CH_2); 34.13 (CH_2); 29.42 (CH_2); 29.30 (CH_2); 29.21 (CH_2); 29.07 (CH_2); 28.70 (CH_2); 26.90 (CH_2); 24.72 (CH_2); 13.84 (CH_3). IR: 3700–2800, 2927, 2854, 1707, 1686, 1448, 1212, 1111, 1050. MS(IC^+): 426 $(M+H)^+$, 443 $(M+NH_4)^+$, 303. Anal. calcd for $C_{22}H_{32}O_4S_2$: C 62.23%; H 7.60%. Found: C 62.12%; H 7.64%.

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