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THE PALLADIUM-CATALYSED REDUCTIVE ADDITION OF ARYL IODIDES TO PROPARGYL ALCOHOLS: A ROUTE TO γ,γ-DIARYL ALLYLIC ALCOHOLS

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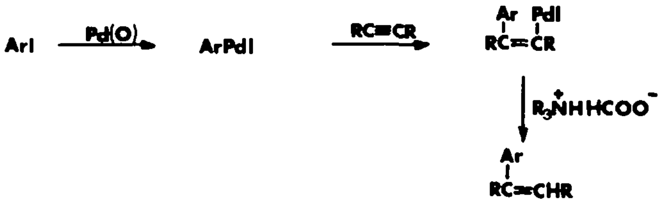
Abstract - The reaction of aryl iodides with ethynyl and arylethynyl,dialkylcarbinols in the presence of the tri- or dialkylammonium formate-palladium reagent provides a convenient route to γ,γ-diarylallylic alcohols. In the presence of arylethynyl,alkylcarbinols a lack of regioselectivity was observed and mixtures of β,γ-, γ,γ-diarylallylic alcohols, and α,β-unsaturated ketones were obtained.

We recently reported that aryl iodides react with alkynes in the presence of a palladium catalyst and trialkylammonium formate to give trisubstituted alkenes according to the scheme I.[1]



Scheme I

The reaction gives good to excellent results with symmetrically substituted acetylenes while a lack of regioselectivity was observed with unsymmetrically substituted acetylenes such as phenyl(4-methoxyphenyl)acetylene and phenyl(4-acetylphenyl)acetylene (where only electronic factors are operative in orienting the addition of the in situ formed arylpalladium intermediate to the carbon-carbon triple bond).

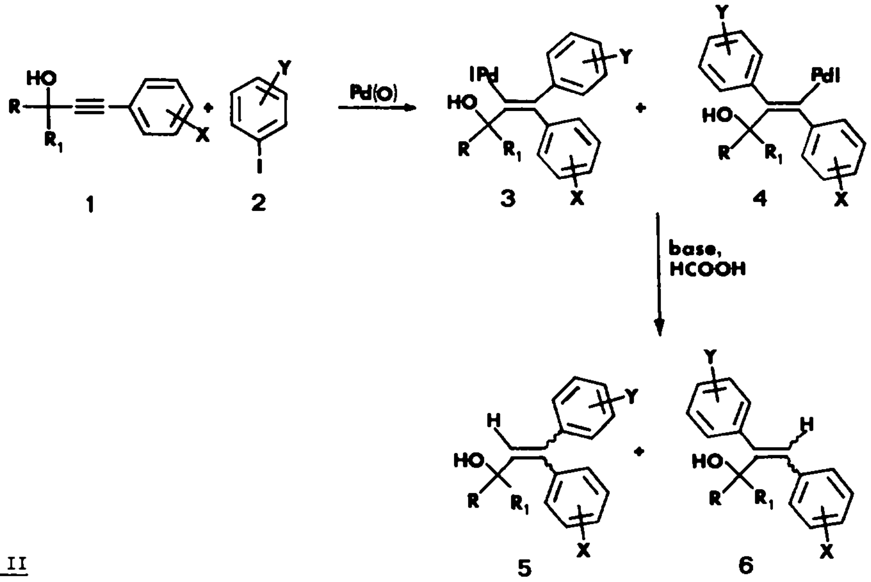
Assuming that introduction of a bulky end on one side of the carbon-carbon triple bond might provide better regioselectivity and noting that arylethynyl,dialkylcarbinols, containing an sp^2 and an sp^3 carbon atom bonded to the ethynyl system, have the desired steric feature, it appeared to us of interest to investigate on the extention of our reductive addition of aryl iodides to these easily available compounds. Herein we report the results of our studies.

RESULTS AND DISCUSSION

Initial studies centered on the reaction of arylethynyl,dialkylcarbinols (1) with aryl iodides in the presence of the trialkylammonium formate-palladium reagent. These compounds were easily prepared in good to high yield by reacting ethynyl,dialkylcarbinols with aryl iodides in the presence of bis(triphenylphosphine)palladium diacetate and cuprous iodide.[2]

Usually, we have found that the presence of cuprous iodide results in better yields and/or shorter reaction times. For example, (4-methoxyphenyl)ethynylcyclohexanol (1b) was obtained in only 40% yield (4.5 h, 60°C) from equimolar amounts of ethynylcyclohexanol, 4-methoxyphenyl iodide, piperidine, and 2 mol % of bis(triphenylphosphine) palladium diacetate. The yield of (1b) raised up to 98 % (2 h, 60°C) by adding 4 mol % of cuprous iodide to the same reaction mixture.

Compounds (1) were reacted with aryl iodides (2) in the presence of piperidine or tri-n-butylamine, formic acid, and bis(triphenylphosphine)palladium diacetate in DMF or MeCN to give regioselective formation of γ,γ-diarylallylic alcohols (5)[*] in good yield (Scheme II).



Scheme II

The isomeric β,γ-diarylallylic alcohols (6) were usually obtained in only 5-10 % yield. Variable amounts of the starting material were recovered.

The results obtained (table 1) suggest that steric hindrance can effectively control the direction of addition of arylpalladium species to unsymmetrically substituted triple bond. The aryl moiety of the palladium complex tends to go on the less crowded carbon atom of the triple bond favouring the formation of intermediates (3). Electronic factors, as previously reported, do not seem to play an important role whereas it appears not unreasonable to suppose the involvement of hydroxyl coordination in the addition step (hydroxyl coordination has already been proposed to affect the palladium-catalysed reaction of aryl iodides with allylic alcohols[3]). The presence of this effect, paralleling the dominant steric control of the regiochemistry of addition, appears to be supported by the result obtained in the reaction of 1-(4-methoxyphenyl)-3,3-dimethyl-but-1-yne,[**] an alkyne with a bulky end not containing the hydroxy group, with 4-methoxyphenyl iodide. In this case the isomeric addition products, 1,1- and 1,2-di(4-methoxyphenyl)-3,3-dimethylbut-1-

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[*] The structure of compounds (5) and (6) was assigned on the ground of spectroscopic and chemical data. Vinylic protons in compounds (6) are down field from vinylic protons in compounds (5). As an example, in compounds (6a) and (5a), δ values (Me_2CO-d_6) of vinylic protons are 6.42 and 6.23, respectively. In addition, oxidation of (5) with $KMnO_4$ gives the corresponding benzophenones. In the case of (5a) again, benzophenone was obtained in 91 % yield.

[**] 1-(4-methoxyphenyl)-3,3-dimethyl-but-1-yne was prepared and reacted with 4-methoxyphenyl iodide according to the procedure B (vide supra).

TABLE 1 - PALLADIUM-CATALYSED REDUCTIVE ADDITION OF ARYL IODIDES TO ARYLETHYNYL,DIALKYLCARBINOLS (1)

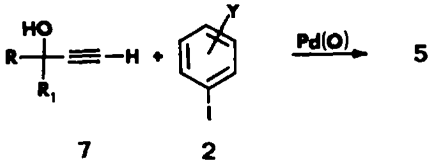
Entry	Alkyne (1)			Aryl iodide (2)	Reaction time	Yield of (5), %^{a,b}
	R	R_1	X	Y	(hr)	
a	$-(CH_2)_5-$		H	H	10	78 (70, -,6)
b	$-(CH_2)_5-$		4-MeO	4-MeO	8	80 (78, -,5)
c	Me	Me	3-MeCONH	3-MeCONH	22	54 (46,21,-)
d	Me	Me	4-MeCONH	4-MeO	8	90 (61, -,-)

a) Yields are not optimized, are calculated on the starting alkyne, and are given for pure, isolated products. b) Figures in parentheses refer to overall yields (ethynylation and reductive addition), to isolated starting material, and ß,γ-isomers (6) respectively.

-enes, were obtained (70 % overall yield) in a ratio 83:17 (85:15 as determined by HPLC). The regioselectivity is still good but slightly worse than that observed in the reaction of the related (4-methoxyphenyl)ethynylcyclohexanol (Table 1, entry b).

The E,Z configuration of compounds (5d) and (5l) (as well that of 10a-d; vide supra) was not investigated.

The reaction has also been carried out by reacting ethynyl,dialkylcarbinols (7) directly with an excess of aryl iodides (Scheme III, Table 2, entries a,b,f-i,n,o; procedure A).

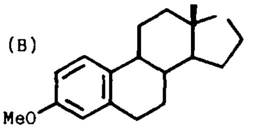


Scheme III

The efficiency of this one-pot procedure depend on the different reactivity that aryl iodides show in the alkynylation and in the reductive addition step. For example, aryl iodides containing electron-withdrawing groups are known to improve the yields in the alkynylation step.[4] However, we have found that better results in the reductive addition step are often obtained with aryl iodides containing electron-donating groups.[1,5] Therefore, when ethynylcyclohexanol was reacted with aryl iodides containing electron-withdrawing and electron-donating groups such as 4-carbomethoxyphenyl iodide and 4-methoxyphenyl iodide, the γ,γ-diarylallylic alcohols (5g) and (5b) were isolated in 19 % yield (table 2, entry g, procedure A) and 40 % yield (table 2, entry b) respectively. Large amounts (79 %) of the intermediate (1g) were isolated while, apparently, all of the formed (1b) has been trapped by the 4-methoxyphenylpalladium complex. Better results were obtained by reacting the same couple of aryl iodides with the corresponding, previously prepared (4-carbomethoxyphenyl)-ethynylcyclohexanol (table 2, entry g, procedure B - vide supra) and (4-methoxyphenyl)ethynylcyclohexanol (table 1, entry b). The trend of the overall reaction, however, is essentially the same as the higher yield is obtained again with the aryl iodide containing an electron donating group.

Is is worth to point out that treatment of ethynylcyclohexanol with 4-methoxyphenyliodide according to the one-pot procedure, in the presence of cuprous iodide (60°C; 8 hr) (in the presence of cuprous iodide the ethynylation step proceed almost quantitatively), led to a more complex reaction mixture we have not fully analyzed. The γ,γ-diarylallylic alcohols (5b) was isolated in 40 % yield, the intermediate (1b) was obtained only in traces (about 3 % yield), and no starting

TABLE 2 - PALLADIUM-CATALYSED REDUCTIVE ADDITION OF ARYL IODIDES TO ETHYNYL,DIALKYLCARBINOLS (7)

Entry	(procedure)	Alkyne (7)		Aryl iodide (2)	Reaction time (hr)	Yield of (5), %^{a,b}
		R	R_1	Y		
a	(A)	$-(CH_2)_5-$		H	18	66 (-, 5)
b	(A)	$-(CH_2)_5-$		4-MeO	12	40 (-, -)
e	(B)	$-(CH_2)_5-$		2-MeO^c	30^d	57 (18, 6)
f	(A)	$-(CH_2)_5-$		3-MeOOC	48	21 (74, -)
g	(A)	$-(CH_2)_5-$		4-MeOOC	30	19 (79, -)
	(B)	$-(CH_2)_5-$		4-MeOOC^c	20^d	45 (25, -)
h	(A)	$-(CH_2)_5-$		4-Cl	24	71 (-,10)
i	(A)	$-(CH_2)_5-$		2-Cl	30	— (91, -)
l	(B)	$-(CH_2)_5-$		H; 4-MeO^e	12^d	70 (-, 9)
m	(B)	$-(CH_2)_4-$		H^c	18^d	54 (-, 6)
n	(A)	Et	Me	H	24	56 (-, 9)
o	(A)	Me	Me	H	24	55 (-, 6)
p	(B)			4-MeO^c	12^d	65 (16, -)

a) Yields are not optimized, are calculated on the starting alkyne, and are given for pure, isolated products. b) Figures in parentheses refer to isolated reaction intermediates (1) and to β,γ-isomers (6), respectively. c) The reaction was carried out by using the same aryl iodide in the ethynylation and in the reductive addition step. d) Reaction time for the reductive addition. Under our conditions, the ethynylation reaches completion in about 2 hr. e) Phenyl iodide and 4-methoxyphenyl iodide were used in the ethynylation and in the reductive addition step, respectively.

material was recovered.

In some cases it is possible and convenient to carry out the reductive arylation of the carbon-carbon triple bond by simply adding the palladium catalyst, the base, the formic acid, and an excess of aryl iodide to the reaction mixture derived from palladium-catalysed alkynylation of the aryl iodide filtered through a short column of florisil (Table 2, entries e,l,m,p; procedure B). It may be noted that this procedure allows even the introduction of two different aryl units γ to the hydroxyl group (Table 2, entry l).

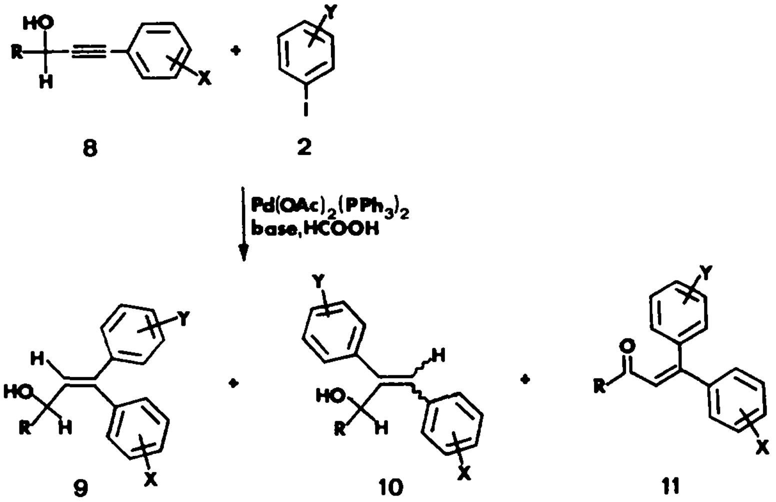
When the reaction is extended to the less hindered arylethynyl,alkyl carbinols (8), a marked worsening of the degree of regioselectivity is observed (table 3).

TABLE 3 - PALLADIUM-CATALYSED REDUCTIVE ADDITION OF ARYL IODIDES TO ARYLETHYNYL,DIALKYLCARBINOLS (8)

Entry	Alkyne (8)		Aryl iodide (2)	Reaction time (hr)	Addition product % yield^a		
	R	X	Y		9	10	11
a	Et	H	H	14	29	42	23
b	$Me(CH_2)_4$	4-MeO	4-MeO	10	31	40	25
c^{b,c}	$Me(CH_2)_4$	4-MeO	4-MeO	24	19	32	
d	Ph	H	H	14	10	31	42

a) Yields are not optimized, are calculated on the starting alkyne, and are given for pure, isolated products. b) The reaction was carried out by using the tetrahydropyranyl derivative of (8b) as the starting alkyne. c) Compound (8c) was recovered in 46% yield.

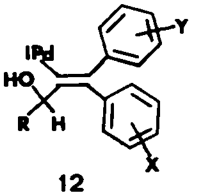
Moreover, in addition to the isomeric alcohols (9) and (10), even α,ß-unsaturated ketones (11) were isolated in significant yield (scheme IV).



Scheme IV

Clearly, formation of (11) does not involve the presence of the formate anion in the catalytic cycle. When 1,4-diphenyl-prop-1-yn-3-ol (8d) was reacted with phenyl iodide in the absence of formic acid the corresponding α,ß-unsaturated ketone was isolated in 40 % yield.

Since the oxidation of (9) to (11) was ruled out on the ground of experimental evidences ((9d) was recovered in almost quantitative yield when reacted under usual conditions with and without formic acid), the formation of compounds (11) can be reasonably accounted for by assuming the involvement of a ß-elimination of HPdI from intermediate (12), competitive with its formate reduction to (9).



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In conclusion, the present extention of our palladium-catalysed reductive addition of aryl iodides to acetylenes provides new insights into the features of the reaction and a useful route to γ,γ-disubstituted allylic alcohols from propargylic alcohols derived from ketones.

Work along this line is in progress.

EXPERIMENTAL

M.ps are uncorrected and were determined with a Büchi 510 apparatus. All of the starting materials, the catalysts, the solvents, and the amines are commercially available and were used without further purification. 3-Acetylamino- and 4-acetylaminophenyl iodides, as well as 3-carbomethoxy- and 4-carbomethoxyphenyl iodides were prepared from commercially available anilines and carboxylic acids according to standard methods.

Reactions were carried out on a 1.0-4.0 mmol scale. The products were purified by flash chromatography on silica gel 60 40-63 μ (Merck), or by preparative HPLC on axially compressed columns (Cromatospac Prep 10 from Jobin Yvon equipped with a PrepLC/System 500A - solvent delivery

TABLE 4 - CHARACTERIZATION OF COMPOUNDS (1).

Compound	M.p. (°C)	I.R. ν(cm^{-1})	^{1}H-NMR δ(ppm)
1a	59-60	3419, 2224, 1599[a]	7.63-7.17 (m,5H), 2.27 (s, exchange with D_2O,1H), 2.18-1.1 (m, 10H).[c]
1b	138-139	3250, 2850, 2220, 1605, 1250, 1040, 830[b]	7.18 (AA'BB', J=9Hz, 4H), 4.29 (s, exchange with D_2O, 1H), 3.81 (s, 3H), 2.13-1.13 (m, 10H).[d]
1c	139-140	3250, 1670, 1610, 1585, 1555, 795, 690[a]	9.33 (bs, exchange with D_2O,1H), 7.97-7.0 (m,4H), 4.5 (s, exchange with D_2O, 1H), 2.1 (s, 3H), 1.53 (s, 6H).[d]
1d	151-152	3300, 2215, 1675, 1600, 1535, 830[b]	9.38 (bs, exchange with D_2O, 1H), 7.52 (AA'BB',J= 9 Hz, 4H), 4.43 (s, exchange with D_2O, 1H), 2.07 (s, 3H), 1.51 (s, 6H).[d]
1e	92-93	3340, 2850, 2220, 1595, 1250, 1020, 750[b]	7.57-6.8 (m, 4H), 3.88 (s, 3H), 2.63 (s, exchange with D_2O, 1H), 1.17 (m, 10H).[c]
1f	106-107	3230, 1720, 1595, 760, 690[b]	8.23-7.3 (m, 4H), 3.93 (s,3H), 2.5 (s, exchange with D_2O, 1H), 2.2-1.17 (m, 10H).[c]
1g	84-85	3220, 2220, 1720, 1605, 855[b]	7.76 (AA'BB', J=9 Hz, 4H), 3.92 (s, 3H), 2.43 (s, exchange with D_2O, 1H), 2.17-1.17 (m, 10H).[c]
1i	67-68	3300, 2220, 1590, 755[b]	7.65-7.05 (m,4H), 2.42 (s, exchange with D_2O,1H), 2.29-1.02 (m, 10H).[c]
1p	60-62	3460, 2860, 2220, 1605, 1250, 1030, 830[b]	7.53-6.57 (m,7H), 4.18 (s, exchange with D_2O,1H), 3.77 (s, 3H), 3.72 (s, 3H), 0.9 (s, 3H).[d]

a) $CHCl_3$. b) KBr. c) $CDCl_3$. d) Me_2CO-d_6.

system and refractive index detector - from Waters) packed with LiChroprep Si-60 15-25 μ (Merck) eluting with n-hexane/AcOEt mixtures. HPLC analyses were performed by using a Waters ALC/GPC 202 chromatograph equipped with a U6K injector, a Model 6000 solvent-delivery system, a variable wavelenght UV/visible detector Model 481, and a Waters Data Module.

^{1}H-NMR spectra were recorded with a Varian EM390 spectrometer (TMS internal standard). IR spectra were recorded with a Perkin-Elmer 683 spectrometer.

All of the isolated products gave satisfactory microanalyses and MS spectra in agreement with the proposed structures.

General procedure of synthesis of arylethynyl,dialkylcarbinols (1).

This is exemplified by the reaction of ethynylcyclohexanol with 4-methoxyphenyl iodide. To a stirred solution of 4-methoxyphenyl iodide (0.94 g, 4.03 mmol), piperidine (0.4 ml, 4.03 mmol) in DMF (2 ml) were added ethynylcyclohexanol (0.5 g, 4.03 mmol), $Pd(OAc)_2(PPh_3)_2$ (0.06 g, 0.08 mmol), and CuI (0.03 g, 0.16 mmol). The mixture was gently purged with nitrogen. Then the mixture was stirred for 2 hr at 60° under a nitrogen atmosphere, AcOEt and water were added, and the organic layer was separated, washed with water, dried ($MgSO_4$), and concentrated under reduced pressure. The residue was purified by flash chromatography. Elution with a 90/10 n-hexane/AcOEt mixture gave compound (1b) (0.91 g, 98 % yield).

General procedure of reaction of arylethynyl,dialkylcarbinols (1) and arylethynyl,alkylcarbinols (8) with aryl iodides.

This is exemplified by the reaction of (1d) with 4-methoxyphenyl iodide (table 1, entry d). To a stirred solution of 4-methoxyphenyl iodide (0.59 g, 2.54 mmol), piperidine (0.35 ml, 3.57 mmol) in DMF (2 ml) were added compound (1d) (0.23 g, 1.05 mmol) and $Pd(OAc)_2(PPh_3)_2$ (0.016 g, 0.02 mmol). The mixture was gently purged with nitrogen, and formic acid (2.77 mmol) was added all at once. The mixture was stirred at 60°C under a nitrogen atmosphere for 8 hr, AcOEt and water were added, and the organic layer was separated, washed with water, dried ($MgSO_4$), and concentrated at reduced

TABLE 5 - CHARACTERIZATION OF COMPOUNDS (5).

Compound	M.p. (°C)	I.R. ν(cm^{-1})	^{1}H-NMR δ(ppm)
5a	47-48	3580, 3450, 1600, 775, 700[a]	7.57-7.17 (m, 10H), 6.23 (s,1H), 2.71 (s, exchange with D_2O, 1H), 1.87-0.97 (m, 10H)[b]
5b	88-90	3590, 3460, 1605, 830[a]	7.36-6.72 (m, 8H), 6.1 (s, 1H), 3.8 (s, 3H), 3.74 (s,3H), 2.87 (s, exchange with D_2O, 1H), 1.76-1.06 (m, 10H)[b]
5c	98-100 (dec.)	3300, 1670, 1605, 1585, 790, 710[c]	9.31 (bs, exchange with D_2O,2H), 7.93-6.83 (m,8H), 6.31 (s, 1H), 3.36 (bs, exchange with D_2O, 1H), 2.07 (s, 3H), 2.03 (s, 3H), 1.21 (s, 6H)[b]
5d	84-85	3300, 2830, 1665, 1600, 1530, 1245, 1035, 830[c]	9.36 (bs, exchange with D_2O, 1H), 7.93-6.7 (m,8H), 6.24 (s, 1H), 3.76 (s, 3H) 3.33 (s, exchange with D_2O,1H), 2.08 (s, 3H), 1.17 (s, 6H)[b]
5e	105-107	3495, 2850, 1595, 1250, 1020, 755[c]	7.4-6.76 (m, 8H), 6.03 (s, 1H), 3.85 (s, 3H), 3.65 (s, 3H), 2.88 (s, exchange with D_2O, 1H), 1.8-1.2 (m, 10H)[d]
5f	97-98	3520, 1710, 1595, 760, 695[c]	8.2-7.83 (m, 4H), 7.73-7.33 (m, 4H), 6.32 (s, 1H), 3.90 (s, 3H), 3.88 (s, 3H), 2.93 (s, exchange with D_2O, 1H), 1.87-1.07 (m, 10H)[b]
5g	64-65	3500, 1720, 1605, 855[c]	8.18-7.89 (m, 4H), 7.62-7.26 (m, 4H), 6.27 (s,1H), 3.91 (s, 6H), 1.83-1.3 (m, 10H), 1.14 (s, exchange with D_2O, 1H)[d]
5h	59-60	3595, 3450, 1590, 765, 695[a]	7.63-7.06 (m, 8H), 6.23 (s, 1H), 2.88 (s, exchange with D_2O, 1H), 1.9-1.0 (m, 10H).[b]
51	oil	3490, 2850, 1595, 1260, 1030, 840, 740, 700[a]	7.53-6.7 (m, 9H), 6.11 (s, 1H), 3.74 (s, 3H), 2.80 (s, exchange with D_2O, 1H), 1.83-1.13 (m, 10H).[d]
5m	59-60	3570, 3450, 1600, 760, 700[a]	7.6-7.13 (m, 10H), 6.31 (s, 1H), 1.9-1.5 (m, 8H), 1.32 (s, exchange with D_2O, 1H).[d]
5n	32-33	3580, 3440, 1600, 760, 700[a]	7.6-7.37 (m, 10H), 6.24 (s, 1H), 2.78 (s, exchange with D_2O, 1H), 1.56 (q, J=7.5 Hz,2H), 1.14 (s,3H), 0.9 (t, J=7.5 Hz, 3H).[b]
5o	56-57	3570, 3370, 1600, 760, 700[a]	7.57-7.2 (m, 10H), 6.27 (s, 1H), 1.53 (s, exchange with D_2O, 1H), 1.31 (s, 6H)[d]
5p	96-98	3570, 2870, 1605, 1245, 1035, 830[c]	7.4-6.57 (m, 11H), 6.3 (s, 1H), 3.83 (s, 3H), 3.75 (s, 3H), 3.73 (s, 3H), 2.47 (s, exchange with D_2O, 1H), 0.85 (s, 3H).[b]

a) Liquid film. b) Me_2CO-d_6. c) KBr. d) $CDCl_3$.

TABLE 6 - CHARACTERIZATION OF COMPOUNDS (8), (9), (10), AND (11).

Compound	M.p. (°C)	I.R. ν(cm^{-1})	^{1}H-NMR δ(ppm)
8a	oil	3330, 2230, 1600, 755, 690[a]	7.63-7.27 (m,5H), 4.7-4.3 (m,2H, one exchange with D$_2$O), 1.97-1.55 (m, 2H), 1.04 (t, J = 7.5 Hz, 3H)[b]
8b	oil	3340, 2850, 2210, 1605, 1245, 1030, 830[a]	7.13 (AA'BB', J = 9 Hz, 4H), 4.73-4.43 (m, 1H), 4.25 (d, J = 5.2 Hz, exchange with D$_2$O, 1H), 3.78 (s, 3H), 1.93-0.73 (m, 11H)[b]
8c	oil	2870, 2220, 1605, 1250, 1180, 1170, 1125, 1115, 1035, 1020, 830[a]	7.14 (AA'BB', J = 9 Hz, 4H) 5.11 (m, 1H), 4.66 (t, J = 6 Hz, 1H), 3.79 (s, 3H), 3.62 (m, 2H), 2.13-2.07 (m, 17H)[c]
8d	oil	3540, 3350, 2230, 1600, 755, 695[a]	7.8-7.17 (m,10H), 5.67 (bs,1H), 2.85 (bs, exchange with D$_2$O, 1H)[c]
9a	67-69	3340, 1600, 765, 700[a]	7.6-7.16 (m, 10H), 6.08 (d, J = 9 Hz,1H), 4.08 (m, 1H), 3.7 (bs, exchange with D$_2$O, 1H), 1.52 (m,2H), 1.77-1.33 (t, J = 7.5 Hz, 3H)[b]
9b	oil	3360, 1605, 1245, 1035, 830[a]	7.33-6.73 (m, 8H), 5.93 (d, J = 9 Hz, 1H), 4.3-4.0 (m, 1H), 3.81 (s, 3H), 3.77 (s, 3H), 3.63 (bs, exchange with D$_2$O, 1H), 1.73-0.67 (m, 11H)[b]
9c	oil	2860, 1605, 1180, 1175, 1130, 1110, 1035, 1020, 830[a]	7.37-6.73 (m, 8H), 5.84 (d, J = 9.5 Hz, 1H), 4.71 (m,1H), 4.5-4.17 (m,1H), 3.83 (s,3H), 3.78 (s,3H), 3.57-3.2 (m, 2H), 2.0-0.67 (m, 17H)[c]
9d	oil	3560, 3430, 1600, 765, 700[a]	7.6-7.13 (m,15H), 6.3 (d, J = 9 Hz, 1H), 5.23 (dd, J = 9 Hz, J = 4.5 Hz,1H), 4.49 (d, J = 4.5 Hz, exchange with D$_2$O, 1H)[b]
10a	oil	3560, 3400, 1600, 770, 700[a]	7.97-7.2 (m, 10H), 6.76 (s, 1H), 4.82 (m,1H), 4.13 (d, J = 4.5 Hz, exchange with D$_2$O, 1H), 1.77-1.27 (m, 2H), 0.73 (t, J = 7.5 Hz, 3H)[b]
10b	oil	3420, 1610, 1250, 1035, 835[a]	7.77-6.8 (m, 8H), 6.36 (s, 1H), 4.93 (m, 1H), 3.96 (d, J = 4.5 Hz, exchange with D$_2$O,1H), 3.8 (s,6H), 1.7-0.6 (m, 11H)[b]
10c	oil	1605, 1075, 1125, 1110, 1035, 1020, 830[a]	7.67-6.8 (m, 9H), 5.13 (t, J = 6 Hz, 1H), 4.66 (m, 1H), 3.81 (s, 6H), 3.47-3.13 (m,2H), 1.97-0.67 (m, 17H)[c]
10d	97-98	3260, 1600, 760, 690[d]	7.93-7.13 (m, 16H), 6.41 (d, J = 4.5 Hz, 1H), 4.93 (d, J = 4.5 Hz, exchange with D$_2$O, 1H)[b]
11a	44-46	1695, 1660, 1590, 770, 700[a]	7.67-7.07 (m, 10H), 6.63 (s, 1H), 2.25 (q, J = 7.5 Hz, 2H), 0.93 (t, J = 7.5 Hz, 3H)[c]
11b	oil	1680, 1650, 1605, 1250, 1035, 835[a]	7.5-6.8 (m, 8H), 6.5 (s,1H), 3.86 (s,3H), 3.83 (s, 3H), 2.24 (t, J = 7.5 Hz, 2H), 1.77-0.7 (m, 9H)[c]
11d	83-84	1655, 1600, 765, 695[a]	8.1-7.87 (m, 2H), 7.57-7.1 (m, 14H)[c]

a) Liquid film. b) Me_2CO-d_6. c) $CDCl_3$. d) KBr.

pressure. The residue was purified by flash chromatography. Elution with a 50/50 n-hexane/AcOEt mixture gave compound (5d) (0.307 g, 90 % yield).

General procedure of reaction of ethynyl,dialkylcarbinols (7) with aryl iodides. Procedure A.

This is exemplified by the reaction of ethynylcyclohexanol with 3-carbomethoxyphenyl iodide (table 2, entry f). To a stirred solution of 3-carbomethoxyphenyl iodide (3.59 g, 13.7 mmol), piperidine (1.92 ml, 19.4 mmol) in DMF (2 ml) were added ethynylcyclohexanol (0.5 g, 4.03 mmol) and Pd(OAc)$_2$(PPh$_3$)$_2$ (0.06 g, 0.08 mmol). The mixture was purged with nitrogen, and formic acid (15.07 mmol) was added all at once. The mixture was stirred at 60° under a nitrogen atmosphere for 30 hr, AcOEt and water were added, and the organic layer was separated, washed with water, dried (MgSO$_4$), and concentrated at reduced pressure. The residue was purified by flash chromatography. Elution with a 85/15 n-hexane/AcOEt mixture gave (5f) (0.303 g, 21 % yield) and the intermediate derived from the ethynylation (1f) (0.730 g, 74 % yield).

General procedure of reaction of ethynyl,dialkylcarbinols (7) with aryl iodides. Procedure B.

This is exemplified by the reaction of ethynylcyclohexanol with 2-methoxyphenyl iodide (table 2, entry e). To a stirred solution of 2-methoxyphenyl iodide (0.934 g, 4.03 mmol), piperidine (0.4 ml, 4.03 mmol) in DMF (2 ml) were added ethynylcyclohexanol (0.5 g, 4.03 mmol), Pd(OAc)$_2$(PPh$_3$)$_2$ (0.06 g, 0.08 mmol), and CuI (0.03 g, 0.16 mmol). The mixture was gently purged with nitrogen. Then, the mixture was stirred for 2 hr at 60° under a nitrogen atmosphere, diluted with Et$_2$O, filtered through a short column of florisil and concentrated under reduced pressure. The residue (0.990 g) was diluted with DMF (2 ml) and 2-methoxyphenyl iodide (2.26 g, 9.7 mmol), Pd(OAc)$_2$(PPh$_3$)$_2$ (0.06 g, 0.08 mmol), and piperidine (1.35 ml, 13.7 mmol) were added. The stirred mixture was purged with nitrogen, and formic acid (10.6 mmol) was added all at once. The mixture was stirred at 60° under a nitrogen atmosphere for 30 hr, worked-up as reported in the procedure A, and chromatographed (flash chromatography) by eluting with a 92/8 n-hexane/AcOEt mixture to give compound (5e) (0.79 g, 58 % yield) and the isomeric ß,γ-allylic alcohol (6e) (0.085 g, 6 % yield): mp = 97-98°C; IR (KBr) 3520, 2920, 1600, 1250, 1040, 760 cm^{-1}; ^{1}H-NMR δ (CDCl$_3$) 7.69-6.81 (m, 8H), 6.40 (s, 1H), 3.89 (s, 3H), 3.88 (s, 3H), 3.12 (s, exchange with D$_2$O, 1H), 1.74-1.04 (m, 10H).

Further elution with a 85/15 n-hexane/AcOEt mixture gave the reaction intermediate (1e) (0.165 g, 18 % yield).

Treatment of 1,3,3-triphenyl-prop-2-en-1-ol (9d) with phenyl iodide,bis(triphenylphosphine) palladium diacetate, and piperidinium formate.

To a stirred solution of (9d) (0.116 g, 0.41 mmol), piperidine (0.134 ml, 1.36 mmol) in DMF (1.6 ml) were added phenyl iodide (0.196 g , 0.96 mmol) and Pd(OAc)$_2$(PPh$_3$)$_2$ (0.012 g, 0.016 mmol). The mixture was purged with nitrogen and formic acid (1.06 mmol) was added all at once. The mixture was stirred at 60° under a nitrogen atmosphere for 14 hr, Et$_2$O and water were added, and the organic layer was separated, washed with water, dried (MgSO$_4$), and concentrated at reduced pressure. The residue was chromatographed (flash chromatography) by eluting with a 96/4 n-hexane/AcOEt mixture to give (9b)(0.106 g, 91 %).

Treatment of 1,3,3-triphenyl-prop-2-en-1-ol (9d) with phenyl iodide and bis(triphenylphosphine) palladium diacetate

The reaction was carried out as described above without the addition of formic acid. After 24 hr the mixture was worked-up and the residue was chromatographed to give the unreacted (9b) in 94 % yield.

The reaction of 3,3-dimethyl-but-1-yne with 4-methoxyphenyl iodide.

To a stirred solution of 3,3-dimethyl-but-1-yne (0.5 g, 6.09 mmol), 4-methoxyphenyl iodide (1.425 g, 6.09 mmol), and Et$_2$NH (8 ml), were added CuI (0.046 g, 0.24 mmol), and Pd(OAc)$_2$(PPh$_3$)$_2$ (0.091 g, 0.121 mmol). The mixture was purged with nitrogen. Then the mixture was stirred for 20 hr at room temperature under a nitrogen atmosphere, AcOEt and water were added, and the organic layer was separated, washed with water, dried (MgSO$_4$), and concentrated at reduced pressure. The residue (1.39 g) was diluted with DMF (2 ml) and 4-methoxyphenyl iodide (3.415 g, 14.59 mmol), Pd(OAc)$_2$(PPh$_3$)$_2$ (0.091 g, 0.121 mmol), and piperidine (2.041 ml, 20.67 mmol) were added. The stirred mixture was purged with nitrogen, and formic acid (16.05 mmol) was added all at once. The mixture was stirred at 60° under a nitrogen atmosphere for 20 hr, worked-up as reported in the procedure A, and subjected to HPLC analysis on a Hibar LiChroCART prepacked with LiChrosorb Si 60 (Merck) by eluting with a 98/2 n-hexane/AcOEt mixture (1 ml/min) (the 1,1-:1,2-di(4-methoxyphenyl)--3,3-dimethyl-but-1-ene ratio was 85:15). Preparative HPLC on LiChroprep Si 60 15-25 μ by eluting with a 98/2 n-hexane/AcOEt mixture gave pure 1,1-di(4-methoxyphenyl)-3,3-dimethyl-but-1-ene (1.05 g, 58 % yield; oil; IR (liquid film) 1605, 1244, 1036, 829 cm^{-1}; ^{1}H-NMR δ (CDCl$_3$) 7.30-6.75 (m, 8H), 6.05 (s, 1H), 3.87 (s, 3H), 3.80 (s, 3H), 1.03 (s, 9H); MS(m/e) 296 (M$^+$), 281 (M$^+$-15)) and 1,2-di(4-methoxyphenyl)-3,3-dimethyl-but-1-ene (0.21 g, 12 % yield; mp = 49-51°C; IR (liquid film) 1607, 1246, 1038, 835, 825 cm^{-1}; ^{1}H-NMR δ (CDCl$_3$) 6.83 (AA'BB', J = 3.5 Hz, 8H), 6.53 (s, 1H), 3.86 (s, 3H), 3.72 (s, 3H), 1.20 (s, 9H); MS (m/e) 296 (M$^+$), 281 (M$^+$-15)).

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TABLE 7 - Microanalytical data for compounds (1).

Compound	Calculated			Found		
	C %	H %	N %	C %	H %	N %
1a	83.99	8.05		83.88	8.09	
1b	78.23	7.88		78.27	7.90	
1c	71.87	6.96	6.45	71.80	6.92	6.40
1d	71.87	6.96	6.45	71.81	6.90	6.41
1e	78.23	7.88		78.19	7.83	
1f	74.39	7.02		74.31	7.00	
1g	74.39	7.02		74.32	6.99	
1i	71.64	6.44		71.59	6.47	
1p	80.73	7.74		80.68	7.72	

TABLE 8 - Microanalytical data for compounds (5).

Compound	Calculated			Found		
	C %	H %	N %	C %	H %	N %
5a	86.29	7.97		86.25	7.99	
5b	78.07	7.74		78.00	7.71	
5c	71.57	6.86	7.95	71.64	6.86	7.92
5d	73.82	7.12	4.30	73.87	7.09	4.27
5e	78.07	7.74		78.04	7.75	
5f	73.08	6.64		73.12	6.61	
5g	73.08	6.64		73.10	6.62	
5h	69.17	5.80		69.05	5.78	
5l	81.78	7.84		81.88	7.86	
5m	86.32	7.63		86.20	7.59	
5n	85.67	7.99		85.77	7.95	
5o	85.67	7.61		85.75	7.57	
5p	80.12	7.68		80.18	7.71	

TABLE 9 - Microanalytical data for compounds (8), (9), (10) and (11)

Compound	Calculated		Found	
	C %	H %	C %	H %
8a	82.46	7.55	82.61	7.52
8b	77.55	8.68	77.60	8.70
8c	75.91	8.92	76.01	8.88
8d	86.51	5.81	86.47	5.83
9a	85.67	7.61	85.65	7.56
9b	77.61	8.29	77.68	8.21
9c	76.38	8.55	76.46	8.46
9d	88.08	6.34	88.14	6.37
10a	85.67	7.61	85.72	7.68
10b	77.61	8.29	77.56	8.25
10c	76.38	8.55	76.48	8.48
10d	88.08	6.34	88.04	6.36
11a	86.41	6.82	86.39	6.83
11b	78.07	7.74	78.15	7.70
11d	88.70	5.67	88.67	5.63

1,1-di(4-methoxyphenyl)-3,3-dimethyl-but-1-ene

Calculated	C % : 81,04	H % 8.16
Found	C % : 81.12	H % 8.19

1,2-di(4-methoxyphenyl)-3,3-dimethyl-but-1-ene

Calculated	C % : 81.04	H % 8.16
Found	C % : 81.00	H % 8.12