

"Process for the synthesis of intermediates of Nebivolol"

FIELD OF THE INVENTION

The present invention relates to a novel process for the synthesis of chromanyl haloketone and oxiranylchroman compounds, which are useful as intermediates in the synthesis of Nebivolol.

PRIOR ART

Nebivolol is a racemic mixture of the two enantiomers $[2S[2R[R[R]]]]$ α, α' -[imino-bis (methylene)] bis[6-fluoro-chroman-2-methanol] and $[2R[2S[S[S]]]]$ α, α' -[imino-bis (methylene)] bis[6-fluoro-chroman-2-methanol] (Figure 2).

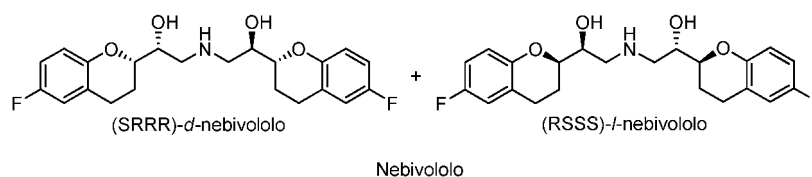


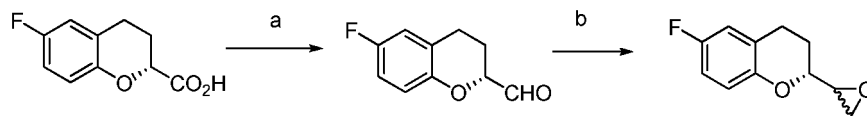
Figure 2

The fact that the molecule of Nebivolol contains 4 asymmetric centers, from which, in theory, 16 possible stereoisomers can originate, reduced to 10

due to the symmetry of the molecule, explains the complexity of the structure thereof and the many synthetic approaches developed for the preparation thereof.

The epoxide (I), as a key intermediate in the synthesis of Nebivolol, has been the subject of many synthetic approaches developed for the preparation thereof.

EP0334429 reports the synthesis of the epoxide 6-fluoro-2-(oxiran-2-yl)chroman in the form of the separate diastereomers RS and SR from an ester of chroman carboxylic acid in accordance with a method widely reported in the literature for obtaining carboxylic ester epoxides. The ester of 6-fluoro-chroman carboxylic acid, after resolution of the racemic form into the two enantiomers with (+)-dehydroabietylamine, is reduced at low temperature with diisobutyl aluminium hydride to the corresponding aldehyde, which is in turn converted into the epoxide by reaction with sodium hydride and trimethylsulfonium iodide in dimethylsulfoxide. The following synthetic scheme (Scheme) describes the conversion of the acid R.

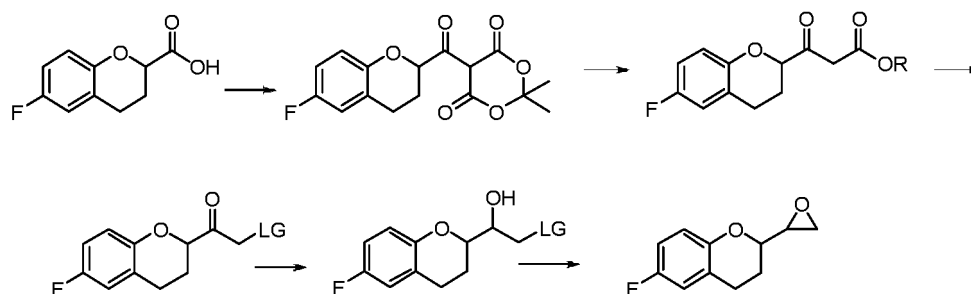


a) 1. CDI, THF, rt; 2. DIBALH, -70°C ; b) $(\text{CH}_3)_3\text{SO}^{(+)}\text{I}^{(-)}$, NaH, DMSO

Scheme 1

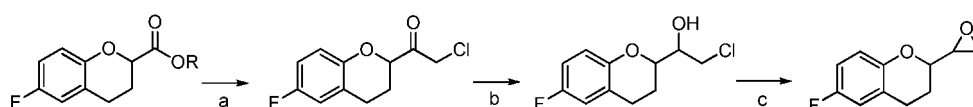
The obtained 6-fluoro-chroman-2-yl aldehyde is not particularly stable and is prone to racemization if it is prepared in optically active form.

EP1803715 (Cimex) reports a synthesis (Scheme 2) in which chroman carboxylic acid is transformed into acyl chloride and is made to react with Meldrum's acid so as to then produce the corresponding alpha-chloroketone in three steps. The alpha-chloroketone is then reduced and cyclized to yield epoxide. The sequence however, which is also known to work on chiral acids R and S, is long and laborious.



Scheme 2

WO2010034927 (Zach System) reports the preparation of epoxides from the corresponding carboxylic esters, both in racemic form and in individual chiral isomers, via the formation of alpha-haloketone (Scheme 3).

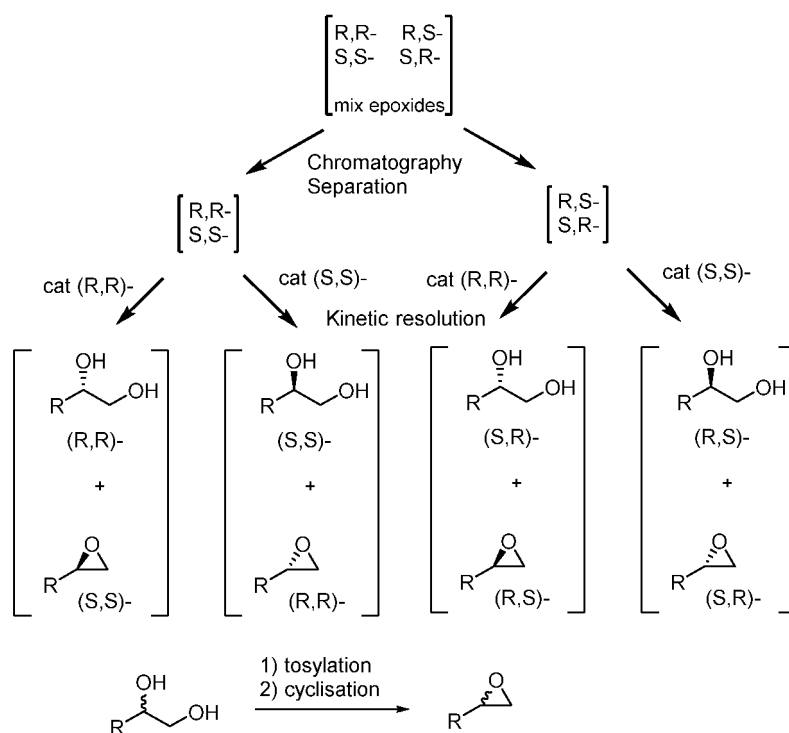


Scheme 3 a. BuLi, CH₂BrCl, -80 °C, then AcOH; b. NaBH₄, EtOH, 0 °C; c. *i*-PrOH, NaOH

The chroman carboxylic ester is treated at a very low temperature with LiCH₂Cl so as to obtain, after quenching with acetic acid, the corresponding alpha-chloroketone, which is then reduced to alpha-chloro alcohol and is cyclized to yield epoxide.

WO2008064826 (Zach System) describes an industrially applicable method which makes it possible to obtain the 4 possible enantiomers of 6-

fluoro-chroman epoxide without resorting to chiral chromatography (Scheme 4).

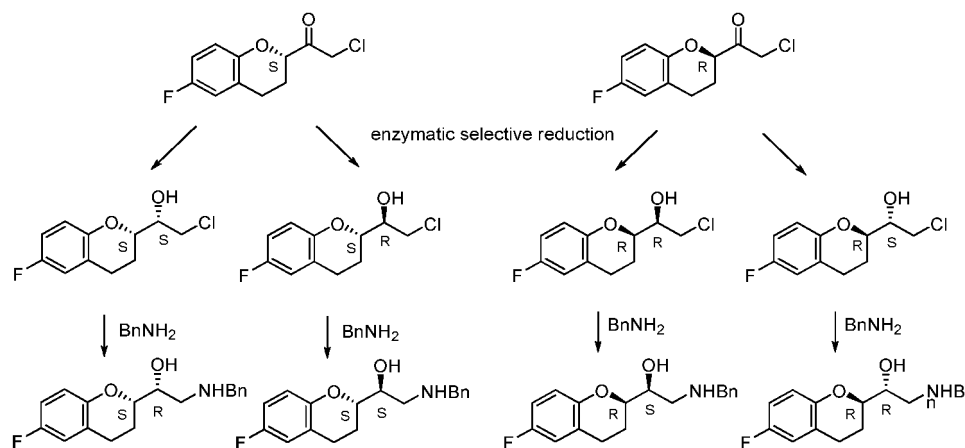


Scheme 4

After separation by chromatography of the two diastereomer epoxides (both a racemic mixture), each of the two isomers is subjected to enantioselective opening of the ring in the presence of a chiral catalyst of cobalt. At the end of the process, the unreacted, enantiomerically pure diol and epoxide are easily separated using the

methods known in the literature. The diols are reconverted to epoxides via tosylation and cyclization. The synthesis nonetheless still provides chromatographic separation of two diastereoisomers.

WO2011091968 (Corden Pharma) describes a method for obtaining enantiomerically pure chromanyl chloro alcohols by means of enzymatic reduction of the corresponding chloroketones (Scheme 5):



Scheme 5

The chloro alcohols thus obtained are developed into the corresponding amino alcohols, without the transition to epoxides, by means of a reaction with

basic catalysis. The reaction of the amino alcohols with the appropriate chloro alcohols results in the various isomers of Nebivolol. Such reactions both involve very long times.

SUMMARY

What is described here is a novel efficient process, which is also applicable on an industrial scale, for the synthesis of chromanyl haloketones of formulas IIIa and IIIb and of 6-fluoro-(oxiranyl)chromans of formula Ia-d (epoxide).

Such compounds can be used advantageously as intermediates for the synthesis of Nebivolol.

In particular, the disclosed process optimizes the synthesis of the above-mentioned compounds, allowing a reduction of the synthetic steps.

In some cases, the optimization involves an elimination or reduction of steps aimed at the separation of the enantiomers, for example the

enantiomeric epoxide pairs (RR/SS RS/SR), and of other diastereoisomeric intermediates.

The process of the disclosure, *in primis*, provides an efficient synthesis of chromanyl haloketones of formulas IIIa and IIIb. Such haloketones, which are starting compounds for the synthesis of the epoxides of formula (Ia-d), are synthesized from the corresponding chromanyl esters of formulas IIa and IIb in a single step and with an increased chemical purity of 96-98 %. Such a purity can be brought subsequently to a value greater than 99 % (HPLC), after a single crystallization.

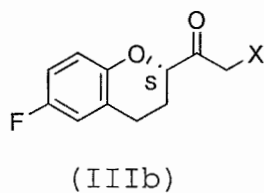
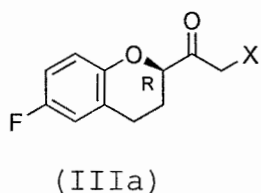
In addition, the process comprises a step of enantioselective reduction of the chromanyl haloketones of formulas IIIa and IIIb into haloalcohols of formula IVa-d.

In particular, it has been found that such a reduction occurs with sufficient enrichment into one of the two diastereomers of formula IV if an apolar solvent is used, such as cyclohexane or heptane or methylcyclohexane. This is a particularly surprising aspect insofar as apolar

solvents have never been described in the literature as solvents suitable for oxazaborolidine-catalyzed reductions. In addition, as reported in Table 1 below, solvents normally used in such reductions, namely THF, toluene, and DCM, do not make it possible to obtain an equally high diastereoisomeric excess.

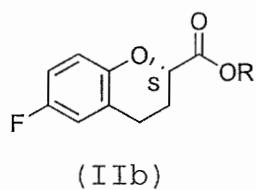
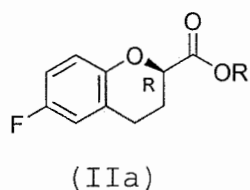
The following thus forms a first subject of the present disclosure:

- a process for the synthesis of chromanyl haloketones of formula IIIa-b as separate isomers or as a racemic mixture

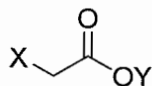


comprising the following steps:

a. reacting an ester of formula IIa-IIb,



wherein R is a linear C₁-C₆ alkyl group, in the form of a separate isomer or as a racemic mixture with a metal-organic compound and a salt of the alpha haloacetic acid of general formula A



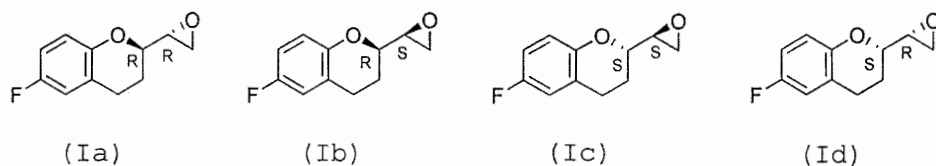
Formula A

wherein X is halogen and Y is H, or metal;

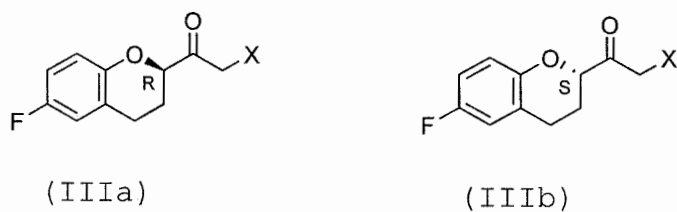
b. carrying out an *in situ* decarboxylation by treatment with an aqueous inorganic acid to give the corresponding chromanyl haloketone of formula IIIa-b in the form of a separate isomer or in racemic form.

The second subject of the disclosure is formed by the above process comprising the following

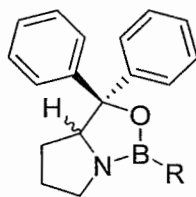
additional steps in order to obtain the epoxides of formula Ia-Ic in the form of separate optically active isomers



c. reducing in an apolar solvent the haloketone of formula IIIa or IIIb



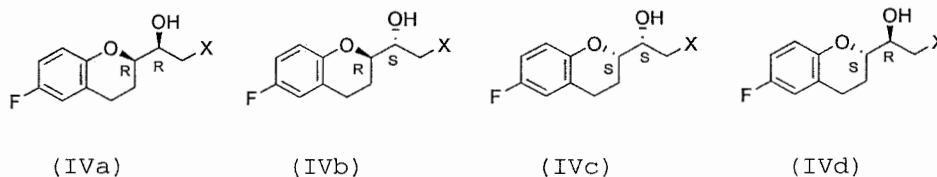
with a complex of borane in the presence of an oxazaborolidine catalyst (RCBS) of formula B



Formula B

wherein R = methyl or butyl,

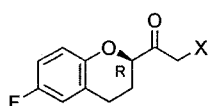
wherein said catalyst has *R* or *S* chirality,
to obtain the respective haloalcohol of formula IV



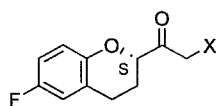
d. carrying out an *in situ* cyclization of the
said alcohol with an aqueous solution of an
alkaline base, to give the corresponding epoxides
of formula Ia-Id.

A further subject of the disclosure is formed
by the above process comprising additional steps
for obtaining benzylamines of formula V,
benzylneбивolol of formula VI, and Nebivolol.

In one aspect, there is provided a process for the synthesis of chromanyl haloketones of formula IIIa and/or IIIb as separate isomers or as a racemic mixture



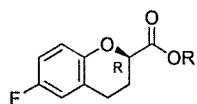
(IIIa)



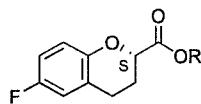
(IIIb)

comprising the following steps:

a. reacting an ester of formula IIa and/or IIb,



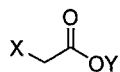
(IIa)



(IIb)

wherein R is a linear C₁-C₆ alkyl group, in form of separate isomer or as a racemic mixture

with a metal-organic compound and a salt of a haloacetic acid of general formula A



Formula A

wherein X=F, Cl, Br, I and Y= Li, Na, K, Mg;

wherein the reaction of said ester with the metal-organic compound is carried out at a temperature between -10°C and +10°C,

wherein the metal-organic compound is an organic magnesium compound of formula RMgX, where X is a halogen and R is a linear or branched, preferably tertiary, C1-C6 alkyl residue.

b. carrying out an *in situ* decarboxylation by treatment with an aqueous inorganic acid until reaching a pH equal to or less than 5, to give the corresponding chromanyl haloketone of formula IIIa and/or IIIb in the form of a separate isomer or in racemic form.

The process described here makes it possible to eliminate the disadvantages of the known synthesis pathways used for the synthesis of chromanyl haloketones of formulas IIIa and IIIb and for the synthesis of oxiranylchromans of formula Ia-d, these disadvantages being summarized by:

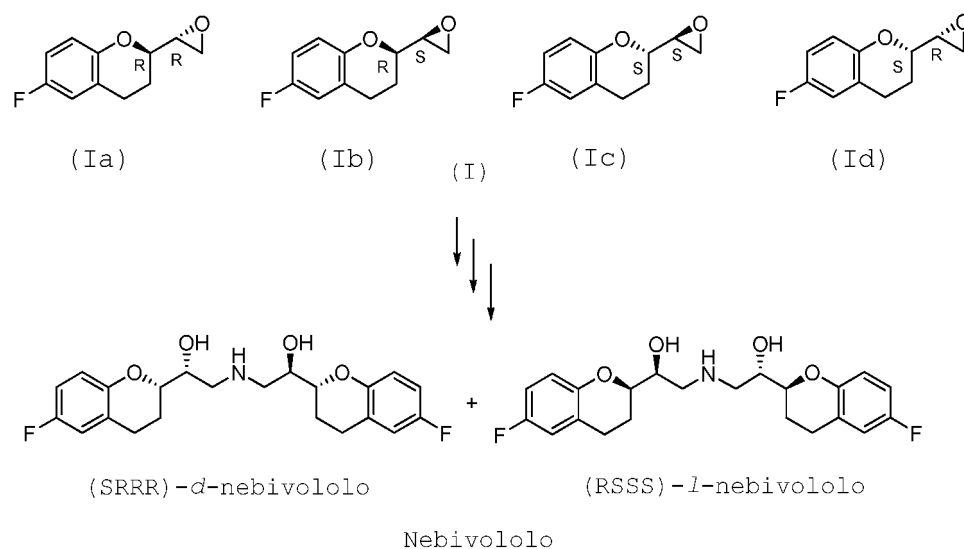
- length and complexity of the synthesis processes,
- need for chromatographic purification,
- reaction conditions not easily applicable on an industrial scale, such as very low temperatures or instability of intermediates.

The epoxides, which are obtained easily and in industrial quantities in accordance with the process forming the subject of the disclosure, can be used in the synthesis of the active ingredient Nebivolol.

Further advantages and features of the present disclosure will become clear from the following detailed description.

DETAILED DESCRIPTION OF THE INVENTION

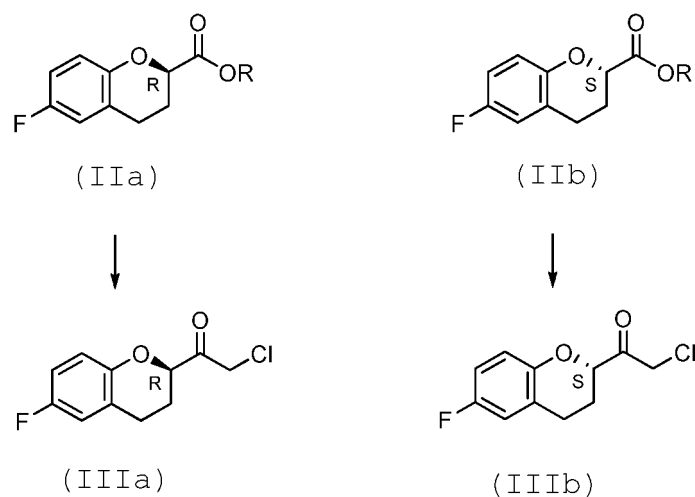
The present invention describes a process for the synthesis of the intermediates constituted by chromanyl haloketones of formulas IIIa and IIIb and 6-fluoro-2-(oxiran-2-yl)chromans of formula Ia-d (epoxides). Such intermediates can be used in the preparation of Nebivolol in accordance with the following scheme:



Scheme 6

I Chromanyl haloketones (IIIa-b)

The process for preparing the compounds IIIa-b starting from the esters IIa and b is illustrated in Scheme 7 below.

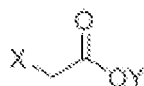


Scheme 7

The starting product is the ester of 6-fluorochroman 2-carboxylic acid of formula (IIa) and/or (IIb). Although such an ester can be used in racemic form, for the purposes of the present invention it is preferably used in the form of a pure enantiomer (R) or (S).

The radical R in formula II is a C₁-C₆ alkyl group, preferably a methyl, ethyl, n-propyl, iso-propyl, or (n-, t-, sec)butyl group. The ester is treated

(step a.) with a metal-organic compound in the presence of an alpha-haloacetic acid of general formula A



Formula A

The metal-organic compound can have the formula RMgX , wherein X represents a halogen and R represents a C1-C6 alkyl residue. The alkyl group can be linear or branched, preferably tertiary. For example, such a compound is tert-butylmagnesium chloride ($t\text{BuMgCl}$). Alternatively, the compound can be a magnesium amide. The magnesium amide can be prepared, even at the time of use, from dialkylamine, for example diisopropylamine, and RMgCl , wherein R is an alkyl group.

The alpha-haloacetic acid of formula A can be selected from those acids in which X is a halogen, for example F , Cl , Br , I , and Y is hydrogen (H) or an alkali metal or alkaline earth metal, for

example Li, Na, K, Mg. by way of example, the acid can be chloroacetic acid or the salt thereof, i.e. sodium chloroacetate.

The reaction can be carried out by adding the metal-organic reagent, for example $t\text{BuMgCl}$, dropwise to the mixture containing the chromanyl ester (II) and the acid. Alternatively, the metal-organic reagent can be added, again dropwise, simultaneously with the ester (II) and at the same time to a suspension of the acid, so as to maintain a high dilution of ester and metal-organic base throughout the course of the reaction. The temperature is maintained within the range $-10/+10\text{ }^{\circ}\text{C}$, preferably between $-5/+5\text{ }^{\circ}\text{C}$, or between $-3/+3\text{ }^{\circ}\text{C}$.

The synthesis reaction of chromanyl ketones (III) is carried out in inert organic solvent, for example a solvent belonging to the family of the ethers. By way of example, the solvent is tetrahydrofuran, alone or in mixture with methyl tert-butyl ether (MTBE).

The next step (step b.) is a decarboxylation *in situ* of the formed 2-chloro-3-(6-fluorochroman-2-yl)-3-oxopropanoic intermediate, resulting in the corresponding chromanyl haloketones of formula IIIa or IIIb. These will be in the form of separate enantiomers or a racemic mixture, depending on whether the starting ester is in the form of a separate enantiomer or is in racemic form, respectively. Clearly, if in racemic form, the separate enantiomers of the 6-fluoro chromanyl haloketone of formula IIIa or IIIb can be isolated from the racemic mixture in accordance with any technique considered suitable for this purpose by a person skilled in the art.

An inorganic aqueous acid is then added to the reaction mixture of step (a), preferably slowly and whilst keeping the temperature unchanged, for example $-5\text{ }^{\circ}\text{C}/+5\text{ }^{\circ}\text{C}$, or between $-3\text{ }^{\circ}\text{C}/+3\text{ }^{\circ}\text{C}$, in order to achieve a pH of the mixture that is equal to or less than 5, preferably a pH between 1-3. The acid can be, for example, HCl or NaHSO_4 . The reaction time in order to obtain directly the

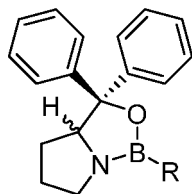
haloketones (IIIa-b) is approximately 20 minutes. The mixture is then left under stirring at ambient temperature for at least 30 minutes. The haloketones IIIa-b are therefore obtained in a single step and with an increased chemical purity of 98 %. Such a purity can then be brought to a value greater than 99 % (HPLC), after a single crystallisation.

The haloalcohols (IVa-d).

The process described above can comprise an additional step (step c.) of enantioselective reduction of the 6-fluoro chromanyl haloketone of formula IIIa or IIIb so as to obtain the corresponding haloalcohols (IVa-d).

The enantioselective reduction is carried out with an oxazaborolidine catalyst (R-CBS), and with a complex of borane.

The oxaborolidine catalyst has the formula B,



Formula B

wherein R = a selection from methyl (Me) or butyl (Bu) to give MeCBS and BuCBS respectively.

The catalyst itself has *R* or *S* chirality: *R*-(*R*-CBS) or *S*-(*R*-CBS).

The reduction reaction is carried out in an apolar solvent. The optimal apolar solvent is selected from cyclohexane, methylcyclohexane, heptane or mixtures thereof. The complex of borane is selected from the group comprising borane-diethylaniline (BH₃*DEA), borane-dimethylsulfide (BH₃*DMS), borane-tetrahydrofuran (BH₃*THF). The complex is preferably BH₃*DEA.

The stereoselectivity of the reduction reaction is dependent both on the solvent used and on the *R* or *S* chirality of the catalyst. Depending on the chirality of the catalyst, an *R* or *S* alcohol will

be obtained, respectively. Consequently, the reduction reaction of the chromanyl haloketone (III) will produce the four possible diastereoisomers of the chromanyl alcohol of formula IVa-d in different percentages depending on the conditions adopted. In particular, the enantioselective reaction starting from the (*R*)chromanyl haloketone IIIa with the catalyst *R*-(*R*-CBS) will lead to the formation of the chromanyl haloalcohol of formula IVa, whereas the reaction of the same haloketone IIIa with the catalyst *S*-(*R*-CBS) will lead to the formation of the chromanyl haloalcohol of formula IVb. Alternatively, the enantioselective reaction starting from the (*S*)chromanyl haloketone IIIb with the catalyst *R*-(*R*-CBS) will lead to the formation of the chromanyl haloalcohol of formula IVd, whereas the reaction of the same haloketone IIIb with the catalyst *S*-(*R*-CBS) will lead to the formation of the chromanyl haloalcohol of formula IVc.

The temperature of the reduction reaction can be between 15 °C and 50 °C, for example between 25 °C and 45 °C.

At the end of the reaction, the complex of borane can be neutralized with acetone where appropriate.

The reaction as described above leads to the formation of the haloalcohols with a diastereomeric purity at least equal to 90 %.

As reported in Table 1, the specific selection of the apolar solvent and the chirality of the catalyst make it possible to obtain diastereomeric mixtures heavily enriched with one of the diastereoisomers of formulas IVa to IVd.

Table 1

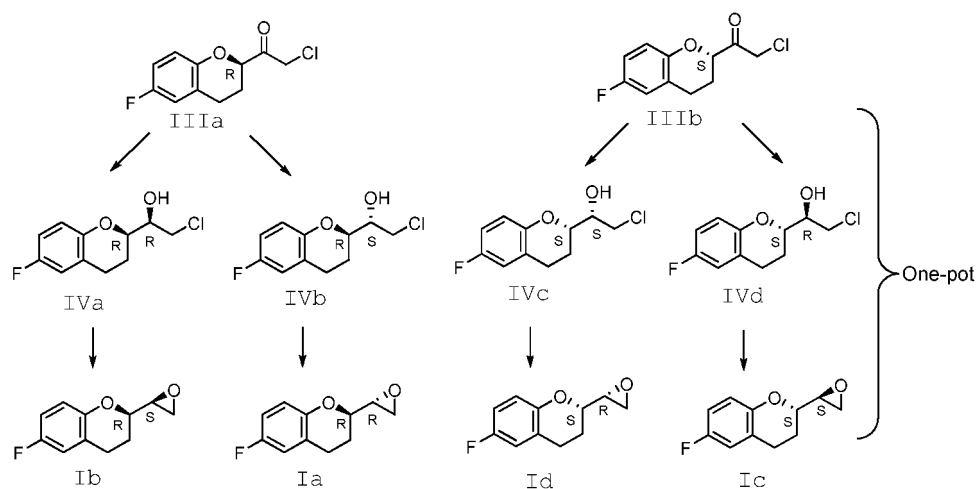
N°	III	MeCBS or BuCBS	Diastereomers
1	IIIa (R)	S	Ia (RR) / Ib (RS)
2	IIIb (S)	R	Ic (SS) / Id (SR)
3	IIIa (R)	R	Ia (RR) / Ib (RS)
4	IIIb (S)	S	Ic (SS) / Id (SR)

N°	Solvent	Diastereomeric excess (Ia/Ib o Ic/Id)
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N°	Solvent	Diastereomeric excess (Ia/Ib o Ic/Id)
1 o 2	THF	80/20
	DCM	85/15
	Toluene	88/12
	Xylene	98/2
	Cyclohexane	98/2
	Methylcyclohexane	98/2
	Heptane	96/4
3 o 4	THF	27/73
	DCM	24/76
	Toluene	21/79
	Xylene	18/82
	Cyclohexane	10/90
	Methylcyclohexane	10/90
	Heptane	12/88

I Fluoro-oxiranyl chroman

The process described above can comprise an additional step of one-pot intramolecular cyclization (step d.) of the chromanyl haloalcohols of formula IV so as to obtain the epoxides (Ia-d) according to the following scheme:



Scheme 8

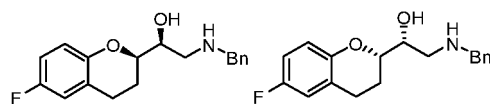
The cyclization is carried out by adding to the reaction mixture an aqueous solution of an alkaline base, such as NaOH, LiOH or KOH. The base is preferably 50 % aqueous.

The base is added at low temperature, for example $T=0^{\circ}\text{C}$. The mixture thus obtained can then be left at ambient temperature.

The epoxides of formula I obtained as described above are intermediates in the preparation of Nebivolol in the form of a racemic mixture of the two enantiomers $[2S[2R[R[R]]]] \alpha, \alpha'$ -[imino-bis (methylene)] bis[6-fluoro-chroman-2-

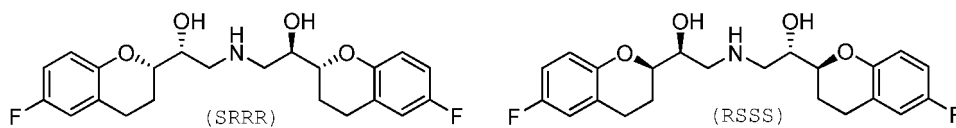
methanol] and [2R[2S[S[S]]]] α,α' -[imino-bis(methylene)] bis[6-fluoro-chroman-2-methanol].

For this purpose, the process described above can be integrated with additional well-known steps, in which the isomer SR of the epoxide (Id) and the isomer RS of the epoxide (Ib) are reacted separately with benzylamine so as to obtain the corresponding benzylamines RS and SR of formula (V)



(V)

These amines can then be reacted separately with the chromanyl epoxides of suitable configuration. In particular, the amine (V) RS is reacted with the epoxide SS (Ic), and the amine (V) SR is reacted separately with the epoxide RR (Ia) so as to give, separately, the isomers RSSS and SRRR of the benzylnebivolol of formula VI.



Formula VI

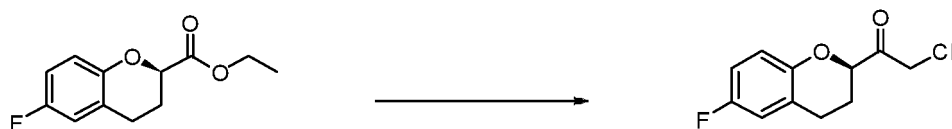
The isomer SRRR and the isomer RSSS of benzylneбиволol can then be reunited and crystallised so as to obtain a racemic mixture. The protective benzyl group can then be removed, and the hydrochloride salt can be formed so as to obtain the final product, neбиволol hydrochloride ((SRRR)*d*-neбиволol + (RSSS)*l*-neбиволol).

The removal of the benzyl group can be achieved for example by means of catalytic hydrogenation using a catalyst Pd(OH)₂. In such conditions the hydrogenation can be carried out in a ratio of acetic acid solvent:water of 7:1.

The hydrochloride salt can be obtained by means of cationic exchange with a solution of NaCl.

EXAMPLES

EXAMPLE 1: Synthesis of (R)-2-chloro-1-(6-fluorochroman-2-yl)ethan-1-one



A solution of *t*BuMgCl 1M in THF (21 l, 21 mol) and a solution containing 1.6 Kg (7.2 mol) of carboxylated (R)-ethyl 6-fluorochromanyl IIa in MTBE (8 L) are added dropwise and at the same time to a sodium chloroacetate suspension (1.74 Kg, 15.1 mol) in MTBE (8 L) at 0 °C in a nitrogen atmosphere. The speeds of dripping of the two solutions are regulated so as to obtain a simultaneous dripping of the two solutions, also ensuring that the temperature remains in the range 3 °C/+3 °C during the entire course of the addition (1.5-2.0 hours). At the end of the addition of the reagents, the solution is kept under stirring at a temperature -3 °C/+3 °C. After confirming that the reaction is complete by means of HPLC analysis, the

suspension is added, dropwise, to a mixture composed of a solution of 50 % H_2SO_4 (5.4 Kg), ice (17 Kg) and H_2O (17 Kg), and is held at a temperature of $-5\text{ }^\circ\text{C}$, ensuring that the temperature remains in the range $0\text{ }^\circ\text{C}/+5\text{ }^\circ\text{C}$ during the addition. At the end of the addition, it is checked that the pH of the aqueous phase lies within the range $\text{pH} = 1-3$, then the solution is brought to ambient temperature, keeping it under stirring for 20 min. The organic phase, which is separated, is treated with 150 mL of NaHCO_3 saturated sol. (13.2 Kg), 150 mL of NaHCO_3 / H_2O 1:3 (13.2 Kg), and lastly H_2O (13.2 Kg).

The organic phase is concentrated at reduced pressure, three solvent exchanges are performed with isopropanol (360 mL in each case), and then the mixture is crystallized in isopropanol (3.9 Kg, 1.5 volumes), resulting in 1.3 Kg of a solid (79 % yield, purity HPLC >99 %).

^1H NMR (400 MHz, DMSO-d_6) δ 6.98-6.90 (m, 2H); 6.90-6.84 (m, 1H), 4.90-4.86 (d, 1H, $J = 16.0\text{ Hz}$); 4.89-

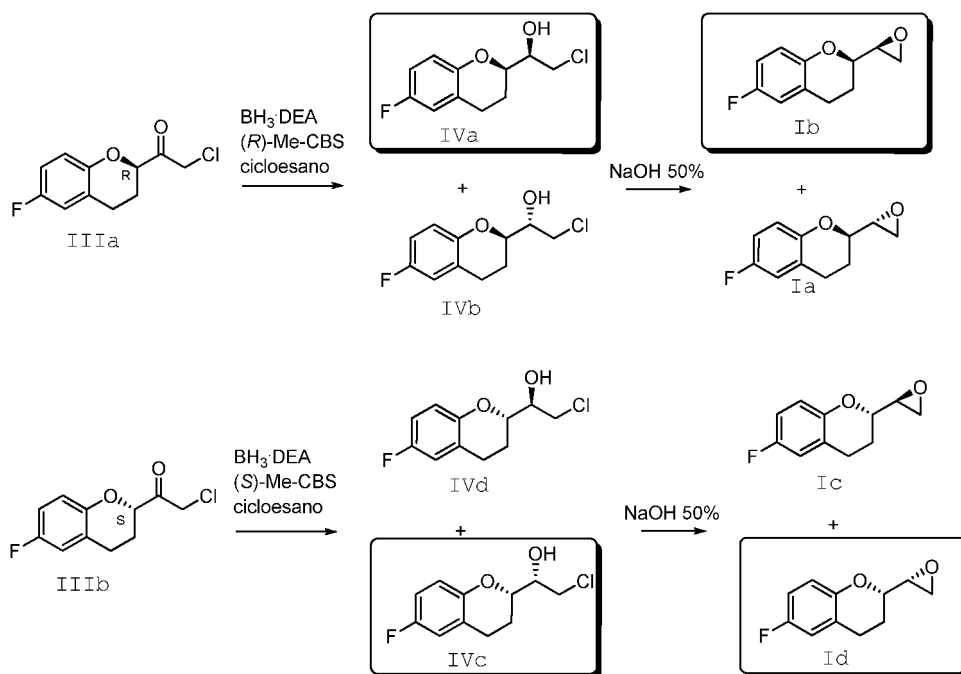
4.87 (m, 1H); 4.79-4.75 (d, 1H, $J = 16.0$ Hz); 2.88-2.78 (m, 1H); 2.72-2.60 (m, 1H); 2.25-2.10 (m, 1H); 2.08-1.93 (m, 1H).

EXAMPLE 2: Synthesis of

(S)-2-chloro-1-(6-fluorochroman-2-yl)ethan-1-one

The methodology described in Example 1 is applied similarly to the isomer carboxylated (S)-ethyl 6-fluorochromanyl IIb, resulting in an equal yield of the corresponding product (S)-6-fluoro-chromanyl chloroketone IIb.

EXAMPLE 3: Synthesis of (R)-6-fluoro-2-((S)-oxiran-2-yl)chroman and of (S)-6-fluoro-2-((R)-oxiran-2-yl)chroman

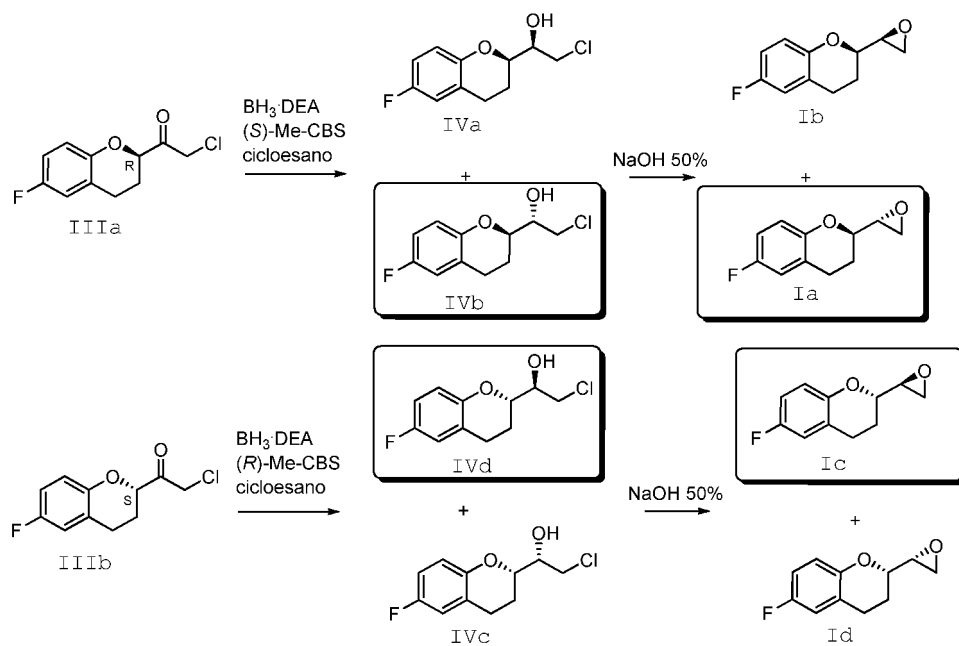


(*R*)-methyl oxazaborolidine (*(R)*-MeCBS) or (*S*)-methyl oxazaborolidine (*(S)*-MeCBS) (35.9 g, 0.129 mol, 3.3 %) is added to a solution of $\text{BH}_3 \cdot \text{DEA}$ (0.70 Kg, 4.3 mol) in cyclohexane (8 Kg) under flow of N_2 , and the obtained suspension is left under stirring at ambient temperature for 15 minutes. The chloroketones **IIIa** or **IIIb** (0.9 Kg, 3.9 mol) are added, respectively, to such a reducing mixture in portions of 45 g/10 minutes. After 20 minutes following the last addition, the HPLC analysis

reveals the almost total disappearance of the starting product (6-fluoro-chroman-2-yl chloroketone < 0.5 %) and the formation to a predominant extent, equal to 90 % (enantiomeric purity), of the isomer (R)-2-chloro-1-((R)-6-fluorochroman-2-yl)ethan-1-ol (IVa) compared to the isomer (S)-2-chloro-1-((R)-6-fluorochroman-2-yl)ethan-1-ol (IVb), or, respectively, in the case of IIIB as starting product, of the isomer (S)-2-chloro-1-((S)-6-fluorochroman-2-yl)ethan-1-ol (IVb) compared to (R)-2-chloro-1-((S)-6-fluorochroman-2-yl)ethan-1-ol (IVc), depending on the chirality of the used catalyst. Acetone (0.7 Kg) is added in drops slowly to the reaction mixture, cooled to 0-5 °C, the temperature is returned to ambient value, and the mixture is left under stirring for 1 hour. After this, an aqueous solution of 50 % NaOH (16 Kg) is added, dropwise, to the mixture, cooled to 0 °C-5 °C, continuing the stirring at ambient temperature (12-15 hours). After filtration of the mixture, the organic phase is separated, treated with H₂SO₄ 1M (7.5 Kg), then with H₂O (2 x 8 Kg),

and the solvent is removed at reduced pressure so as to obtain, respectively, (R)-6-fluoro-2-(S)-oxiranylm chroman (Ib) or (S)-6-fluoro-2-(R)-oxiranylm chroman (Id), with a yield for the two steps equal to 90 %.

EXAMPLE 4: Synthesis of (R)-6-fluoro-2-((R)-oxiran-2-yl)chroman and of (S)-6-fluoro-2-((S)-oxiran-2-yl)chroman

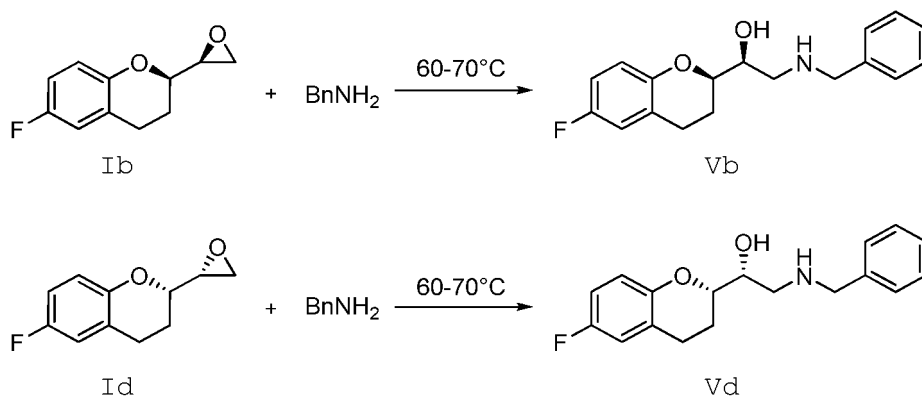


(*R*)-methyl oxazaborolidine ((*R*)-MeCBS) or (*S*)-methyl oxazaborolidine ((*S*)-MeCBS) (35.9 g, 0.129 mol, 3.3 %) is added to a solution of $\text{BH}_3\cdot\text{DEA}$ (0.70 Kg, 4.3 mol) in cyclohexane (8 Kg), under flow of N_2 , and the obtained suspension is left under stirring at ambient temperature for 15 minutes. The chloracetone IIIa or IIIb (0.9 Kg, 3.9 mol) is added, respectively, to such a reducing solution in portions of 45 g/10 minutes. After 20 minutes following the last addition, the HPLC analysis reveals the almost total disappearance of the starting product (6-fluoro-chroman-2-yl chloroketone < 0.5 %) and the formation to a predominant extent, equal to 98 % (diastereomeric purity), of (*S*)-2-chloro-1-((*R*)-6-fluorochroman-2-yl)ethan-1-ol (IVb) compared to the enantiomer (*R*)-2-chloro-1-((*R*)-6-fluorochroman-2-yl)ethan-1-ol (IVa), or of the isomer (*R*)-2-chloro-1-((*S*)-6-fluorochroman-2-yl)ethan-1-ol (IVd) compared to the corresponding isomer (*S*)-2-chloro-1-((*S*)-6-fluorochroman-2-yl)ethan-1-ol (IVc), depending on the chirality of

the used catalyst. Acetone (0.7 Kg) is added in drops slowly to the reaction mixture, cooled to 0-5 °C, the temperature is returned to ambient value, and the mixture is left under stirring for 1 hour. After this, an aqueous solution of 50 % NaOH (16 Kg) is added, dropwise, to the mixture, cooled to 0 °C-5 °C, continuing the stirring at ambient temperature (12-15 hours). After filtration of the mixture, the organic phase is separated, treated with H₂SO₄ 1M (7.5 Kg), then with H₂O (2 x 8 Kg), and the solvent is removed at reduced pressure so as to obtain, respectively, (R)-6-fluoro-2-((R)-oxiran-2-yl)chroman (Ia) and (S)-6-fluoro-2-((S)-oxiran-2-yl)chroman (Ic), with a yield for the two steps equal to 90 %.

Example 5: Synthesis of the amines Vb RS and Vd SR from the epoxides Ib RS and Id SR

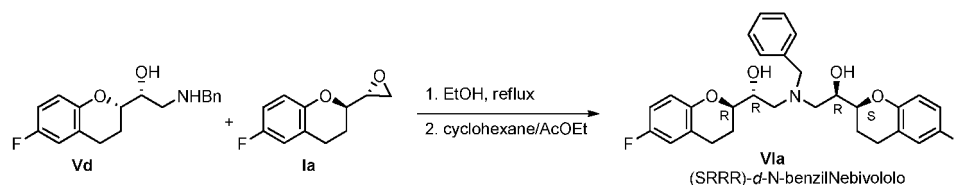
(R)-2-(benzylamino)-1-((S)-6-fluorochroman-2-yl)ethan-1-ol; (S)-2-(benzylamino)-1-((R)-6-fluorochroman-2-yl)ethan-1-ol



The epoxide (Ib) or (Id) (0.68 Kg, 3.5 mol) is suspended in BnNH₂ (3.76 Kg). The mixture is heated to 60-70 °C for 2 h (complete solubilization), then the temperature is increased to 90±5 °C, with distillation under vacuum of half of the added BnNH₂. After cooling to ambient temperature, heptane (6.1 Kg) is added to the reaction mixture, which is left under vigorous stirring, still at ambient temperature, for at least 12 h. The obtained suspension is filtered, and the solid obtained is suspended in cyclohexane (7 Kg), and the suspension is heated under reflux for 30 minutes, then cooled slowly at ambient temperature and left under stirring for 1-2 hours. After filtration and drying in a vacuum oven at 35 °C for

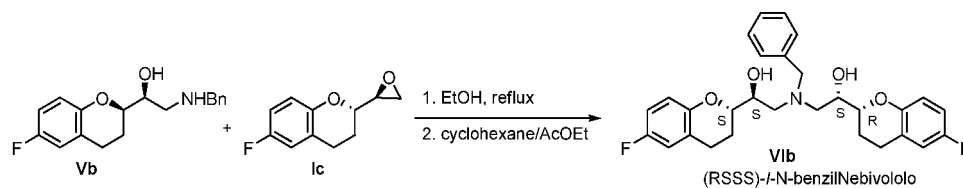
at least 8 hours, the (S)-2-(benzylamino)-1-((R)-6-fluorochroman-2-yl)ethan-1-ol Vb and the (R)-2-(benzylamino)-1-((S)-6-fluorochroman-2-yl)ethan-1-ol Vd with a purity > 98 % (HPLC) and a yield equal to 63 % are obtained, respectively, from the chloroketones IIIa and IIb.

EXAMPLE 6: Synthesis of (SRRR)-d-N-benzylneбивolol VIa



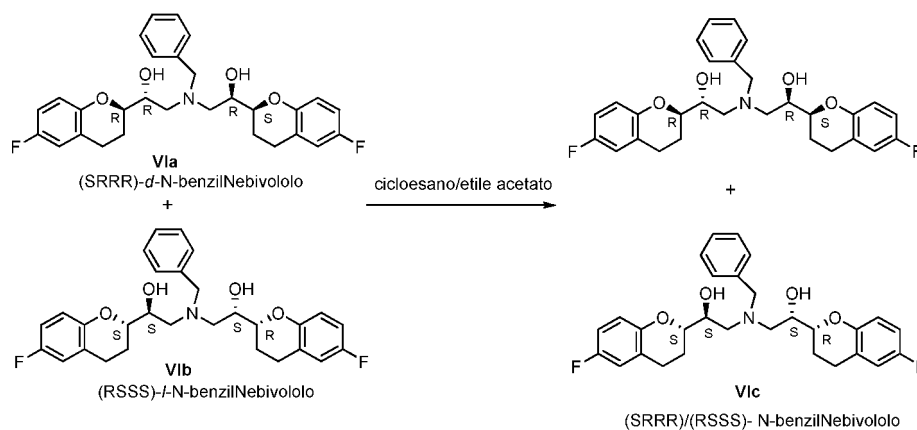
(R)-2-(benzylamino)-1-((S)-6-fluorochroman-2-yl)ethan-1-ol Vd (0.66 Kg) is added to a solution of the epoxide Ia (0.45 Kg) in absolute ethanol (2.5 L). The suspension is heated to 80-90 °C for 24-48 hours until completion of the reaction (reagents < 2 %).

EXAMPLE 7: Synthesis of (RSSS)-l-N-benzylneбивolol VIb



(R)-2-(benzylamino)-1-((S)-6-fluorochroman-2-yl)ethan-1-ol Vb (0.66 Kg) is added to a solution of the epoxide Ic (0.45 Kg) in absolute ethanol (2.5 L). The suspension is heated to 80-90 °C for 24-48 hours until completion of the reaction (reagents < 2 %).

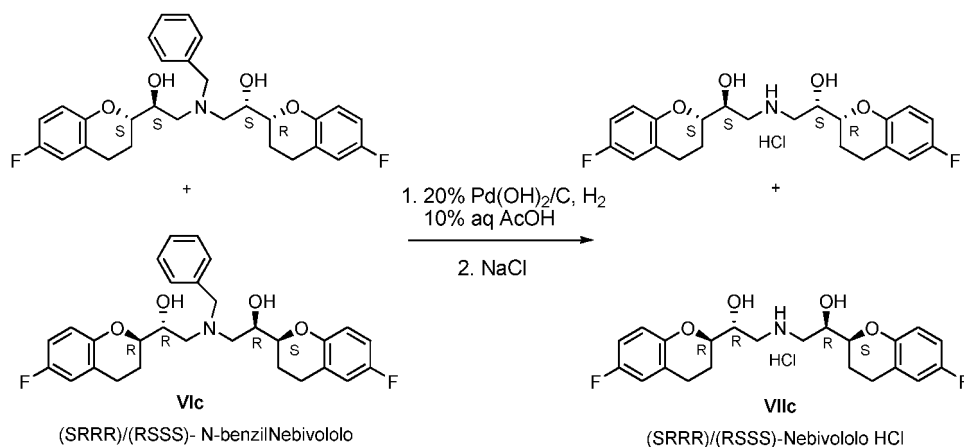
EXAMPLE 8: Synthesis of *d,l*-benzylnebivololo



The two mixtures containing the isomers *d*- and *l*-N-benzylnebivololo VIa and Vib, obtained respectively as described in Example 6 and in Example 7, are

combined and concentrated at reduced pressure. The obtained residue (purity > 85 %) is crystallized from a mixture 7:1 cyclohexane/EtOAc (12.6 volumes), so as to obtain N-benzylnebivolol VIc (1.77 kg) with a yield equal to 80.5 % compared to the amino alcohol VI.

EXAMPLE 9: Synthesis of Nebivolol hydrochloride

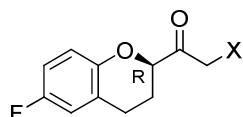


20 % Pd(OH)₂/C (50 % wet) (approximately 24 g) is added to a suspension of (RSSS)/(SRRR)-N-benzylnebivolol VIc (1.5 Kg) in AcOH (10 Kg) and H₂O (1 Kg). The suspension is left under stirring in an H₂ atmosphere for approximately 12 hours. At the end of the reaction, the catalyst is filtered

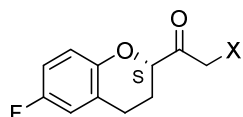
off and an aqueous solution of NaCl (1.06 Kg of NaCl in 21 kg of H₂O) is added under stirring, with observation of the spontaneous precipitation of a white solid. After stirring for at least 8 hours, the suspension is filtered and the solid is washed with 400 mL of H₂O (6 Kg), then with EtOH (3 Kg), so as to obtain the nebivolol hydrochloride as a white solid (1.1 Kg, yield 95 %, purity HPLC 99.7 %).

CLAIMS

1. A process for the synthesis of chromanyl haloketones of formula IIIa and/or IIIb as separate isomers or as a racemic mixture



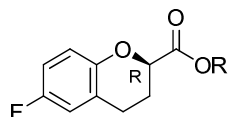
(IIIa)



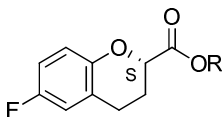
(IIIb)

comprising the following steps:

a. reacting an ester of formula IIa and/or IIb,



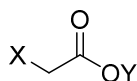
(IIa)



(IIb)

wherein R is a linear C₁-C₆ alkyl group, in form of separate isomer or as a racemic mixture

with a metal-organic compound and a salt of a haloacetic acid of general formula A



Formula A

wherein X=F, Cl, Br, I and Y= Li, Na, K, Mg;

wherein the reaction of said ester with the metal-organic compound is carried out at a temperature between -10°C and +10°C,

wherein the metal-organic compound is an organic magnesium compound of formula RMgX , where X is a halogen and R is a linear or branched, preferably tertiary, C1-C6 alkyl residue.

b. carrying out an *in situ* decarboxylation by treatment with an aqueous inorganic acid until reaching a pH equal to or less than 5, to give the corresponding chromanyl haloketone of formula IIIa and/or IIIb in the form of a separate isomer or in racemic form.

2. The process according to claim 1, wherein said metal-organic compound is $t\text{-BuMgCl}$.

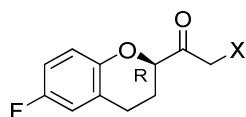
3. The process according to any one of claims from 1 to 2, wherein said haloacetic acid is chloroacetic acid or said salt is sodium chloroacetate.

4. The process according to any one of claims from 1 to 3, wherein the reaction of said ester with the metal-organic compound is carried out at a temperature between -5°C and $+5^{\circ}\text{C}$, or between -3°C and $+3^{\circ}\text{C}$.

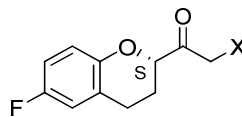
5. The process according to any one of claims from 1 to 4, wherein the solvent used in the reaction of said ester with the metal-organic compound is an ether, preferably selected from tetrahydrofuran, methyl tert-butylether or mixtures thereof.

6. The process according to any one of claims from 1 to 5, comprising the following additional step

c. reducing in an apolar solvent the haloketone of formula IIIa or IIIb

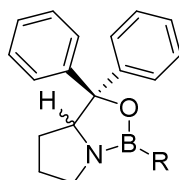


(IIIa)



(IIIb)

with a complex of borane in the presence of an oxazaborolidine catalyst (RCBS) of formula B

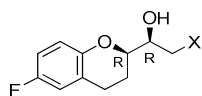


Formula B

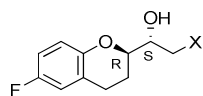
wherein R = methyl or buthyl,

wherein said catalyst has *R* or *S* chirality,

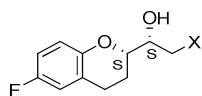
to obtain the respective haloalcohol of formula IV



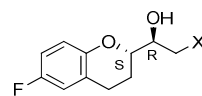
(IVa)



(IVb)



(IVc)



(IVd)

7. The process according to claim 6, wherein said apolar solvent in step c is selected from the group comprising cyclohexane, methylcyclohexane and heptane.

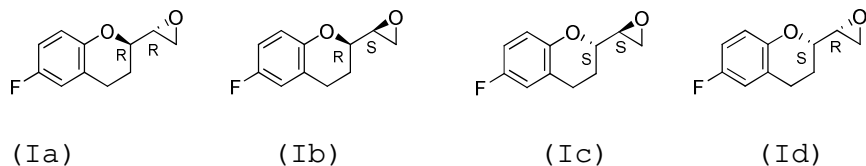
8. The process according to claim 6 or 7, wherein the catalyst is (R)MeCBS or (S)MeCBS.

9. The process according to claim 6 or 7, wherein the catalyst is (R)BuCBS or (S)BuCBS.

10. The process according to any one of claims from 6 to 9, wherein the complex of the borane is selected from the group comprising borane-diethylaniline ($\text{DEA} \cdot \text{BH}_3$), borane-dimethylsulfide ($\text{BH}_3 \cdot \text{DMS}$), borane-tetrahydrofuran ($\text{BH}_3 \cdot \text{THF}$).

11. The process according to any one of claims from 6 to 10 comprising the following additional step:

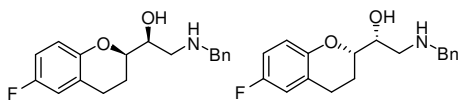
d. carrying out an *in situ* cyclization of the said haloalcohol IVa-IVd with an aqueous solution of an alkaline base, to give the corresponding epoxides of formula Ia-Id in the form of separate optically active isomers:



12. The process according to claim 11, wherein the alkaline base at step d is a NaOH, LiOH or KOH solution.

13. The process according to any one of claims from 11 to 12, comprising the following additional step:

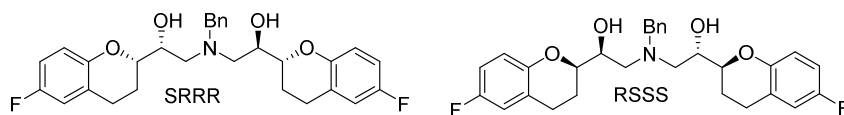
e. reacting separately the SR isomer of the epoxide (Id) and the RS isomer of the epoxide (Ib) with the benzylamine to obtain the RS and SR benzylamine of formula (V)



(V)

14. The process according to claim 13, comprising the following additional step

f. reacting separately the RS amine (V) with the SS epoxide (Ic) and the amine SR (V) with the epoxide RR (Ia) to give separately the SSSR and SRRR isomers of benzylnebivolol of formula (VI)



(VI)

15. The process according to claim 14, comprising the following additional steps :

g. combining the solutions of RSSS and SRRR isomers of benzylnebivolol of formula (VI), and

h. carrying out a crystallization to obtain the SRRR/RSSS benzylnebivolol as a raceme.

16. The process according to claim 15, wherein said crystallization is carried out with a ethyl acetate/cyclohexane mixture and eventual trituration in hot cyclohexane.

17. The process according to any one of claims from 15 to 16, comprising the following additional step:

i. removing the benzyl protecting group and forming a hydrochloride salt, to obtain a product Nebivolol hydrochloride.

18. The process according to claim 17, wherein the benzyl group is removed by catalytic hydrogenation with $\text{Pd}(\text{OH})_2$ catalyst.

19. The process according to claim 18, wherein the solvent of the hydrogenation is acetic acid water 7: 1

20. The process according to any one of claims from 17 to 19, in which the hydrochloride salt of Nebivolol is obtained by cation exchange with NaCl solution.